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青年优秀论文复赛摘要

主办单位：

中国生物医学工程学会

承办单位：

东南大学

中国医学科学院系统医学研究院/苏州系统医学研究所

苏州大学附属第一医院

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S01
生物医学检测、处理与分析
Biomedical Signal Processing

ID 159

心脏细胞传感技术与系统

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目的：心血管疾病是全球死亡的主因，人类健康的最大威胁，亟需心脏疾病研究与治疗药物开发的技术平台。心脏具有独特的兴奋收缩特性，因而这些技术平台的开发也主要围绕这个特性展开。传统的动物、组织模型与技术平台操作复杂效率低下，无法从细胞层面开展高效高时空分辨的精准研究；基于侵入式与标记的心脏细胞传感技术，会对细胞产生不可逆的损伤，无法开展长时研究；而无损非标记心脏细胞传感技术，则存在着信号质量低、单一孤立、信号间关联性低等问题，因此，心脏细胞兴奋收缩特性的技术平台开发仍然面临着巨大挑战。

方法：团队致力于发展全新的单细胞分辨的心脏细胞电生理和机械信号同步传感技术，为心脏疾病研究与药物分析筛选，提供高通量、高时空分辨、高内涵、高灵敏的心脏细胞兴奋收缩特性研究平台。

结果：从心脏细胞分辨高通量多功能微电极传感器件的研制、心脏细胞电生理与机械信号同步一体化传感技术与系统的开发、心脏细胞精准药物分析筛选模型的建立等方面发展了心脏细胞传感技术与系统。

结论：解决心脏细胞电生理与机械特性同步传感检测、心脏细胞高质量胞内电生理传感检测的技术难题，最终实现高通量、高时空分辨、高内涵、高灵敏的心脏细胞兴奋收缩特性研究。

关键字：细胞传感检测技术开发、微纳细胞传感器件与试剂制备、多模态一体化细胞传感系统研制、生物医学中的研究与应用

ID 211

Detection of the ERP Biomarker in Major Depressive Disorder using an Xgboost Method

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Objective: Depression is a prevalent mental disorder in modern society, causing many people to suffer even commit suicide. Finding non-invasive electroencephalography (EEG) biomarkers for depression is important to diagnose the depressive disorder in a more Objective way and to search the superior treatment option for patients suffering from the depressive disorder.

The current event-related potentials (ERP) research is based on eXtreme Gradient Boosting (XGBoost) machine learning algorithm to explore the effective biomarkers for depression recognition.

Methods: An XGBoost ensemble model was trained and tested to classify major depressive disorder (MDD) (24 patients) and healthy control (HC) (29 patients) from the multi-modal open dataset for mental-disorder analysis (MODMA), which applied a modifed affective priming dot-probe paradigm. Then, based on different ERP to emotional pictures, we extracted 6 features: 3 emotional cues (happy, sad , and fear), 3 emotional targets (happy, sad, and fear), and applied the Fisher-Score feature selection method to select the voltage features with high mutual information. Overall, 80% of the data was selected to establish XGBoost model with five-fold cross-validation, so as to achieve the outstanding prediction effect.

Results: We identified biomarkers with voltage features number in the interval of 170-230 s to distinguish patients with depression, and these features and labels are the most correlated mutual information. After five-fold cross-validation, the XGBoost model had the comprehensive accuracy, precision, recall, F1-score, (Area Under Curve)AUC was 99.52%, 99.39%, 99.67%, 99.52%, 99.98% for 6 biomarkers of ERP signal in MDD. Our model shows improved performance compared to other models or previous work on the same dataset.

Conclusion: An ensemble learning system for classification using the XGBoost model and feature selection using Fisher score has the potential to be used in clinical prediction of depressive symptoms in patients with ERP signals.

Key words: major depressive disorder, biomarkers, ERP, XGBoost, classification

ID 326

生物组织电特性的磁声成像处理方法研究

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目的：磁声成像为监测生物电流和早期肿瘤诊断提供了重要的依据。然而，常用单脉冲激励产生的磁声信号的低信噪比（SNR）限制了成像质量。本研究发展了编码激励的信号处理方法，以提高磁声信号的信噪比。

方法：本研究通过仿真研究了不同编码方式下的信噪比提升特性。并通过实验验证仿真结果。实验样本由高电导率介质和牛肉及脂肪制成。为了评估信噪比提升，本研究提出了单位脉冲持续时间的 SNR 改善，和单位时间的单位脉冲宽度的 SNR 提高等参数，结合处理速度评估了信噪比的改善。

结果：结果表明，与波形平均方法相比，编码方法可以快速提高磁声信号的信噪比，磁声信号的信噪比提高了 100 倍以上，图像质量获得明显改善。检测成像速度显著提高，单个检测点的处理时间短为 0.867 秒。

结论：本研究将为提高磁声成像的信噪比提供了一种有效的方法，并将有助于实时的磁声成像。

关键字：磁声成像，信噪比，编码激励

ID 403

放射性核素弹丸注射仪在动态显像中的应用

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目的：临床中放射性核素动态显像技术要求使用弹丸注射方法完成注射。由于医师手工弹丸注射的失败率约为 5%，欠佳率约为 10%，即便富有经验的医师在执弹丸注射时仍然承担着很大的心理负担。本研究结合各种手工注射模式的优劣势，开发了放射性核素弹丸注射仪，以代替核医学医师完成弹丸注射并提高弹丸注射质量和重复注射一致性。

方法：本研究从辐射防护性、阻塞响应性、注射过程的无菌性及弹丸注射效果四个方面设计模拟实验，探究自动注射在弹丸注射领域的应用性。

结果：止血带配合注射器人工注射的半峰全宽为 4.2（±0.216）秒，三通管人工弹丸注射的半峰全宽为 4.57（±0.216）秒，本研究开发的放射性核素弹丸注射仪半峰全宽为 2.1（±0.0816）秒。体现了更好的注射效果和重复一致性，同时降低了医师手掌所受 98.9% 的辐射剂量，并保证了更高效的静脉阻塞识别功能和整个注射过程的无菌性。

结论：基于自动注射法的放射性核素弹丸注射仪具备代替人工完成弹丸注射的潜力，并为动态显像结果的精准评估提供参考标准。

关键字：放射性核素动态显像；弹丸注射；自动注射装置

ID 405

金银铂纳米三角板的表面等离子体光学特性及其在催化和比色检测中的应用

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目的：近年来，贵金属纳米颗粒以其独特的物理及化学性质得到极大关注。而各向异性的贵金属纳米颗粒因其易于调控的光学特性尤其是较强的等离子体共振在化学及生物分子检测方面得到极大应用。贵金属纳米三角板因其六个尖锐的角具有较强的局域电场，更多的表面等离子体共振（SPR）带，所以在检测中发挥重要作用。与单金属纳米材料相比，多金属纳米材料由多种金属组成，具有许多特殊的光学性质。近年来，结构新颖的铂基多金属纳米结构由于其优异的催化性能而备受关注，在生物传感、医学成像和治疗、催化、检测等领域具有潜在的应用价值。

方法：本论文在硼氢化钠（$NaBH_4$）的存在下，通过将 4- 硝基苯酚还原为 4- 氨基苯酚来确定金银铂纳米三角板的催化能力，通过调节金银铂纳米三角板制备过程中硝酸银（$AgNO_3$）的体积、氯铂酸（H_2PtCl_6）的体积以及金纳米三角板尺寸，得到催化能力最强的金银铂纳米三角板。

结果：同时，本文建立了一种简单的比色法来检测抗坏血酸（AA），其检测限为 1.99μM，该检测实现了对 AA 检测的低检测限和对干扰物质的高选择性。

结论：在本文中建立的比色法可以应用于生物医学、食品科学、环境监测和其他领域，以准确检测某些复杂系统中的抗坏血酸。

关键字：金纳米三角板、铂基多金属纳米颗粒、催化、比色检测

ID 435

基于免疫 PCR 原理用于肝癌 CTC 与 ctDNA 一体化检测

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目的：液体活检中的循环肿瘤细胞（CTC）和循环肿瘤 DNA（ctDNA），对于肿瘤的疾病监测和预后评估等具有重要临床意义。CTC 与 ctDNA 的检测难点在于其低丰度与多靶标，且不同方法或平台具有差异性，使其在肿瘤检测的全面性 、精准性和一致性等方面欠佳。所以本研究旨在开发肿瘤 CTC 和 ctDNA 一体化检测方法，用同一方法或平台给临床提供更全面且精准的肿瘤信息。

方法：本工作以肝癌为研究对象，首先基于免疫 PCR 策略开发多靶标定量检测 CTC 的分子标签，将 CTC 的抗原检测转化核酸检测，定量评估 CTC 的多种抗原表达；同时，采用磁珠法对血浆中的 ctDNA 进行提取与纯化，再根据肝癌常见的突变设计对应的引物探针，构建合适的 PCR 体系，借助 qPCR 平台完成 CTC 和 ctDNA 多维度一体化定量分析。

结果：PCR 结果显示，该方法可检测 CTC 的 3 个靶标，其中 EpCAM 检测灵敏度低至 342fg ；同时，可检测 ctDNA 的 3 个突变基因，其中 TP53 检测灵敏度低至 0.05%。

结论：本工作基于免疫 PCR 开发了肝癌 CTC 和 cfDNA 一体化检测技术。相比于传统单一检测技术，该方法可更全面揭示肿瘤信息，具有广阔的临床应用前景。

关键字：免疫 PCR，循环肿瘤细胞，循环肿瘤 DNA，一体化检测

ID 465

具有多重 SERS 增强的核 - 壳 - 卫星纳米组装体用于脑卒中标志物的检测

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目的：作为脑卒中标志物的 S100B 在血液中的释放量极小，这对检测的灵敏度提出了要求。基于表面增强拉曼散射（SERS）的检测方法具有高灵敏、快速、便捷等优势，对微量分析物的检测具有潜力。然而，目前的 SERS 基底难以兼具优异的 SERS 增强特性稳定性。

方法：本研究制备了一种基于核 - 壳 - 卫星结构、具有多重 SERS 增强的 AuAgNB@SiO_2-AuNP 纳米组装体，并通过免疫夹心法将其用于 S100B 的检测。组装体包含表面粗糙和空心多孔的金银纳米盒核心，标记拉曼分子的硅夹层，以及纳米金球卫星。

结果：通过调控拉曼分子浓度、硅层厚度、核心尺寸和卫星尺寸和数量，优化了纳米组装体的结构。纳米组合体的 SERS 活性通过纳米组合体中 AuAg-SiO_2-Au 异质界面的等离子体耦合、尖端效应和化学增强而得到了多重增强。此外，纳米组装体的结构和拉曼信号的稳定性通过硅层和卫星的覆盖得到了明显改善。通过免疫夹心法将纳米组装体用于 S100B 的检测。研究结果表明其具有优异的灵敏度和重现性，检测范围为 10 fg-10 ng/mL，检测限低至 1.7 fg/mL。

结论：制备的纳米组装体有望应用于脑卒中的临床诊断，并为 SERS 传感平台的设计提供新思路。

关键字：纳米盒，核 - 壳 - 卫星纳米结构，表面增强拉曼散射 (SERS)，脑卒中，S100 钙结合蛋白 B (S100B)

ID 506

Quantitative Detection of the Magneto-acoustic (MA) Coupling Electric Field and Investigation of MA Coupling Efficiency in Saline Solution

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Objective: Transcranial magneto-acoustic stimulation (TMAS) is a novel multi-physical field coupled neurostimulation technique. The real electric field (current) distribution in TMAS is the important physical basis. In this paper, we quantitatively detected the vector MA coupling electric field in saline solution with different low conductivities and explored the MA coupling efficiency for the first time.

Methods: We built a three-dimensional vector electric field detection system for accurate measurement of weak signals. A 64-element 2D plane array transducer excited by Verasonics Vantage system was used to produce focused ultrasonic field with a main frequency of 500 kHz and the maximum ultrasound pressure was 2.1MPa. The MA electrical signal was detected at the focal point in a Nacl solution (σ=4S/m) at different magnetic induction (±0.1T, ±0.5T, 0T). In the direction orthogonal to the direction of ultrasound propagation and magnetic field, the MA signals were detected by a self-made double silver sheet electrode. Then the signals were collected and displayed by an oscilloscope after amplification of 60dB and band-pass filtering of 400kHz-600kHz.

Results: For the first time, a MA electric field orthogonal to the direction of ultrasound propagation was quantitatively detected in saline solution with low conductivities. The MA electric field intensity were 20mV/m (B=0.1T) and 50mV/m (B=0.5T). The MA signals are positively correlated with the magnetic induction, and their directions changing with the direction of the magnetic field. Moreover, the electric signals were still present at B=0. Based on the quantitative results,a MA coupling efficiency model of low conductivity materials is explored.

Conclusion: Unlike metallic materials, the MA coupling electric field of low conductivity tissue-like materials is lower than the theoretical value, and the coefficient of MA coupling efficiency is really exist in TMAS at low conductivity condition. In tissue-like materials and biological tissues, there may be a more complex distribution of electric fields in TMAS.

Key words: Transcranial magneto-acoustic stimulation, Electrical signals, Coupling efficiency

ID 514

A Biomimetic Cardiomyocyte-based Biosensor for the Detection of Medium Chain Fatty Acids

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Objective: Biomimetic cell-based biosensors have been developed for applications in many fields such as food, beverage, pharmaceutical and environment safety. However, the limited sensitivity and specificity still hampered their further development and practical applications.

Methods: In recent years, biomimetic biosensors based on the combination of biomaterials as sensitive materials and various detection device as transducers have been widely proposed for the purpose of bridging the gap between the electronic system and the biological sense of smell. In this work, a biomimetic biosensor based on SD primary cardiomyocytes as the main sensitive element and microelectrode array (MEA) as the transducer device was developed for medium-chain fatty acid (MCFA) detection for the first time.

Results: The extracted primary cardiomyocytes endogenously expressing the OR51E1 olfactory receptor cultured on the MEA surface and formed syncytium for potential conduction and mechanical beating. The obtained Live/dead staining Results indicated that the surface coating of MEA chip provided good biocompatibility for cardiomyocyte culture, allowing for the further measurement on cell responsive signals. And the experiments of norepinephrine treatment and electroporation stimulation confirmed the availability of integrated MEA system on the electrophysiological recording of cardiomyocyte. Then, the MCFAs including nonanoic acid, orthogonic acid and pentanoic acid, with different concentrations were added into the cardiomyocytes cultural chip and the real-time corresponding response were recording with MEA system in real time. The measurement Results demonstrated that the MCFAs have obviously regulating effect on the electrophysiological of cardiomyocytes cultural in vitro. Corresponding radar map and PCA classification Results indicated that different MCFAs has different regulating effect on the electrophysiological of cardiomyocytes.

Conclusion: The cardiomyocyte-based biosensor developed in this work provides a new method for biomimetic biosensor construction and has promising applications in olfactory detection and pharmaceutical researches.

Key words: biosensor; cardiomyocyte; microelectrode array; OR51E1 olfactory receptor

ID 538

基于动态迁移学习的房颤检测

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目的：深度学习技术已经成功应用于房颤的自动诊断，然而，由于个体差异以及数据采集环境、采集设备的不同，使心电数据间存在分布差异，导致房颤检测模型在新的数据库上泛化性能下降。

方法：本文提出了一种基于动态迁移网络的跨数据库房颤检测方法。首先，提出了一个动态残差块来缓解数据分布差异的影响，动态残差块由普通卷积和动态卷积组成，其中，动态卷积能够根据输入信号调整模型参数，自适应地学习不同心电数据的特征；然后，引入最小化类混淆损失来增强类别的可分辨性，从而提高房颤检测的准确率。

结果：在实验中选取三个公开的心电数据库来进行房颤检测迁移任务：麻省理工学院的 MIT-BIH 房颤数据库（AFDB）、2017 PhysioNet/CinC 挑战赛数据库（Phy2017）、2018 中国生理信号挑战赛数据库（CPSC2018）。对于迁移任

务 AFDB → Phy2017，相较于直接迁移，该方法迁移后的准确率和 F1 分数分别提高了 8.5% 和 9.45%；对于迁移任务 AFDB → CPSC2018，准确率和 F1 分数分别提高了 9.95% 和 10.85%。

结论：实验结果证明了该动态迁移网络能够缓解心电数据的分布差异，并提高了跨数据库的房颤检测性能。

关键字：房颤检测，动态残差块，动态迁移学习，类混淆损失

ID 569

基于人工神经网络的心肌细胞生理信号分析方法研究 及其在心脏药物毒性评估应用

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之江实验室

目的：细胞生理活动的监测与分析对理解细胞活动机理、破解疾病的奥秘进而服务人类生命健康具有十分重要的意义。电生理活动是兴奋性细胞重要的生理活动之一。传统的细胞生理信号分析方法主要依赖于基于先验知识的信号特征提取与匹配，存在着过于依赖先验知识、分析对象单一、分析精度不足的问题。

方法：本研究采用多种以人工神经网络为核心的生理信号分析方法以解决传统的细胞生理信号分析方法存在的局限性问题。本研究直接训练人工神经网络建立模型方法从离体培养的心肌细胞搏动信号时间序列中提取信号特征进行心脏药物毒性评估。并且，本研究提出将非线性理论与神经网络算法有机结合以实现基于非信号切割的细胞生理信号分析方法。

结果：本研究可以实现对药物是否存在心脏毒性的识别判断，准确率超过 99%。进一步，该方法可以实现对药物心脏毒性的不同作用机理的分类识别和毒性强度的预测，准确率高于 90%。最终，以人工神经网络为核心建立的心肌细胞生理信号分析方法可以泛化地鉴定识别未经训练的药物性心脏毒性，准确率超过 85%。

结论：这种基于人工神经网络的分析方法精准高效，可用于各类基于细胞生理信号的传感检测平台，具有广阔的应用前景。

关键字：人工神经网络；细胞生理信号；药物心脏毒性；心肌细胞；生理信号分析

ID 653

Autofluorescence and Diffuse Reflectance Detection System with Data-driven Diagnostic Algorithm for Real-time Classification of Potentially Malignant Mucosa lesions

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Objective: A detection system combined with autofluorescence and diffuse reflectance spectroscopic techniques, which integrates dual-distance fiber configuration and data-driven decision, is developed for quantifying and diagnosing mucosa abnormalities.

Methods: This hybrid system consists of a source module for illumination at two different source-to-detector separations of 500 μm and 900 μm, respectively, with two ultraviolet LEDs at 380 nm wavelength and two white ones, and a minia-

turized spectrometer for acquisition of depth-resolved AF and DR data. A LabView software are programmed for system control and diagnosis decision.

Results: The system stability and reliability are firstly assessed by phantom experiments, showing a measurement variation lower than 1% within 20 minutes. In-vitro and in-vivo validations are then conducted for tissue identification and lesion differentiation. For enhanced decision, a data-driven diagnosis algorithm is explored in pilot under different experimental configurations. The Results conclude a promising accuracy of >96% for the in-vivo classification as well as an excellent sensitivity of ＞ 88% for the in-vitro mucosa lesions detection, and demonstrate sound potential of the system in early detection of mucosa lesions.

Conclusion: The experimentations have proved the designed hybrid system can obtain dual-distance spectroscopy information, and achieve tissue classification in a data-driven way, which indicates the sound potential of the system in early detection of mucosa lesions.

Key words: autofluorescence spectroscopy; diffuse reflectance spectroscopy; early detection of mucosa lesions

ID 663

低成本的尿液 VOCs 膀胱癌标志物荧光传感阵列信号采集与分析系统的软硬件开发

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目的：尿液可挥发性有机化合物（VOCs）蕴含丰富的人体代谢信息，其组成特征有望用于疾病的无创诊断。本研究以前期开发的尿液 VOCs 膀胱癌标志物荧光传感阵列为基础，适配开发了一套低成本的传感阵列信号采集与分析系统，有望用于尿液 VOCs 膀胱癌标志物的快速检测。

方法：下位机使用低成本的 Arduino 通过 A4988 芯片控制样品台运动，通过 MCP4725 芯片控制激光光源，通过 USB 串口与上位机进行通讯。上位机控制程序基于 MATLAB 开发，控制微型光纤光谱仪采集荧光信号，使用 PCATools 对信号进行处理和识别。整个硬件系统使用功率约 125W 的多路输出开关电源供电。

结果：系统工作流程如下：上位机读取位移指令表，控制下位机驱动样品滑台移动，使传感器试纸条依序通过光纤探头的采集窗口，同时激光光源和光谱仪依序开闭采集光谱并处理保存。实测系统完成 10 单元传感阵列试纸条采集的时间约为 40 秒，样品台单向运动精度误差小于 0.1mm，系统总运行功率约 80W，峰值功率 100W，最大激光输出功率为 25mW。

结论：本研究成功开发了一套低成本的传感阵列信号采集与分析系统，后续将利用 VOCs 标准品和临床病人尿样对检测性能进行验证，并持续迭代优化。

关键字：可挥发性有机化合物（VOCs），荧光传感阵列，软硬件系统开发，信号采集与分析

ID 869

基于脑电信号多特征融合优化的运动想象分类研究

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目的：脑电能记录大脑的活动，经解码可控制外部设备，是最常见的脑机接口（BCI）方式，其中运动想象在医疗及康复领域有广泛的应用。

方法：本文采用共空间模式算法和小波包能量算法分别对运动想象脑电信号进行特征提取，利用支持向量机模型研究了多特征融合优化分类。

结果：实验中，选取 2003 年 BCI 竞赛数据库的左右手运动想象 3 导联（C3、C4、Cz）脑电信号，提取 6 维空域特征和 64 维能量特征构成每个样本脑电的特征集，在不同的特征融合下开展了大量分类测试对比实验，实验中结合 4 种训练集进行交叉验证测试。

结论：结果表明：在单种特征下，小波包能量特征分类准确率高于共空间模式特征的分类准确率，其中采用 db3 小波基函数的小波包能量特征（16 维）分类准确率高达 87.1429%，共空间模式特征（6 维）的最高分类准确率为 75.7143%；在不同种类特征融合下，采用 db3 小波基函数的小波包能量特征（32 维）与共空间模式特征（6 维）构成优化的融合特征（38 维）来分类，最高分类准确率可达 90.0000%，从而证实多特征融合的显著改进效果。

关键字：运动想象脑电信号；共空间模式；小波包变换；支持向量机

ID 914

A Single-channel EEG Automatic Artifact Rejection Framework Based on Hybrid Approach

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Objective: Dealing with the physiological artifacts is a challenge in the period of recording electroencephalography (EEG), especially with a restricted number of channels. EEG contaminated with the Electromyogram (EMG) and electrooculogram (EOG) can affect the subsequent analysis. In order to more effectively reject the artifacts and not degrade the quality of the recorded EEG signals, a new framework with signal decomposed technology and blind source separation (BSS) is proposed.

Methods: First, the framework detects and classifies EMG and EOG artifacts, and then uses CEEMDAN-CCA and SSA-SOBI **Methods:** to remove artifacts for EMG and EOG signals respectively. The method of removing the artifacts of EOG combines fuzzy entropy to distinguish the components of EOG.

Results: The Methods proposed are evaluated on semi-simulated data. Almost all the artifact fragments can be detected and type of the artifacts can be classified correctly. The two denoising algorithms achieve high correlation with the original signal under a low SNR condition.

Conclusion: The Results demonstrate the superior performance in single-channel EEG automatic artifact rejection.

Key words: Automatic artifact rejection, Blind source separation , Single-channel EEG

ID 1002

Uncertainty Quantification for Deep Learning-based Remote Photoplethysmography

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Objective: Remote photoplethysmography (rPPG) is a non-contact technique for measuring cardiac signals from facial videos. Recently, deep learning (DL) based remote photoplethysmography (rPPG) Methods have made great progress in non-contact heart rate (HR) measurements. However, the reliability of rPPG measurements is still a bottleneck for realistic applications due to its susceptibility to motion and illumination noise. At present, most rPPG-based HR quality evaluations rely on the comparison with the contact-based reference signal. It is increasingly important to develop reference-free quantitative assessment Methods for rPPG measurements.

Methods: In this paper, we propose to quantify the uncertainty of a convolutional neural network (CNN)-based rPPG model as the reference-free quantitative quality assessment metric. Specifically, we evaluate and compare both the Bayesian neural network (BNN) method and the deep ensemble method to estimate the uncertainty of HR measurements from the CNN model. In order to quantitatively evaluate the performance of the uncertainty prediction, we calculate the correlation coefficient between the predicted uncertainty and the true absolute error, conduct the reliability analysis, and calibrate the uncertainty.

Results: The effectiveness of the predicted uncertainty from both Methods is verified on the public UBFC-RPPG and MAHNOB-HCI databases, where the uncertainty is found to be highly correlated with the true absolute error.

Conclusion: To the best of the authors' knowledge, this is the first attempt to assess the uncertainty as the reference-free quantitative quality metric for rPPG measurements. The obtained uncertainty highly correlates with the true absolute error of CNN-predicted HRs.

• The performance of two popular uncertainty quantification Methods is evaluated and compared for assessing rPPG measurements. The pros and cons of the two Methods are also summarized.

• The investigation is very instructive to other DL-based rPPG Methods to achieve a reference-free quantitative quality assessment.

Key words: Remote photoplethysmography; heart rate estimation; uncertainty; Bayesian neural network; deep ensembling

ID 1244

利用银包裹海胆状金纳米粒子的表面增强拉曼散射灵敏检测水产养殖水中的孔雀石绿

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目的：海胆状金纳米颗粒（ULGNs）由于具有可调整的枝权数量和枝权长度，表现出丰富的表面等离子体光学特性，具有较强的拉曼增强能力。通过调节 ULGNs 的枝权数量和长度，并在其外围包裹银层，可以得到 SERS 性能更好的银包裹海胆状金纳米颗粒（ULGNs@Ag），将其作为基底，从而实现孔雀石绿的高灵敏检测。

方法：通过一锅法合成 ULGNs，通过电偶置换法合成 ULGNs@Ag；两者均采用吸收光谱及电镜表征；通过加标回收实验验证检测方法的可行性。

结果：通过调整一锅法合成过程中硝酸银、抗坏血酸的用量以及合成温度，合成了不同形貌的 ULGNs；通过调整银包裹海胆状金纳米颗粒的银层厚度，改变枝杈与银层的相对位置，制备了高 SERS 增强效果的 ULGNs@Ag，将其作为 SERS 基底，实现水产养殖用水中孔雀石绿的灵敏检测。

结论：使用 ULGNs@Ag 作为 SERS 基底检测孔雀石绿具有较宽的线性检测范围和较低的检测限，并可成功用于水产养殖水中孔雀石绿的检测，表明 ULGNs@Ag 在生化传感方面具有一定的应用价值。

关键字：局域表面等离子体；银包裹海胆状纳米颗粒；表面增强拉曼散射；孔雀石绿

ID 1263

生物组织介电特性与离体时间的相关性研究

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目的：生物组织介电特性是电磁诊疗、生物电磁防护等领域的重要基础，由于医学伦理、患者安全等原因，通常采取体外测量获得。但生物组织会随着离体时间延长逐渐失去活性，导致介电特性与在体时相差甚远。因此离体组织的时间依赖特性研究具有重要意义。本研究拟探讨一种数学方法拟合生物组织介电特性与离体时间的相关性，以便获取接近在体组织介电特性的数据。

方法：本研究采用阻抗分析仪测量 100MHz 以下、不同离体时间猪正常肝组织的介电特性。根据电导率与介电常数随时间变化的曲线趋势，采用统计分析、10 折交叉验证确定拟合效果最优的数学方法，并通过 10 折交叉验证以及误差分析验证数学方法的预测性能。所有测量过程均在婴儿保温箱内完成（温度 37℃，湿度 98%）。

结果：二元五阶多项式对肝组织介电特性与频率、时间的拟合效果最优。电导率和介电常数的确定度均为 0.99，MRSE 分别为 0.01 和 0.02，拟合误差分别为 3.03% 和 2.09%，预测误差分别为 3.25% 和 4.87%。

结论：二元五阶多项式能够拟合生物组织介电特性与离体时间的相关性，为生物电磁研究领域提供更准确的介电特性数据。而且多项式拟合方法计算简单，为进一步探讨多因素影响下的介电特性奠定基础。

关键字：生物组织，介电特性，离体时间，二元高阶多项式

ID 1314

无接触式生理信号感知磁共振成像技术研究

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目的：当采用磁共振成像技术（MRI）检查胸腹时，经常产生由心脏、呼吸等生理现象引起的运动伪影，可能导致医学误诊或重复采集。准确的运动探测对于解决运动成像伪影至关重要。相比于传统传感，无接触式检测技术在保护病人隐私的同时大大提高了扫描时的舒适性，越来越受到大家重视。

方法：在西门子 1.5T 磁共振设备下对比了导频音（PT）和节拍导频音（BPT）技术。PT 是频率为 63MHz 的正弦波，BPT 的两路信号频率分别为 2.4 和 2.463GHz。信号由天线发射，被受试者的运动调制，MR 线圈接收，通过算

法解调分离出呼吸、心跳信号。将相同运动状态的 k 空间数据融合，重建图像。

结果：对于呼吸信号，两种技术均能正确捕捉。分别选择调制信号幅度最大的两个线圈，计算调制百分比。BPT 的调制幅度比 PT 大了 2 倍以上。对于微小的心跳信号，BPT 能够较为稳定的检测出来，而 PT 难以精准地捕捉。利用 BPT 信号重排 k 空间数据后重建，大大改善了成像效果。

结论：本文对比了 PT 和 BPT 两种新型无接触式生理信号检测技术，通过算法分离出受试者的呼吸、心跳运动。证明了 BPT 比 PT 能提供更高灵敏度的小尺度运动检测。利用 BPT 信号重排数据进行重建，得到了更好的医学图像。

关键字：磁共振　运动传感　运动伪影　呼吸、心跳　射频

ID 1339

磁声成像扇形扫描检测装置设计

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目的：磁声耦合成像是一种结合了磁声效应和超声成像的高空间分辨率无创电特性成像技术。传统的电导率成像方式需对待成像物体进行圆周扫描，再进行图像重建，该方法系统较为复杂，扫描检测相对耗时。本研究设计了扇形扫描成像装置，该装置可以在保证成像质量的情况下简化扫描装置结构，并且进一步提高信号的抗干扰能力。

方法：本研究设计了一种扇扫探头成像装置，其硬件系统包括激励、采集和控制模块。信号由超声换能器发出，由采集卡进行信号采集。控制部分经 RS485 协议进行位移传感器数据传输，以提高抗噪声性能。软件系统主要实现探头的扇形旋转扫描控制，以及图像的重建显示。程序由位移传感器角度反馈，电机控制，采集信号显示与保存，成像模块组成。

结果：本研究先对扇形扫描成像系统的运动控制能力进行了测试，采取 ±35 度的扇形范围扫描。结果表明，系统可实现磁声信号的扇形扫描检测，成像结果可以较为明显的观察到凝胶仿体的前后电导率边界，在保证成像质量的情况下，较传统扫描方法进一步缩短成像时间。

结论：本研究设计了扇形扫描成像装置系统，并实现了凝胶仿体的磁声电导率成像，解决了圆周扫描成像方法速度慢，过程繁琐的问题，为进一步提升成像效率，推进其应用提供了一种新方法。

关键字：磁声耦合成像；扇形扫描；信号处理；重建

ID 1354

基于自适应卡尔曼滤波的听觉诱发电位提取技术研究

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目的：目前临床中听觉诱发电位（Auditory Brainstem Response，ABR）提取需要受试者保持不动，存在采集要求高，抗噪性能差的问题，本文将从信号提取算法方面对强噪声干扰状态下的 ABR 采集进行优化。

方法：在传统的卡尔曼滤波算法基础上，提出自适应卡尔曼滤波算法，相较于传统方法，自适应卡尔曼滤波算法引进了两条迭代规则，能够动态持续更新测量误差和预测误差，通过测试不同噪声强度下的 ABR 信号提取研究其性能。

结果：自适应卡尔曼滤波算法能够在大噪声（噪声平均幅度比 ABR 信号幅度大 100 倍）的干扰下提取到与参考 ABR 波形一致的 ABR 信号；在不同的动作（咀嚼和张嘴）干扰下，该算法也能提取到与原始波形相关系数最高的 ABR 信号；此外，在不同的动作干扰下，该算法所取得的波形潜伏期相较于传统方法，也具有最高的一致性。

结论：所提出的自适应卡尔曼滤波算法能够优化临床 ABR 信号质量及抗噪性能，为快速、高效的 ABR 信号采集提供了新思路。

关键字：听觉诱发电位 ; 动态 ; 自适应卡尔曼滤波

ID 1589

基于 CEEMDAN-MPE 和凸组合 LMS 自适应滤波器计算运动血氧饱和度研究

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目的：基于光电检测的血氧饱和度（血氧）检测仪器其性能在很大程度上受到光电容积描计法（PPG）信号中运动伪影（MA）的影响。

方法：本文提出了一种基于完全自适应噪声集合经验模态分解 - 多尺度排列熵（CEEMDAN-MPE）联合凸组合 LMS 自适应滤波器的运动噪声消除方法计算运动血氧。本算法首先对光电传感器采集得到的 PPG 信号通过带通滤波器进行预处理，然后将被 MA 破坏的 PPG 信号用 CEEMDAN 分解成若干个本征模态函数和一个残余量，再计算这若干个本征模态函数的多尺度排列熵，通过仿真设置合理阈值为 0.3510，将 MPE 大于此阈值的本征模态函数重构成噪声参考信号，将预处理之后 PPG 信号和重构噪声信号同时输入到凸组合 LMS 自适应滤波器中，最后对自适应滤波器输出的误差信号利用血氧计算公式计算血氧值。

结果：仿真、测试结果表明，人体正常行走以及慢跑的运动状态下，降噪后 PPG 信号的计算血氧值与市面上某手环显示的血氧值方差均小于 2，平均绝对误差百分比不超过 1%。

结论：该方法有效地降低了 PPG 信号中的运动伪影，能够准确计算出运动状态的血氧，有利于人体运动状态下的生理监测。

关键字：PPG 信号；CEEMDAN ； 多尺度排列熵；凸组合 LMS ； 运动血氧

1632

A Novel EEG and ECG Multimodal Feature Combination for Automatic Sleep Staging Task

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Objective: Accurate sleep staging evaluates the quality of sleep, supporting the clinical diagnosis and intervention of sleep disorders and related diseases. Manual scoring undertaken by sleep experts is a tedious and time-consuming task. An accurate and efficient automatic sleep stage classification method is thus of great significance. In this study, we proposed a generalized EEG and ECG multimodal feature combination to classify sleep stages with high efficiency and accuracy.

Methods: Briefly, a hybrid feature combination in terms of multiscale entropy and intrinsic mode function was used to reflect nonlinear dynamics in multi-channel EEGs, along with heart rate variability measures over time/frequency domains, and sample entropy across scales was applied for ECGs. For both the max-relevance and min-redundancy method and principal component analysis were used for dimensionality reduction. Ten-fold cross-validation was performed. Macro-F1 score, macro-geometric mean, and Cohen kappa value are used to evaluate the classification performance of each class in an imbalanced dataset. Multiple traditional machine-learning classifiers were used for sleep stages classification to investigate the generalization ability of the proposed multimodal feature combination, including support vector machine (SVM), random forest (RF), k-nearest neighbor (kNN), and linear discriminant analysis (LDA).

Results: The proposed combination achieved the highest accuracy of 84.3% and the highest kappa value of 0.799 on ISRUC-S3 dataset by using support vector machine, suggesting the proposed multimodal feature combination is promising in accuracy and efficiency compared to other state-of-the-art methods.

Conclusion: In this paper, an accurate and efficient multimodal feature combination was proposed, which is promissing in supporting clinical treatment of sleep-related diseases.

Key words: Sleep stage classification, Multiscale entropy analysis, Empirical mode decomposition, Multimodal, Heart rate variability.

ID 1646

临床药师基于 TDM 在一例奥氮平超常量 治疗精神疾病中的应用分析

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目的：探讨临床药师基于 TDM(治疗药物监测) 数据，参与精神科住院病区查房、病情讨论，在患者个体化精准药物治疗中的应用效果和价值。

方法：运用溯源法，回顾一例精神病患者在住院期间，药师借助 TDM 监测数据所处该药物治疗血液浓度安全范围区间位置，建议床位医师大胆而谨慎予以奥氮平短期内超说明书常规药量（低于药物治疗极量）治疗、控制患者精神病症状的效果分析。

结果：结果：药师基于 TDM 数据为依据，根据监测数据所处该药物治疗血液浓度安全范围区间位置、结合该患者既往病史、身体状况、精神症状、治疗过程，建议临床医生大胆而谨慎予以奥氮平短期内超说明书常规药量治疗（低于药物治疗极量），控制患者精神病症状，治疗效果明显好转。

结论：药师基于 TDM 在精神科个体化精准药物治疗中，具有实用价值，而且基于 TDM 数据，可以正确、准确、客观评判床位医师给予患者“超说明书”用药的治疗方案的合理性，在后期的医嘱点评中具有重要的支撑价值，值得借鉴。

关键字：关键词　治疗药物监测　精准药物治疗　个体化给药　居家服药

1904

基于深度学习的动态单分子传感技术

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目的：动态单分子检测已成为检测低丰度分子标志物的重要手段，如何准确区分特异性结合是单分子检测的关键科学问题，现有的单分子溯源通过对单分子信息进行筛选，获得更准确的特异性结合数据，如动力学指纹和时间窗筛选，但在识别准确度上还存在不足，这是因为不同于传统终点检测，动态检测通过对分析物结合过程进行持续检测以获取多维度的信息，单一维度的筛选标准无法很好区分特异性和非特异性结合。

方法：这里，我们通过深度学习对 miR-155 的单分子结合过程进行运动跟踪和动力学特征量化，其中，事件频率（Eventfreq）包含了结合时间和动力学参数等多个维度的信息，因此该特征展现出较时间窗筛选更高的溯源准确性。

结果：对同一数据的分析，时间窗筛选的灵敏度为 65.81%，特异性为 84.06%，分析物浓度的校准曲线图的拟合直线线性度为 0.56，而在事件频率方法下，对照组中 92.1% 非特异性事件被筛除，灵敏度为 69.19%，特异性提升至 86.74%，拟合直线线性度提升至 0.95，LoD 值达到亚 fM。模型的受试者工作曲线（ROC）显示该模型 AUC 面积为 0.95

结论：该方法能以更小的灵敏度牺牲获取更高特异性提升，极大的提升了检测精度。

关键字：单分子检测；单分子溯源；动力学特征

ID 1923

基于深度学习的高灵敏散射成像技术

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目的：干涉散射显微镜 (iSCAT) 和表面等离子体共振显微镜 (SPRM) 等基于散射的显微成像技术具有无标记、高灵敏等优点，被广泛应用于生物检测中。然而，量子噪声限制了散射显微成像对小生物样本的快速检测。提高入射光强或相邻图像平均的方法都可以提高成像灵敏度，但存在光损伤和时间分辨率丢失等问题。本文目标是突破光散粒噪声极限，打破散射显微系统灵敏度与时间分辨率间的严格关系，实现具有高灵敏度、高时间分辨率的散射显微成像系统。

方法：我们发展了一种基于深度学习的技术 Deep-SM，其以二维 Unet 和 长短期记忆网络（LSTM）为基础，结合 COX 数学模型，利用生物样品信号以及量子噪声的时空相关特性来降低噪声幅度，以突破光散粒噪声极限。

结果：将 Deep-SM 应用在 iSCAT 和 SPRM 的仿真数据上，测试结果证明 Deep-SM 在维持散射显微成像高时间分辨率的同时可以有效提高检测灵敏度。再者，将 Deep-SM 应用于 SPRM 实验数据分析，结果表示其可以有效提高纳米颗粒结合和解离过程的检测灵敏度，以及提升颗粒运动轨迹、布朗运动追踪和细胞内细胞器跟踪过程的时间分辨率。

结论：Deep-SM 是提升散射显微成像系统灵敏度或时间分辨率的有力工具。

关键字：iSCAT，SPRM, Deep Learning, 灵敏度，时间分辨率

ID 1924

同型半胱氨酸荧光检测与生物成像

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目的：生物硫醇包括半胱氨酸（Cys）、同型半胱氨酸（Hcy）和谷胱甘肽（GSH），对维持多种生命活动过程中的氧化还原平衡具有重要作用。巯基强亲核性的特点被广泛用于检测生物硫醇分子的荧光探针的开发，然而由于 Hcy 在分子结构和化学性质上与 Cys 的高度相似性，导致能够识别 Hcy 的荧光探针极易受到来自 Cys 的干扰。虽然能够选择性识别 Hcy 的荧光探针已经取得了一些进展，但是能够检测细胞内源性 Hcy 水平波动的探针依然具有挑战性。

方法：在这项工作中，我们基于二硫醚乙烯基功能化茚酮烯共轭受体构建了一种检测 Hcy 的荧光探针 TPA-CA。

结果：该探针能够快速（一级反应速率常数为 0.058 min-1）、高灵敏度（LOD = 45 nM）、特异性识别 Hcy 而不受其它生物硫醇干扰，实现了细胞外源性和内源性 Hcy 的成像。

结论：该探针本身不发荧光，与 Hcy 发生分子内环化反应后形成的六元杂环具有强荧光，且具有大斯托克斯位移（217 nm）。该探针不仅能够在活细胞内检测外源性 Hcy 含量的变化，还可以监测到过氧化氢诱导的氧化应激导致的内源性 Hcy 浓度的波动，对深入研究 Hcy 在生命活动中的作用具有重要应用价值。

关键字：同型半胱氨酸；荧光探针；共轭受体；大斯托克斯位移；氧化应激

ID 1980

基于静息态脑功能连接与基因表达的疼痛敏感性个体差异研究

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目的：疼痛敏感性存在较大的个体差异，基因表达及脑功能都会对疼痛敏感性产生影响，然而其影像及遗传学机制仍并不十分清楚。本研究结合影像与遗传数据，挖掘疼痛敏感性个体差异的脑功能连接机制与基因表达特征。

方法：本研究招募了 432 名健康被试采集静息态功能磁共振影像数据，利用激光刺激对被试进行疼痛阈值测量并分为高低敏感性两组。在遗传数据方面，基于 AHBA 公开数据库，提取全脑不同脑区的基因表达数据。首先构建静息态脑功能连接网络，并提取与疼痛敏感性相关的脑功能连接强度特征。其次，将基因表达特征与脑功能连接强度特征进行偏最小二乘回归，定义与疼痛敏感性相关的基因集。最后，对所得到的基因集进行组织特异性、细胞类型特异性及时间特异性表达分析。

结果：本研究定义了与疼痛敏感性相关的 624 个基因。组织特异性分析显示其主要在脑组织中进行表达。细胞类型特异性分析显示主要富集在胆碱能神经元、第 5a 层免疫细胞和 Pnoc+ 神经元。时间特异性分析显示其优先在新生儿早期表达，并集中在丘脑区域。

结论：本研究结合脑影像与基因表达数据，探究了疼痛敏感性的影像遗传机制，加深了我们对疼痛敏感性个体差异的理解，并对临床实践中如何实现个体化疼痛评估和管理提供了思路。

关键字：疼痛敏感性，功能连接，基因表达，影像遗传学，静息态

ID 1988

基于视频和 FMCW 雷达信息融合的非接触式人体呼吸率测量研究

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目的：近年来，基于视频或 FMCW 雷达的非接触式呼吸测量受到越来越多的关注，但两种呼吸测量方法均易受到噪声干扰。为了更鲁棒地测量非接触式呼吸率（RR），本文提出在特征和决策层面上开展视频和 FMCW 雷达的呼吸信息融合测量，以准确估计人体呼吸率。

方法：在特征融合层面，视频和 FMCW 雷达分别提取目标肩部和胸口目标区域的含噪呼吸信号，进而采用多元奇异谱分析（MSSA）提取双模态共享呼吸信号。在决策融合层面，通过对单模态呼吸信号，以及 MSSA 双模态共享呼吸信号以功率占比加权求和，计算最终的目标 RR 值。

结果：在自采的多场景呼吸数据集上对所提方法开展了评估，其中共 15 名健康受试者在自然光照条件下休息、讲话、步行和跑步。实验结果验证了融合方法的优越性，其中休息场景的均方根误差 (RMSE）达到每分钟 0.82 次（bpm），讲话场景为 2.36 bpm，步行场景为 2.81 bpm，跑步场景为 3.40 bpm，变化场景为 2.99 bpm。

结论：本文在特征和决策两个层面上开展视频和 FMCW 雷达的融合呼吸测量，在多场景下取得了相比单一模态显著的性能提升，有效地拓展了视频和 FMCW 雷达融合测量的应用范围。

关键字：非接触式；呼吸率；视频；FMCW ；融合；多元奇异谱分析

ID 2065

液态金属生物软体电子

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目的：传统坚硬、干燥的刚性电子接口器件与湿润、柔软的生物体之间存在较大的机械强度和界面化学差异，容易引起接触不良、信号干扰、电信号转换效率低和毒副化学反应等问题，不仅影响生物体的正常生理活动，而且严重影响了电信号传输的准确性、安全性和传输效率。为提升电信号传输准确性和稳定性，降低干扰和异物反应，提升舒适性和安全性，我们开展了基于新型软体电子材料的生物电子接口研究。

方法：以离子凝胶为接口材料，以液态金属为电气连接材料，通过调控液态金属在凝胶中的表面张力，实现了与软组织适配且不易断裂分层的液态金属 - 凝胶复合结构，展现了在植入式软体电子电路、压力传感器及组织电刺激等生物电子中的应用前景。

结果：建立了液态金属 - 导电凝胶的复合软体生物电子平台技术，开发了与组织模量适配的高顺应性、低热损伤、高电流注入效率的组织电刺激阵列技术。

结论：基于液态金属 - 凝胶软体复合结构，展示了软体生物电子如植介入式电子电路、压力传感器、电刺激器及电渗促释放的伤口敷料等应用可行性，体现了良好的生物电子应用前景。

关键字：软体生物电子接口、液态金属、导电水凝胶、电刺激器、植介入电子

ID 2072

基于纳米模板的微电极阵列用于心肌细胞胞内动作电位记录

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目的：电生理记录是研究电兴奋细胞的重要手段，对于疾病的机制探索、治疗和预防至关重要。建立稳定、灵敏、可靠、可扩展、低成本的电生理检测平台是人们长期追求的目标。虽然三维微 / 纳米器件结合各种透膜方式已经成功记录到细胞内动作电位，但复杂的微 / 纳米制造工艺阻碍了其广泛应用。

方法：我们以聚对苯二甲酸乙二醇酯多孔膜作为模板，采用简单的制造工艺开发了两种纳米结构微电极阵列。基于多孔模板的结构特点，我们采用标准微加工工艺制造了纳米陷阱电极。此外采用原子层沉积，我们还在模板上制造了纳米垂直电极。

结果：这两种电极的制备工艺均兼容大规模微加工技术，且两种电极都可以与心肌细胞形成紧密的耦合，获得灵敏、高质量、长时间的细胞内动作电位记录（幅值达到 ~6 mV，时间超过 100 分钟）。进一步对比不同纳米结构微电极阵列，我们可以改善细胞 - 纳米界面以提高电极的细胞内记录性能。

结论：基于纳米模板的微电极阵列在细胞内动作电位记录上具有巨大的潜力，有望广泛应用于生物医学领域的基础研究和临床试验。

关键字：纳米模板；细胞内电生理；动作电位记录；电穿孔；心肌细胞

ID 2167

一种用于校准血糖无创拉曼检测的组织仿体

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目的：血糖浓度是人体最重要的生理指标之一，对其准确监测是避免老年人、孕妇、糖尿病患者出现不可逆转健康损伤的前提。基于葡萄糖特征峰的拉曼光谱法是最有希望实现高精度无创血糖测量的方法之一。然而，拉曼检测设备存在性能不稳定、参数容易漂移的问题，必须引入周期性的标定来避免因检测误差导致的误诊或误判。

方法：相对于经验值等标定法，在功能和结构特性上与组织接近的固态组织光学仿体被认为是最佳的光学仪器校准器件，并且已经被大量的应用于光学设备的标定领域。但是现有组织仿体大多由极性高分子聚合物制备，存在干扰葡萄糖拉曼特征光谱的分子结构，而非极性聚合物与葡萄糖的均匀混合存在很大挑战。本研究创新性的提出通过油浴将不同光学调节颗粒、极性葡萄糖均匀分散在弱极性聚二甲基硅氧烷中来模拟不同类型组织中的血糖特性。

结果：光学参数检测表明通过调节印度墨水和二氧化钛的浓度可模拟具备不同吸收、约化散射系数的组织。拉曼检测证明仿体基底材料不存在荧光干扰，并且在 785nm 激发波长下的葡萄糖对应特征峰强度与仿体中葡萄糖浓度成正比。

结论：制备的组织血糖仿体可以用于校准和标定拉曼无创血糖检测设备，可进一步推动无创血糖检测技术的发展。

关键字：拉曼、仿体，血糖，光学参数。

ID 2184

The Total Internal Reflection Detection System Based on Weak Measurement for the Precise Determination of Ultra-thin Films

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Objective: We built a total internal reflection detection system based on weak measurement which is one of the significant discoveries in recent decades and we apply this physical theory to chemical and biological detection.

Methods: In this system, the detection result comes from the change of the double peaks pointer with a different refractive index between the measured materials and then converts the change of the double peaks spectrum signal to the center wavelength digital signal through the written program and thereby quantifying the detection result.

Results: In the process of detecting sodium chloride solution, we obtained that the sensitivity of the detection system is 2727.21 nm/RIU and the resolution is 7.2×10-6 RIU. We achieved in situ detection of the growth process of nanometers range TA/Fe(Ⅲ) assembly films and the experimental Results are consistent with a theoretical calculation based on Maxwell Garnett effective medium.

Conclusion: We theoretically calculate the detection limit for the thickness of the film is 22 pm. Due to this total internal reflection structure, this system could also detect other biological reaction processes and it will accumulate experience for us to perform clinical detection in the future.

Key words: weak measurement, total internal reflection, refractive index, Maxwell Garnett effective medium.

ID 2200

一种用于眼底相机标定的三维眼球组织血氧仿体

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目的：视网膜血管结构与氧饱和度的准确测量可以提供很多的病理、生理学信息，可用作临床疾病的诊断依据。双波长眼底相机等光学设备可以获取视网膜结构和氧饱和度信息，但是这类光学设备的准确性和稳定性容易受到红细胞、血管直径和眼底色素等因素的影响，必须要引入周期性的标定来保证测量值的临床意义。

方法：目前常用的人体呼吸实验标定法、经验值标定法、电子模拟器标定法无法体现出个体化差异，也不能满足可溯源要求。相比之下，模拟组织光学、结构特性的仿体已经成为学术与商业界公认的最佳可溯源校准标准之一。在本研究中，我们提出结合 3D 打印及复模工艺制备模拟眼球三维结构、光学特性的仿体，配合灌注系统可用于校准光学检测设备的分辨率和血氧饱和度等参数。

结果：光学参数检测表明可通过改变苯胺黑和二氧化钛的浓度调节吸收、约化散射系数，并且光密度比和苯胺黑的浓度成正比。微管道直径最小为 100 微米，管道结构平滑渐变，互相连通，可真实模拟人体视网膜血管结构。

结论：制备的三维眼球血氧仿体解决了现有二维仿体在视网膜形态和生物学上相关性差的问题，可以更好的校准眼底相机等光学检测设备的检测稳定性和准确性，有助于推动眼底光学检测设备在临床上的应用。

关键字：生物光学仿体，3D 打印，数字光处理

ID 2202

心肌细胞电调控生物传感系统电信号及细胞递送自动化分析

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目的：电穿孔调控技术可通过在细胞膜上诱导纳米孔的产生来实现心肌细胞电信号记录和生物分子的传递。然而，在心肌细胞上施加高电压仍然是一个挑战，以获得安全有效的细胞内通路。为了确保细胞的生存能力，微纳米器件配合低压电穿孔技术在研究中经常被使用，并且通常使用流式细胞术等光学成像方法评估细胞内通路的有效性。然而，这些分析方法的复杂性阻碍了原位生物医学研究的效率。

方法：开发了一个心肌细胞电调控生物传感系统，可以有效地记录动作电位，并从细胞存活率、递送效率和死亡率方面评估电穿孔质量。

结果：该系统平台由 ITO-MEA 微纳器件、电穿孔及电信号记录系统和图像采集处理系统组成。ITO-MEA 微纳器件具有传感 / 刺激电极，结合自主研发的系统，通过电穿孔触发实现细胞内动作电位的记录和递送。通过图像采集处理系统可以实现不同电穿孔情况下心肌细胞电信号记录和递送后各种参数的分析。

结论：因此，我们认为该系统具有药物输送治疗和心脏病学病理研究的潜在性能。

关键字：心肌细胞电调控、心肌细胞电信号记录、细胞递送

ID 2355

Noninvasive Electrical Impedance Tomography Information As Indicators of Postoperative Neurological Dysfunction For Patients underwent TaAR: the Correlation Between Electrical Impedance Parameters and Neurological Serum Biomarkers

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Objective: Total aortic arch replacement (TAAR) entangled with cerebral anoxia during the deep hypothermic circulatory arrest (DHCA) which Results in postoperative neurological dysfunction (PND). Our study aimed at explore the relationship between electrical impedance tomography (EIT) parameters and neurological serum biomarkers in order to provide the possibility of using EIT information as indicators for PND.

Methods: An EIT device was adopted to monitor each patient's cerebral impedances intraoperatively. Meanwhile, serum samples were collected before and after surgery, and the concentrations of biomarker GFAP, NSE, S100B and TAU were measured. During their stays, the patients' prognostic information was recorded. EIT signals from HCA phase were analyzed which included the average resistivity value (ARVHCA), the slope of change of ARV before and after HCA (kHCA), the maximum of differences of ARV between left and right brain (MRAI), the time integral of difference of ARV between left and right brain (TRAI) and the integral value of ARV in half flow period (TARVHP). The correlation between those EIT parameters and concentrations of biomarkers were analyzed.

Results: Complete EIT data were available for 57 patients (with average age 49.2±8.9 years and 91.2% were male). Sixteen (28.0%) subjects had at least 1 PND complication. The Results showed that the Spearman correlation coefficient between EIT parameters and serum biomarkers were under 0.3 for non-PND group while the coefficient for PND group were between 0.3-0.6. Particularly, in PND group, moderate strong relationship can be viewed between TAU protein 24h after surgery and kHCA (r= 0.620), TAU protein 24h after surgery and ARVHCA (r= 0.604), S100B 24h after surgery and TRAI (r= 0.550) and S100B 48h after surgery and MRAI (r= 0.510).

Conclusion: The correlation between EIT parameters and neurological biomarkers were significant in patients with PND, which indicated EIT parameters may become indicators for PND for patients underwent TAAR in the future.

Key words: electrical impedance tomography; neurological serum biomarker; total aortic arch replacement; postoperative neurological dysfunction

ID 2430

基于图像特征和机器学习的电磁耦合脑血流搏动信号分析方法研究

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目的：电磁耦合检测脑血流搏动具有无创、穿透性强，可实时连续监测等优势。本文提出一种图像处理和机器学习相结合的方法，实现不同状态健康志愿者的脑血流搏动信号分类，探究不同状态下脑血流搏动特征与电磁耦合信号的关系。

方法：将基于电磁耦合获取的 12 位健康志愿者在口服咖啡因前后的脑血流搏动信号按窗划分，绘制波形图并构建图像数据集；提取图像局部、整体特征，通过人工特征筛选的方式完成降维；基于 KNN、SVM 和随机森林的方法构建不同脑血流搏动水平的分类模型；通过网格搜索的方式用准确率和 F1 值为反馈进行调参；最后以交叉验证计算准确率、AUC 和 F1 参数来进行模型的评估。

结果：基于电磁耦合信号获得总共 14379 维的图像特征。通过人工特征筛选的方法，保留了 8 维的图像整体特征和 18 维图像局部特征。采用 K 近邻、支持向量机和随机森林的方法分别得到了 82.35%，85.29% 和 89.70% 的准确率。其 AUC 值均超过 0.93，F1 值大于 90%。

结论：基于电磁耦合检测信号，结合图像特征分析方法和机器学习模型，能够实现不同脑血流搏动水平的准确分类，分析不同状态脑血流搏动信号特点，为无创、准确地评估脑血流搏动信号建立了新方法。

关键字：电磁耦合；图像特征；机器学习；信号分析

ID 2433

基于 S 参数的精确检测局灶性脑缺血的研究

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目的：脑缺血是目前一种严重的临床疾。目前，传统的 FCI 检测方法用于实现全脑检测。本文提出了一种轴对称分布的天线结构，可以实现以正常半脑为参考的半脑 FCI 检测。

方法：结合脑电磁仿真模型，将模型置于天线底部，测量天线两个端口的 S 参数，同时测量不放置模型的天线的 S 参数作为对照组，以此评估天线的基本性能。测量模型左侧 (患侧) 介电常数和电导率变化的 S11 幅度，同时测量右侧（健侧）没有变化的 S22 幅度作为对照，以此评估天线准确检测 FCI 的可行性。根据模拟盐溶液的脑物理仿真模型，测量 9 次左侧（患侧）浓度逐步降低盐溶液的 S11 幅度，同时测量右侧（健侧）始终为初始浓度的 S22 幅度作为对照组，以评估天线检测局灶性脑缺血的表现。

结果：测量放置仿真模型的天线和未放置模型天线两端口 S 参数中心频率一致且幅度差小于 4.5db。测量仿真模型左侧（患侧）中心频率下 S11 幅度随介电常数的上升呈下降趋势，右侧（健侧）S22 幅度没有改变。测量模拟盐溶液物理仿真模型中心频率下 S11 幅度随盐水浓度的上升呈下降趋势，右侧（健侧）S22 幅度没有变化。

结论：基于测量分析，显示该天线具有独立检测出大脑左右半球介电常数能力，为半脑 FCI 检测提供新的解决方案

关键字：S 参数；脑电磁仿真；近场耦合；脑缺血

ID 2496

心肺运动试验在肺癌患者术后肺部并发症列线图预后预测模型建立中的应用

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目的：将 CPET 与临床指标结合以个体化预测肺癌患者 VATS 术后 PPCs 发生的影响因素，并绘制列线图模型，使预测结果更加直观、可视化。

方法：回顾性分析我院胸外科行 VATS 的肺癌患者相关数据，找出 PPCs 发生的独立影响因素，绘制列线图预测模型，内部验证后绘制校准曲线，作该模型的 ROC 曲线，并计算曲线下面积（AUC）及 95% 置信区间（CI）。

结果：共纳入患者 168 例。结果示：年龄（OR=6.51，95%CI：1.89-22.45，P<0.05）、术中出血量（OR=5.16，95%CI：0.93-1.00，P<0.05）和 VE/VCO2 slope（OR=0.96，95%CI：1.64-16.25，P<0.05）是 PPCs 发生的独立影响因素。构建列线图模型后，再利用 ROC 曲线分析其区分度（AUC），结果示 AUC 为 0.792(95%CI:0.71-0.87)，灵敏度为 76.4%，特异度为 77.8%，区分能力较好。Hosmer-Lemeshowc2=11.595，p=0.170，提示预测模型有较好的校准能力。

结论：CPET 与临床指标相结合，绘制的列线图预测模型，可以直观、客观和个体化评估肺癌患者 PPCs 发生的风险。

关键字：非小细胞肺癌；术后肺部并发症；心肺运动试验；列线图

ID 2588

用于三维细胞动态监测的细胞传感技术与药效评价研究进展

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目的：药物的研发对于疾病治疗及健康保障具有重要意义，准确的药效评价是药物研发的关键。三维细胞在空间结构、细胞微环境、细胞间相互作用等方面更接近在体细胞行为，有望应用于准确的药物药效评价。然而，如何实现药物作用下三维细胞特性的动态监测是药效评价过程中需要研究的重要问题。

方法：针对这一问题，结合三维细胞培养技术，我们设计并研制多种用于三维细胞阻抗检测的传感器，动态采集三维细胞在药物作用下细胞阻抗的变化，实现细胞活性的动态监测。

结果：我们首先研制了一种基于垂直电极结构的三维阻抗传感器，并使用基质胶培养的三维肝癌细胞 HepG2，实现不同抗癌药物作用下三维细胞活性的动态监测及药物药效评价。进一步结合微加工技术，制备了一种三维微腔阻抗传感器，结合三维肺癌细胞验证了传感器可用于不同浓度及不同组合用药的药效评价。同时结合肺癌病人来源的肿瘤组织构建的三维细胞模型，成功地用于不同化疗药物的药效评价。此外，该传感器可同时用于三维心肌细胞的电位检测，实现药物心脏毒性的评价。

结论：我们研制的多种用于三维细胞动态监测的细胞传感技术及器件，可以实现三维细胞实时、动态、长时间的检测，为药物药效及毒副作用的准确评价提供了良好的技术手段。

关键字：细胞传感器；三维细胞；阻抗检测；药效评价；细胞活性检测

ID 2636

Hypothalamic Neuron Network-based Bioelectronic Tongue for real-time Glucose Monitoring

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Objective: The expression of sweet receptors (T1R2 and T1R3) in the hypothalamus may play a role in the control of energy homeostasis and the development of obesity and diabetes. The hypothalamic glucose-sensing neurons are known to detect glucose fluctuations, but the mechanism that mediates the function of these glucose-sensing neurons remains unclear. Conventional detection Methods such as the patch clamp suffer from complex operation, and neuronal calcium imaging is cytotoxic and cannot achieve real-time detection. Therefore, hypothalamic neuron network-based bioelectronic tongue coupling with the microelectrode array (MEA) was constructed for real-time glucose monitoring.

Methods: Primary hypothalamic neuron cells from ICR suckling mice were isolated and then cultured on MEA chips for electrophysiological signal detection. To characterize hypothalamic neuronal networks, immunofluorescence staining was performed using sweet receptor antibodies, neuronal and astrocyte markers.

Results: The endogenous expression of sweet taste receptors (T1R2/ T1R3) in hypothalamic neuronal cells was investigated, laying the foundation of hypothalamic neuron network-based bioelectronic tongue for glucose sensation. The spike signal response under glucose stimulation was shown. Besides, the concentration-dependent response of the bioelec-

tronic tongue was investigated with 10 μM~8 mM glucose.

Conclusion: Glucose excitatory neurons (GE-Neuron), glucose inhibitory neurons (GI-Neuron) and non-glucose-sensitive neuron (GN-Neuron) was successfully detected, which was important for exploring the role of sweet receptors in the brain in maintaining the balance of glucose metabolism. However, whether GE-Neuron and GI-Neuron interact with each other still needs to be further explored through cross-correlation analysis.

Key words: Cell-based biosensor; Sweet taste; Hypothalamic neuron

ID 2678

Multi-time-scales Analysis for Detecting Heart Failure Based on High Quality Ballistocardiography

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Objective: Ballistocardiography (BCG) is a non-contact tool for monitoring cardiovascular function. In previous studies, quantifying the difference in BCG between heart failure (HF) patients and controls were based on heartbeat analysis. However, multi-time-scales analysis can extract more detailed information about short/long-term physiological signals. In this study, we proposed a method for analyzing BCG sequences under multi-time-scales, aimed to extract multi-scale features to identify HF.

Methods: Piezoelectric sensors were used to obtain 30s high-quality BCG signals of subjects (50 HF, 29 healthy adults) at resting-state. Then, the extraction of multi-time-scales features have three main aspects. First, the small-time-scales features contain the statistics of the IJK signals power and the IJK signals similarity (dynamic time warping, DTW), respectively. Second, the middle-time-scales features have the statistics of heartbeats similarity (DTW) and mean square error (MSE), respectively. Finally, the large-time-scales features contain multi-time-scales fuzzy entropy (FE) and classical Lempel-Ziv (LZ) complexity with time scales of 2s, 5s, 10s, 15s, 20s, 25s and 30s, respectively. In addition, heart rate and age were also extracted. These features were used to classify BCG signals based on HF status.

Results: Multi-time-scales features of BCG signals have better performance than single-time-scale features in HF detection, and the sensitivity, accuracy, and F1 scores of the XGBoost classifier Results were 90.00%, 81.01%, and 85.71% using the leave one subject out (LOSO) validation, respectively.

Conclusion: The Results demonstrate the important role of the proposed multi-time-scales features based on high-quality BCG sequences in HF detection.

Key words: ballistocardiography, heart failure, multi-time-scales, XGBoost classifier, smart monitoring

ID 2703

基于声表面波微流控芯片的荧光粒子分选系统

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目的：传统流式细胞仪广泛应用于生物研究和临床应用，但是其设备昂贵、体积庞大并且可能存在诸多潜在问题。近年来生物微机电领域内成为焦点的声流控技术，不仅可以精确操纵粒子和细胞，而且集成度高且生物相容性好，因此本研究设计了可小型化的，基于声表面波的微流控荧光粒子分选系统。

方法：分选系统的原理和方法如下：在微流控芯片层面通过鞘流液将粒子移动轨迹聚焦并形成单排，然后逐个通过 488nm 激光器光斑质询，带有荧光的粒子发出 532nm 的荧光，经由荧光检测系统判断是否为荧光粒子。检测到目标粒子后，控制信号发生器和功率放大器输出信号产生行波场，从而推动目标粒子产生横向位移来实现分选。

结果：从颗粒运动轨迹的角度出发，若声表面波作用时间设定为 0.1ms 时，荧光锁定的颗粒横向偏移达到 20um，若作用时间设定为 1ms 时，可实现 50um 的横向偏移。同时在作用时间不变的情况下，颗粒的偏移与作用功率近似成线性关系，但过大功率可能产生空化以及生物损伤等负面影响。目前初步可以实现的分选频率为 500Hz。

结论：本研究从系统层面验证了基于声表面波实现荧光颗粒分选的可能性及潜力。

关键字：生物微机电，声流控，荧光颗粒分选

ID 2735

人体甲状腺癌变组织介电特性测量

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目的：介电特性（dielectric properties，DPs）是人体组织固有物理属性，表征了电磁场与人体组织相互作用关系。本研究旨在测量甲状腺正常与癌变组织的 DPs 值，并探讨甲状腺癌病理分级分期对 DPs 值的影响，为 DPs 在甲状腺组织的临床鉴别提供理论基础。

方法：使用网络分析仪及介电探头在 10 MHz~4 GHz 的频率范围内测量 73 例患者 259 例手术切除的甲状腺样本，获取反射系数 S11。基于开端同轴重建法由 S11 数据计算所测样本的 DPs 值。根据 TNM 分级和分期标准（AJCC 2018）并结合术后病理报告将癌变样本分为四类：T1aN0M0，T1bN0M0，T1aN1M0 和 T1bN1M0。采用秩和检验分析不同分级分期对 DPs 值的影响。

结果：在 10 MHz~4 GHz 的测试频率范围内，癌变和正常组织的 DPs 之间显示出显著差异，肿瘤大小对 DPs 有显著影响，淋巴结转移情况对肿瘤 DPs 没有影响（$p>0.05$）。

结论：甲状腺癌变和正常组织的 DPs 具有显著差异，不同的分级分期对 DPs 值具有影响。上述研究表明，基于组织 DPs 测量在甲状腺的临床鉴别应用中具有一定潜力。

关键字：介电特性；甲状腺；组织鉴别；分级分期

ID 2761

EEG-based Pitch Perception Analysis using EEGNet

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Objective: Pitch perception is defined as the subjective highness and lowness of a sound, which plays an essential role in language or musical perception and semantic understanding. However, the Objective evaluation method for measuring a human's pitch perception ability has not been well investigated. In this study, EEG combined with deep learning **Methods:** is employed to study Objective evaluation indicators and biomarkers of pitch perception.

Methods: We recruited five participants to conduct an audiometry experiment using a no-feedback Go/NoGo paradigm consisting of 200 trials, and their EEG signals were recorded. A total of six different frequency pairs were considered. Then, EEGNet as a popular deep-learning EEG classification model was used to classify the recorded EEG. The comprehensive comparison experiments were conducted to investigate the optimal hyperparameters of EEGNet. By splitting EEG segments with different lengths of temporal windows, the temporal region of interest was determined. Additionally, we analyzed the frequency characteristics and spatial patterns using the learned temporal filters (kernels) and spatial filters. Moreover, the ERP analysis was conducted with the feature vectors output from EEGNet.

Results: Results show that the frequency pair with the widest interval (i.e., 200Hz and 2000Hz) achieves the best classification performance with an accuracy of 74.10%. The EEG-Net architecture experiments suggest that the EEGNet with 8 temporal filters (pooling stride: 4) and 2 spatial filters (pooling stride: 2) is the optimal architecture. Temporal window selection Results show that 0.2-0.9s after stimuli is the temporal region of interest. Besides, ERP analysis indicates that P300 and P600 components may be related to pitch perception.

Conclusion: In this study, we analyzed the EEG-based pitch perception using EEGNet and investigated the potential biomarkers and Objective evaluation indicators, laying the foundation for Objective assessment of human hearing and CI encoding strategy.

Key words: Pitch perception; EEG; deep learning; EEGNet

ID 2792

Fast-responding Electrochemical Hydrogen Gas Sensor with Pt-Pd Based Electrode and Polymeric Ionic Liquid on Porous substrate

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Objective: As a carbon-free and efficient energy source, hydrogen has been widely used in various applications. Due to the high flammability and explosion risk of hydrogen-air mixtures, it is vital to have fast-responding sensors for hydrogen leak detection from its production to consumption. Electrochemical gas sensors have been developed for hydrogen detection, however, the primary challenge lies in their relatively slow response time. This paper presents a miniaturized flexible electrochemical gas sensor for rapid detection of hydrogen with a response time less than 10s.

Methods: The sensor features a screen-printed electrode on a porous polymeric membrane that enables fast gas diffu-

sion. Based on platinum-palladium (Pt-Pd) alloy nanoparticles as the sensitive transducer material, the electrode was further modified with reduced graphene oxide-carbon nanotube (rGO-CNT) hybrids by electrodeposition of GO-CNT dispersion to promote electron transfer. Polymeric ionic liquid (PIL) was fabricated and utilized as the solid electrolyte to address the mobility/permeability problem of conventional room temperature ionic liquid which can affect the lifespan and limit the applications of the sensor.

Results: The fast-responding hydrogen sensor demonstrates stable and excellent performance with high sensitivity, selectivity and linearity at concentrations below the lower explosive limit of 4 vol-% H_2.

Conclusion: With fast response, miniaturized size, flexible substrate and stabilized structure, this sensor is promising for deployment in wearable devices for real-time point-of-exposure gas hazard monitoring.

Key words: Hydrogen monitoring; electrochemical gas sensor; miniaturized sensor; polymeric ionic liquid; response time

ID 2862

手部力量动态调节过程的感觉运动皮层神经响应

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目的：脑卒中是一种急性神经功能缺损疾病，70% 以上的幸存者会留下上肢运动功能障碍。脑电信号可应用于在临床上肢运动功能康复，探讨手部运动握力调节模式对大脑皮层对侧神经响应的影响，为临床手功能康复提供新的参考。

方法：本研究募集了 8 名健康被试，通过视觉反馈引导受试者右手完成恒定目标力量 (最大自主收缩力的 15%)、力量水平随时间变化 (最大自主收缩力的 15% 叠加不同幅度和频率的正弦波) 的握力跟踪任务。采集了运动任务过程中的大脑皮层 46 通道脑电信号，提取了脑电信号不同模式下对侧感觉皮层事件相关去同步 (Event-related desynchronization, ERD) 在运动任务期间 alpha 频段 (8-13Hz) 和高 beta 频段 (21-28Hz) 的平均强度。

结果：对侧感觉皮层高 beta 频段的 ERD 在恒定力量调节模式下的平均强度小于变化模式下的平均强度；随时间变化的握力跟踪任务中，力量调节幅度相对于调节频率能更多地引起对侧大脑皮层感觉脑电信号的 ERD 平均强度变化。

结论：不同手部运动调节模式引起了不同程度的感觉传入，力量调节幅度和频率对大脑皮层对侧神经响应均有影响，动态力量调节引起大脑皮层对侧的感觉响应更强。

关键字：握力跟踪；动态调节；神经响应；事件相关去同步

ID 2870

用于自闭症识别的脑电图数据增强方法研究

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目的：自闭症 (ASD) 是一种神经发育障碍性疾病，利用脑电图 (EEG) 能体现大脑活动状态，辅助 ASD 识别。然而，

过往筛查 ASD 的研究一直面临着数据规模小的问题。数据增强是解决这类问题的一个途径，如几何变换等传统方法应用于 EEG 都不够有效。因此，本文提出了一种针对 EEG 的深度卷积生成对抗网络 (DCGAN) 方法，从而增加数据规模，并提高 ASD 识别准确率。

方法：首先从 NDA 数据库获得 198 名受试者的 128 通道 EEG。每个个体的信号采用了连续 40 个时间帧，包含任务态与静息态。然后利用皮尔逊相关系数计算 EEG 两两通道间的连通性数值，按时序构建出大脑时序连通图。其次，设计 DCGAN 来对连通图进行学习并生成伪连通图来扩大数据规模。最后，利用长短期记忆网络 (LSTM) 进行 ASD 分类实验。

结果：通过应用 DCGAN 的数据增强方法，ASD 识别准确率有所提高，受试者的任务态和静息态 EEG 经过 LSTM 的十折分类实验分别达到了 67.9% 和 73.3% 的准确率。

结论：本文通过 DCGAN 增加了大脑时序连通图数量，让 LSTM 能更好的学习并完成 ASD 检测任务。本文论证了 DCGAN 对 EEG 数据增强的可行性，可在此基础上探索更多数据增强方法。

关键字：自闭症 (ASD)，脑电图 (EEG)，深度卷积生成对抗网络 (DCGAN)，长短期记忆网络 (LSTM)

ID 3006

单细胞 RNA 测序提示外周 T 辅助（Tph）细胞通过促进 B 细胞分化参与 IgG4 相关性疾病的发生

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目的：IgG4 相关疾病（IgG4-RD）是一种累及多器官的系统性疾病。异常的 B 细胞分化在这一疾病中起着关键作用，但具体机制尚不清楚。

方法：我们使用单细胞 RNA 测序（scRNA-seq）全面研究了三例 IgG4-RD 腹膜后组织和三个对照组织的细胞图谱并全面分析细胞类型和组成。通过免疫荧光染色、外周血流式细胞染色等方法扩大样本进一步验证以上发现。

结果：IgG4-RD 后腹膜组织中 B 细胞、浆细胞和 CD4+T 细胞显著增加。其中，CD4+CXCR5-PD1hiTph 细胞显著增加，伴 IL21 高表达，并在外周血和 IgG4-RD 组织中得到了进一步验证。活动期 IgG4-RD 患者外周血中 Tph 细胞比例显著增高，并与 IgG4-RD 活动性呈正相关。体外研究证实 Tph 细胞通过 IL-21 促进浆细胞分化。

结论：研究表明，Tph 细胞在 IgG4-RD 中增加，并可能通过 IL-21 在 B 细胞分化中发挥关键作用。外周 Tph 细胞是 IgG4-RD 疾病活动性的潜在标志物。这些发现为 IgG4-RD 的发生提供了一种新的致病机制，为今后新的治疗靶点提供依据。

关键字：IgG4 相关性疾病，外周 T 辅助细胞（Tph），浆细胞分化

ID 3020

盐离子对生物膜电穿孔中孔形成和闭合过程的相反作用

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目的：电穿孔在生物学领域具有巨大的应用潜力，但是如何制定合适的实验方案以实现较高的穿孔效率仍然是一个难题。这是因为许多因素对电穿孔的影响机制并不明确，盐离子就是其中一个重要的因素。另外，由于电穿孔发生在纳秒时间范围内且穿孔初期孔的大小也属于纳米范畴，使得电穿孔过程难以被清晰地观察和记录，极大地限制了对其潜在机制的实验研究。

方法：本研究采用分子动力学（MD）模型结合实验方法研究了盐离子对电穿孔过程的影响，其中巨型脂质囊泡（GUVs）被用于细胞模型的构建，氯化钠（NaCl）被选为代表性的盐离子。

结果：结果显示，电穿孔导致的孔体积变化曲线遵循滞后 - 爆发动力学，即在施加电场后先出现滞后期，紧接着快速扩张最后趋于平衡。

结论：首次发现盐离子在电穿孔的不同阶段发挥着相反的作用。具体地，在穿孔初期，由于盐离子累积在膜表面为膜两端提供了附加电势，促进了膜孔的快速形成；在穿孔后，却又由于孔内盐离子的电荷屏蔽作用使得孔的线张力增加，进一步诱发了孔的不稳定，促使了膜孔的闭合。相应的 GUV 电穿孔的实验结果与 MD 模拟结果定性一致。这项工作从理论上解释了盐离子对细胞电穿孔微观机制的影响，并为细胞电穿孔缓冲液的选择提供了理论指导。

关键字：细胞电穿孔；盐离子；巨型脂质囊泡；分子动力学模拟

ID 3115

外周血 NK 细胞与系统性硬化症中的关系研究

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目的：观察系统性硬化症患者外周血中 NK 细胞水平的变化及其临床意义。

方法：收集 79 例初诊 SSc 患者及 80 名健康组的外周血临床标本，比较 SSc 患者与健康组外周血 NK 细胞水平的差异，分析 SSc 患者外周血 NK 细胞数量与炎性指标、生化指标、抗体、细胞因子、器官受累的相关性。统计学方法采用 SPSS 20 对数据进行分析，采用独立样本 t 检验、Mann-Whitney U 检验、卡方检验、Pearson 相关性分析，以 $P < 0.05$ 为差异有统计学意义。

结果：① SSc 患者外周血淋巴细胞亚群绝对计数明显低于健康组，差异均有统计学意义 ($P < 0.05$)；②按照 NK 细胞绝对计数水平将 79 例 SSc 患者分成 2 组：NK 细胞高水平组与 NK 细胞低水平组，两组之间疾病活动度无明显差异；③ NK 细胞数量的减少与 SSc 患者皮肤受累有关（χ^2=3.889，P=0.049，$P < 0.05$）；NK 细胞数量的减少与 SSc 患者肺脏受累有关（χ^2=6.002，P=0.014，$P < 0.05$），有统计学意义。

结论：SSc 患者外周血 NK 细胞水平明显下降，可能与 SCL-70 抗体存在相关性，皮肤及肺脏受累者 NK 细胞水平更低，提示外周血 NK 细胞可能在 SSc 的免疫发病机制中发挥重要作用。

关键字：系统性硬化症；NK 细胞；皮肤纤维化；肺间质纤维化

ID 3189

基于心音迁移学习的 CatBoost 模型识别左心室舒张功能障碍

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目的：左心室舒张功能异常检测在心脏功能筛查中尤为重要，本文提出了一种基于心音图迁移学习的 CatBoost 模型，以非侵入性的方式检测舒张功能异常。

方法：本研究采用短时傅里叶变换、梅尔倒谱系数、S 变换和伽马滤波器对心音信号实现二维图像编码。然后，分别采用预训练的卷积神经网络（CNN），通过迁移学习从心音谱图中提取深度特征。随后，分别对不同特征子集应用主成分分析和线性判别分析进行降维，然后采用 CatBoost 进行分类。最后，比较了不同特征选择算法和机器学习模型的分类性能，本研究中模型的超参数优化是通过网格搜索确定的。

结果：全局特征重要性的可视化结果显示，由 ResNet50 从伽马图谱中提取的深层特征对分类做出了最大的贡献。本研究提出的基于多个领域特定特征融合的 CatBoost 模型与 LDA 实现了最佳性能，测试集上 AUC 为 0.911，准确率为 0.882，灵敏度为 0.821，特异度为 0.927，F1-score 为 0.892。

结论：所开发的基于心音图迁移学习的模型可以帮助舒张功能异常的检测，有助于舒张功能的非侵入性评估。

关键字：心音，迁移学习，CatBoost，左心室舒张功能障碍

ID 3239

Electroencephalography (EEG) Characteristics of Patients with Knee Osteoarthritis during Dynamic Balance Test

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Objective: Knee osteoarthrosis (KOA) is a degenerative knee joint disease, which can lead to loss of proprioception. Electroencephalography (EEG) characteristics may reflect proprioception changes, but there are few studies on EEG characteristics of KOA patients during exercise.This study aimed to explore the EEG characteristics of KOA patients that differed from those of healthy controls when dynamic balance ability was tested.

Methods: 15 KOA patients and 17 healthy subjects were enrolled in this study. When they performed the 'Timed Up and Go Test (TUGT)' and '5-times sit-to-stand (5STS)' test, the EEG characteristics of nine electrodes for the cerebral cortex Cz, C3, C4 and Pz, P3, P4, Oz, O1, O2 of the subjects were recorded. Time domain analysis and frequency domain analysis were taken. Range, power, and other characteristic parameters were obtained and analyzed.

Results: The event-related potentials of Cz, Pz, and Oz electrodes were 103.15μV, 75.40μV, and 99.07μV in KOA patients and 46.82μV, 37.28μV and 36.25μV in the healthy subjects. The waveforms of KOA patients were significantly different from those of the healthy subjects ($P<0.05$). For KOA patients, a positive wave peak appeared 900 ms before the negative wave peak. Compared with healthy subjects, the average EEG power of the KOA patients when performing the TUGT was significantly different at the occipital region electrode sites OZ, O1, and O2 in Delta band and the parietal lobe electrode

sites Pz, P4 ($P < 0.05$), but not at the other bands ($P > 0.05$).

Conclusion: In the 5STS test, the brains of patients were more active when moving than those of healthy subjects. During TUGT, the parietal and occipital lobes of the brain were more active in KOA patients than in healthy subjects. This study is significant to further understanding the change mechanism of proprioception in KOA patients.

Key words: Knee osteoarthrosis; Electroencephalography; proprioception; dynamic balance

ID 3292

运用中医检测功能性病变防治疾病

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目的：在疾病发生之前，提取诊断出来并且治疗，在检测出器质性病变之前的亚健康状态，及时及检测出功能性病变并且消除亚健康状态。

现实中很多疾病尤其是癌症之类的在发现的时候已经很迟，属于中晚期，那个时候治疗已经很难，疾病关键在于早期发现，提早治疗，但是目前运用现代科学仪器根本就很难发现，现代医学能够检测到的都是器质性病变，但是在早期病变的时候身体也会有一些病变，可以通过中医四诊八纲检测，通过望闻问切诊断疾病，这些处于亚健康状态下的病变虽然还没有被现代仪器检测到，但是可以反映在舌苔，脉搏上等等。

方法：通过寻找一些已经有相关症状的亚健康人群进行实验，根据四诊合参分析可能出现的疾病，并且最终验证是否正确。

结果：最终经过一些自愿者的试验验证，最终证明了通过中医检测功能性病变可以检测最终疾病。

结论：最终经过一些自愿者的试验验证，最终证明了通过中医检测功能性病变可以检测最终疾病。

关键字：中医，功能性病变，四诊八纲，亚健康

ID 3311

人体唾液中红外光谱的血糖无创检测研究

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目的：血糖无创检测，对于糖尿病患者具有重要的意义。红外光谱法是实现人体成分无创检测的重要方法之一，其中，近红外吸收光谱可以穿透皮肤到达血液区，一直是研究人体成分无创检测的热点。但是近红外光谱吸收较弱，散射程度较高，信号较弱，检测精度低。而中红外光谱 (MIR)，是很多生物液体分子吸收的“指纹区”，该区域特征吸收峰更清晰，具有较好的特异性。但是中红外光谱穿透性差，不能穿透皮肤到达血液区。

方法：所以本研究以人体唾液为研究对象，采用中红外吸收光谱分析技术，测量了 6 名健康志愿者在不同时间的唾液红外吸收谱，并比较了光谱糖信号波数处的峰值强度。验证健康状况下人体唾液红外吸收光谱的稳定性和特异性。对 3 名健康志愿者进行了口服葡萄糖耐量试验（OGTT），探讨唾液中的葡萄糖含量是否与血糖有关。

结果：结果表明，6 名健康志愿者的红外吸收光谱长期保持稳定，表现出稳定性。且每个人的光谱在一定范围内

波动，但没有完全重叠，显示出特异性。3 名健康志愿者在口服葡萄糖耐量试验（OGTT）中的唾液光谱没有实时反映血糖的上升和下降，但存在延迟相关性。

结论：研究为中红外光谱实现无创检测提供一种思路和方法。

关键字：血糖无创检测　唾液　红外光谱

ID 3525

Enhanced Production of Metallothionein Is Responsibe for Zinc-glutathione Suppression of Chronic Alcoholic Liver Injury in Mice

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Objective: Hepatic zinc deficiency is an important accompanying phenomenon that coincides with chronic alcoholic liver injury. We hypothesize that if zinc remains available after alcohol consumption, alcohol-induced liver injury can be reversed.

Methods: Zinc-glutathione (ZnGSH) was chemically synthesized. Mice fed an ethanol-containing liquid diet for 6 months developed alcoholic liver disease. Then, ZnGSH supplementation was administered to ethanol-exposed mice for 1 month. Liver injury, lipid metabolism production and the content of Zinc, GSH and metallothionein were determined after 30 days treated.

Results: ZnGSH decreased serum ALT and suppressed steatosis and necrosis. It also increased high-density lipoprotein cholesterol (HDL-C), decreased low-density lipoprotein cholesterol (LDL-C) content in the serum and liver, and reduced TG in the serum and liver. We also observed that ZnGSH increased total GSH and the ratio of GSH/GSSG ratio, and zinc concentrations in the liver. Importantly, ZnGSH increase metallothionein (MT) concentrations in the liver.

Conclusion: ZnGSH supplementation reverses alcoholic liver injury by at least partially enhancing MT production in the liver.

Key words: Zinc-glutathione; alcohol; alcoholism; lipid, metallothionein

ID 3543

用于现场尿液检测的快换式“滴管电极”研究

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目的：近年来便携式生化传感器因其小巧便携并且适用于现场检测而成为研究热点。但更需要解决的问题是该类传感器在满足现场高效检测的同时也要能实现自身的清洗、回收和重复利用。为此我们提出了“滴管电极”的概念，并实现了对尿液中钠、钾、钙、氯、氢离子的检测。

方法：我们采用丝网印刷工艺在扇形聚氨酯基底上印刷多壁碳纳米管工作电极、Ag/AgCl 参比电极、银墨引线、碳墨电极接口和绝缘层。将扇形“滴管电极”卷折成滴管形状，并与仪器接口相嵌，实现传感电极与电路部分的连接。滴管电极既能实现传感功能，也作为盛放样本的容器。电极使用后可快速拆换，将使用后的电极插入滴管盒中，可完

成自动清洗。仪器可与手机 App 建立交互，将检测信息传递给用户。我们创新性地利用硅橡胶作为离子敏感膜的基体，避免了传统 PVC 膜制备中大量增塑剂的使用，并采用纳米金和还原氧化石墨烯作为固体转导层，可有效提高传感器的灵敏度和使用寿命。

结果：该仪器可在 30 秒内完成检测，电极更换只需 10 秒，电极对钠、钾、钙、氯、氢离子的灵敏度分别为 59.8、59.1、29.4、-53.4 和 58.3 mv/decade，效果均优于 PVC 膜。

结论：该仪器可满足现场多样本的快速检测需求。

关键字：便携式传感器、离子检测、电化学

S02
医学成像与图像处理前沿进度
New Frontiers of Medical Imaging and Image Processing

ID 191

Development and Performance of SIAT bPET: a High-resolution and High-sensitivity MR-Compatible Brain PET Scanner

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Objective: The aim of this work is to develop an MRI compatible human brain PET scanner with uniform high spatial resolution and high sensitivity by using dual-ended readout detectors to provide a more quantitative tool for measuring the functional and molecular information of brain.

Methods: A high-resolution MR-compatible brain PET scanner, named SIAT bPET, was developed with depth encoding detectors by using dual-ended readout of LYSO arrays with SiPM arrays. The scanner has 224 detector modules arranged in 8 detector rings with 28 detectors per ring, resulting in a detector ring diameter of 376.8 mm and an axial field-of-view (FOV) of 329 mm. The system performance was evaluated following NEMA standards. Imaging studies of two phantoms and two rabbits were performed by PET scanner. The mutual interference of the PET scanner and a 3T MRI was measured, and simultaneously brain PET/MRI imaging of a healthy volunteer was performed.

Results: A peak sensitivity of 14.0% was achieved for an energy window of 350-750 keV. A spatial resolution of ~1.0 mm at the center FOV and better than 1.4 mm within the center 250 mm FOV was obtained. Rods with diameter of 1.4 mm can be resolved from the reconstructed image of the Derenzo phantom. High quality images of the two rabbits were obtained. Detailed structure of the brain can be clearly visualized from the images of the 3D Hoffman phantom. MRI has negligible effect on PET imaging and PET has small effect on MRI imaging. High quality PET and MRI images of a human brain were obtained from simultaneously PET/MRI scans.

Conclusion: The SIAT bPET scanner achieved a uniform high spatial resolution of better than 1.4 mm within the center 250 mm FOV and a peak sensitivity of 14.0%, both were much better than those of the currently commercial brain and whole-body PET scanners.

Key words: Brain PET; MR-compatible; High-resolution; Dual-ended readout; Molecular imaging

ID 196

3D Diffusion MRI with twin-navigator-based GRASE for Tractography and Time-dependent Diffusion Measurements in the Human Cortical Gray Matter

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Objective: 3D pulse sequences enable high-resolution acquisition with a high signal-to-noise ratio (SNR) and ideal slice profiles, which is particularly beneficial for oscillating gradient dMRI that probes diffusion at short diffusion-time (t_d) but is usually low in SNR. 3D dMRI, however, is difficult due to the additional phase errors from diffusion encoding.

Methods: We proposed a twin-navigator-based 3D diffusion-weighted gradient spin-echo (DW-GRASE) sequence to correct the phase errors between shots and between odd and even spin echoes for high-resolution human whole-brain t_d–dMRI acquisition. We then compared the SNR of 3D GRASE and 2D echo-planar imaging (EPI) within the same acquisition time and tested the performance of 2D versus 3D acquisition at equivalent SNR on fiber-tracking and microstructural mapping. Taking advantage of high-resolution, we further investigated the t_d-dependency patterns in different cortical regions with diffusion dispersion exponent (θ) based on the power-law.

Results: We showed that the proposed twin-navigator approach effectively corrected the multishot phase error in diffusion-weighted images. The SNR of the 3D-GRASE sequence was 1.5-1.6 folds higher than the 2D-EPI sequence. We found a significantly higher fiber cross-section in the cerebrospinal tract, as well as richer subcortical fibers (U-fibers) using the 3D sequence compared to 2D. More importantly, we demonstrated that different cortical regions exhibited distinct td-dependency patterns with different θ with the highest dispersion in the pre-and post-central cortex (θ = 2.87) and lowest value in the occipital region (θ = 0.22).

Conclusion: The twin-navigator-based 3D DW-GRASE sequence minimized the multishot phase error, and effectively improved the SNR for whole-brain dMRI acquisition. The differences in fiber tracking and microstructural mapping were possibly due to the different slice profiles. The current finding of higher θ in the sensory cortex and lower θ in the frontal and temporal cortex may indicate more complex organization in the high-order region compared to the sensory cortex.

Key words: twin navigator, 3D GRASE, fixel-based analysis, microstructural mapping, td-dependency

ID 232

Optimization of the T2-weighted MRI Contrast in 0-6-month-old infant Brain Based on Extended Phase Graph Theory

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Objective: 3D T2-weighted MRI of infant brains exhibits poor contrast due to the inherently close T2 relaxation times between white matter (WM) and grey matter (GM). We proposed an extended phase graph (EPG) based method to optimize the variable flip angles (VFA) in 3D fast spin-echo sequence for maximizing the white/grey matter contrast in 0-6-month-old infant brains.

Methods: T1 and T2 relaxation times were simultaneously quantified using "MIX" sequence, which would be used for the

following optimization. Four control flip angles along the VFA train are defined, and the pseudo-steady state (PSS) signals are calculated according to the control angles. The VFA train was generated using the Inverse-EPG algorithm based on the PSS signal profile above. Then we utilized the EPG algorithm to simulate the actual signal intensities of WM and GM. The control angles were designed to maximize the relative contrast (RC) between WM and GM. T2-weighted images of infant brains were acquired using both optimized and default protocols. An automatic segmentation method was used to segment WM and GM in the brains.

Results: In the optimized VFA train, four control angles were set to 150°, 80°, 90° and 120°, respectively. In the default VFA train, an initial flip-angle ramp was followed by constant 35° refocusing pulses. RC was improved by an average rate of 1.98 folds with the optimized VFA train, with the highest improvement in deep GM (2.44 folds) and occipital lobe (2.22 folds). Besides, segmentation Results were improved with the optimized protocol, with fewer segmentation errors between the cortex and subcortical WM.

Conclusion: An effective strategy was proposed to improve the contrast of T2-weighted images of the infant brains by optimizing the flip angles of RF pulses. This method significantly improved GM/WM contrast in 0-6-month-old infant brains, which was especially useful for 4-6-month-old infants when the images were nearly isointense.

Key words: variable flip angle; T2 contrast; fast spin-echo; infant brain

ID 321

New Strategy Integrating Radiomics and Deep Learning with Clinical Factors to Predict Recurrence of Non-muscle-invasive Bladder Cancer

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Objective: Preoperative prediction of recurrence risk is crucial for the proper management of non-muscle-invasive bladder cancer (NMIBC), but current models based mainly on clinical factors, have a substantial probability of producing inaccurate predictions for a proportion of patients, leading to misguided decisions regarding adjuvant therapy.

This study aims to investigate this issue by developing and validating a hybrid model that integrates radiomics and deep learning information derived from intratumoral and peritumoral regions on multiparametric MRI scan with clinical factors, to predict NMIBC recurrence at a 5-year follow-up.

Methods: In this study, 135 NMIBC patients with intact archival records of preoperative multiparametric MRI, clinical diagnoses and postsurgical follow-ups were included between October 2011 and August 2018. Among them, 32 cases received recurrence at 5-yr follow-up. Two regions of interest (ROI) were annotated, including intratumoral ROI and combined ROI which contained both intratumoral and peritumoral regions. Four categories of prediction models were developed, including clinical models, radiomics, DL and hybrid models. Average testing sensitivity, specificity, accuracy, and area under the curve (AUC) with 10-fold cross-validation were utilized for a comprehensive assessment of the performance. Decision curve analysis was further implemented to compare the clinical usefulness of different models.

Results: Results showed that the hybrid model achieved the best performance compared with other models with an average AUC in 10-fold cross-validation (the hybrid model vs radiomics and deep learning: 0.958 vs 0.904 and 0.890, respectively, based on intra-peritumoral ROI; and 0.941 vs 0.904 and 0.833, respectively, based on intratumoral ROI).

Conclusion: The proposed new strategy demonstrates that intratumoral and peritumoral regions on multiparametric MRI contain important prognostic information, and the hybrid model integrating radiomics and deep learning with clinical factors can yield favorable performance for NMIBC recurrence prediction, potentially assisting clinicians in therapeutic de-

cision-making.

Key words: Non-muscle-invasive Bladder Cancer; Recurrence Prediction; Multiparametric MRI; Radiomics; Deep Learning

ID 399

SRSA-Net: Separable ResUnit and Self-Attention Optimized Network for Simultaneous Nuclei Segmentation and Classification In Histology Images

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Objective: Automatic nuclei segmentation and classification plays an important role in histopathological image analysis. However, existing algorithms mainly targeting H&E images have not provided a satisfied performance in processing immunohistochemical (IHC) images. On this account, we propose a multi-task deep learning model termed as the SRSA-Net to simultaneously segment and classify cell nuclei in IHC images.

Methods: The SRSA-Net adopts ResNet50 augmented depth-wise separable convolution within each ResUnit as the feature encoder. Three paralleled decoder branches consist of self-attention modules and a series of DenseUnit and upsampling operations to derive Results of nuclei classification, distance map prediction and nuclei segmentation. The watershed algorithm is finally used as a post-processing step to split touching cell nuclei.

Results: Experiments have been performed on the IHC dataset with more than 9000 cell nuclei, which show that the proposed SRSA-Net outperforms state-of-the-art nuclei segmentation and classification models.

Conclusion: By using our proposed model, pathologists could effectively quantify the number and proportion of positive and negative cell nuclei in IHC images, which assists in quantifying the TIME of cancer patients for precise diagnosis and prognosis.

Key words: Nuclei segmentation and classification, self-attention, depth-wise separable convolution, immunohistochemical, computational pathology

ID 446

In-vivo High-speed Biomechanical Imaging of the Cornea Using Corvis ST and DIC

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Objective: To establish in vivo high-speed biomechanical imaging of the cornea using Corvis ST and incremental digital image correlation (DIC) approach.

Methods: In this study, 20 subjects were enrolled and classified into two groups: the normal (NORM, N=10) group and the keratoconus (KC, N=10) group. Image sequences of the horizontal cross-section of the human cornea under air puff were captured by the Corvis ST tonometer. The macroscale mechanical response of the cornea was determined through image analysis. The high-speed evolution of cross-sectional in-body corneal displacement, velocity, strain, and strain rate was reconstructed using the incremental digital image correlation (DIC) approach. Differences in the parameters between the NORM and KC groups were statistically analysed.

Results: Results indicated that compared with the NORM group, the KC corneas absorbed more energy with smaller tangent stiffness and larger deflection on the macro scale, and the maximum velocity, shear strain, and shear strain rate in the KC group significantly increased at the tissue level ($p < 0.005$)

Conclusion: This is the first time that the incremental DIC method was applied to the in-vivo high-speed corneal deformation imaging in combination with the Corvis ST tonometer. Through the spatial-temporal image registration with incremental DIC analysis, the dynamic strain/strain rate maps of the cornea were estimated at the tissue level, carrying great potential in aiding the diagnosis of keratoconus at a more underlying level.

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Key words: DIC, corneal biomechanical imaging, Corvis ST

ID 449

Research and Clinical Transformation of Novel NIR-II Fluorescence Imaging Technology

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Objective: Difficulty in detecting occult tumor lesions intraoperatively by conventional imaging Methods leads to high tumor recurrence after surgery. Fluorescence imaging in the second near-infrared window (NIR-II) emerges as a promising real-time technology that can improve the detection rate of occult tumor lesions with high resolution and sensitivity. In this report, a series of innovative works on NIR-II imaging conducted by the reporter and the team are introduced.

Methods: Aiming to further improve the detection ability of occult tumor lesions using the novel NIR-II imaging technology, the team focused on creating novel NIR-II fluorescence molecular tomography method, constructing novel small animal imaging and clinical imaging systems, and developing novel probes with pre-clinical research carried out. Furthermore, some developed imaging technologies have been applied in clinical tumor imaging, which helped in the detection of occult tumor lesions and improvement of patient prognosis.

Results: First-in-human clinical application of NIR-II imaging in hepatocellular carcinoma (HCC) patients was carried out using indocyanine green. This demonstrated that NIR-II imaging can detect tumor lesions omitted by conventional imaging modalities. Based on that, the clinical trial of NIR-II fluorescence-guided surgical resection of HCC using a novel probe IgG-IRDye800CW has been carried out, which significantly improved the diagnosis and treatment effect of HCC. For glioblastomas patients, NIR-II imaging brought a complete resection rate of 100%, and helped to prolong the survival. Additionally, it helped to visualize blood vessels and nerves to protect patients' normal functions. NIR-II fluorescence has been used in detection and ligation of the feeding arteries of gliomas, reducing the bleeding volume of patients by 50%. It has also been used in the intraoperative visualization of the nerves during cervical cancer surgery, accelerating the recovery of patients' urinary function.

Conclusion: To summarize, the work of the team formed a full research chain of "imaging method-imaging system-clinical

application-industrialization".

Key words: NIR-II fluorescence imaging; fluorescence iamage-guided surgery; imaging model and reconstruction algorithm; tomography

ID 590

Preliminary Resting State Co-activation Pattern Analysis of Frontoparietal Network.

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Objective: The frontoparietal network (FPN) comprising the dorsolateral prefrontal cortex and lateral parietal cortex is closely associated with the decline of cognitive function during aging.

Methods: In this study, the co-activation pattern analysis was applied to investigate the dynamic change of the FPN of older adults and the relationship with the change in fluid intelligence using resting-state functional MRI data.

Results: The spatial co-activation states of the FPN were identified using the co-activation pattern analysis and the fraction of time (the proportion of time points of the FPN to the total time points), a temporal dynamic metric, was obtained in the older and young adults respectively. Compared to the young adults, the older adults showed a decreased fraction of time of the FPN, and significantly positively correlated with their fluid intelligence scores.

Conclusion: In conclusion, the present study provides further information about the role of the FPN in changes in cognitive function during aging.

Key words: aging, resting state, fMRI, co-activation pattern analysis, FPN.

ID 600

A Low-power Variable Gain Amplifier Design with 70-dB Gain Range and 1.28-dB Gain Error for Ultrasound Imaging System

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Objective: During the ultrasound(US) imaging,the US signal attenuates exponentially with distance when it travels within lossy human tissues.Without proper correction, the US image will be either too bright in the near-surface region or too dark in the deep-inside region.Time-Gain Compensation (TGC) compensates for the distance attenuation of the US echo signal by provid-

ing a variable gain that increases exponentially over time. To realize a TGC and to obtain high quality ultrasound images,dB-linear Variable Gain Amplifier（VGA) is needed.

Methods: A Variable Gain Amplifier (VGA) based on the cell-based topology is designed.By cascading several VGA building blocks, the gain range of the combined dB-linear VGA can be increased. Each VGA building block is designed by common source input MOS transistors working in the triode region to approximate an exponential function for high robustness and low power consumption.

Results: Designed in the 65-nm CMOS process, the presented VGA occupies 0.02 mm2 and can regulate a linear gain variation range in decibels of 70 dB with ±1.28 dB maximum gain error. Meanwhile, more than 80 MHz of -3-dB bandwidth can be realized within the gain range. The total power consumption of the combined VGA is 0.384 mW with a 1.2 V supply voltage, and the input-referred voltage noise density is 20 nV/√Hz. Moreover, the proposed design is robust to temperature variations, process mismatch, and variations, as shown from the temperature simulation Results and 100 Monte Carlo runs.

Conclusion: This work presents a Variable Gain Amplifier (VGA) design with low power consumption and dB-linear characteristic for the ultrasound (US) imaging system.Compared to other VGAs, the power consumption of this design is further saved. A smaller gain error is achieved while the gain range is maintained. It is believed that the presented design can be adequately applied to high-frequency US imaging applications.

Key words: CMOS variable gain amplifier, dB-linear, Ultrasound imaging, cell-based topology, low power amplifier.

ID 620

Altered Spatiotemporal Consistency of Local Neural Activities in Parkinson's Disease

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Objective: Parkinson's disease (PD) is a neurodegenerative disease associated with motor symptoms and other complications. Although PD brings a huge impact on the daily life of patients, the pathophysiological mechanism of this disease is still unknown. The present study aims to explore the local spatiotemporal consistency of brain connectivity in PD patients.

Methods: In total, 30 PD patients and 20 health controls (HC) were collected from the Parkinson's progression markers initiative (PPMI) and their resting state functional MRI images are acquired. FOur-dimensional Consistency of local neural Activities (FOCA) was employed for the first time to explore local brain activity differences between PD and HC groups. To explore the relationship between FOCA values and neuropsychological indices, the Pearson correlation analysis was performed. And receiver operating characteristic (ROC) analysis was carried out to distinguish PD from HC.

Results: Compared with HC, PD patients demonstrated decreased FOCA values in the right inferior temporal gyrus (ITG.R), right middle temporal gyrus (MTG.R), right middle occipital gyrus (MOG.R), right superior occipital gyrus, right inferior occipital gyrus, left precentral gyrus (PreCG.L), left postcentral gyrus (PoCG.L) and left rolandic operculum. The FOCA values in MTG.R and ITG.R were positively related to Montreal Cognitive Assessment (MoCA) values. Negative relationships had been found in FOCA values of PreCG.L and MOG.R and Unified Parkinson's Disease Rating Scale (UPDRS) III scores. What's more, the ROC analysis showed that the FOCA values of altered brain regions can be used to distinguish PD patients from HC with high performance.

Conclusion: PD patients demonstrated disrupted local brain activity in several brain regions. These brain regions are mainly involved in motor, cognitive and emotional functions. The current study perhaps has the potential to provide im-

portant insights into understanding the pathophysiological mechanism of PD symptoms.

Key words: Four-dimensional (spatiotemporal) consistency of local neural activities; Parkinson's disease; resting-state fMRI.

ID 638

Study of Brain Cortical Surface Area in Adolescents with Major Depressive Disorder

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Objective: Major depressive disorder (MDD) is a disabling and severe psychiatric disorder, and adolescence is one of the most probable period for the first onset. The neuroanatomical substrate underlying the adolescent with MDD remains underinvestigated.

Methods: Considering the cortical surface area (SA) measurement is still lacking, we examined the cortical SA alterations in fifty-nine adolescent MDD patients versus thirty-nine healthy controls in this study.

Results: Significantly increased regional SA at left paracentral lobular and mid cingulate cortex, right somatosensory and motor cortex as well as bilateral anterior cingulate and medial prefrontal cortex were found in adolescent MDD compared to controls. Whereas decreased SA at left lateral temporal cortex was found in adolescent MDD compared to controls.

Conclusion: To sum up, the abnormal development of cortical SA was found at frontal-limbic brain areas involved with the cognitive processing and emotional regulation in adolescent MDD. The findings might help elaborate the neural mechanisms underlying the pathophysiology in adolescent depression.

Key words: adolescent MDD, surface area, anterior cingulate, medial prefrontal cortex, lateral temporal

ID 680

Millimeter Wave Radar Image Aliasing Enhancement Method Based on CycleGAN

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Objective: The millimeter wave imaging platform designed based on the principle of MIMO-SAR technology made up for the shortage of a large number of sensors required by the array imaging platforms of synthetic aperture technology, and achieved the same or even better effects using a single radar scan. However, the long scanning has limited practical applications of the platform. The method of increasing the scanning interval can save a lot of scanning time, but it also brings the problem of under-sampling resulting in the aliasing of objects in the images. Super resolution technology can not solve the overlap phenomenon, so it is necessary to find an effective method to deal with the overlapping phenomenon for image enhancement.

Methods: In this paper, we proposed a CycleGAN-based millimeter-wave radar image aliasing enhancement method to trans-form the aliased millimeter-wave images into clear images, and thus significantly reducing the scanning time re-

quired by the imaging platform of array millimeter wave radar under the condition of ensuring the imaging effect.

Results: We trained and validated the method with a self-built dataset, and evaluated the experimental method by peak signal to noise ratio (PSNR) and structural similarity ratio (SSIM).

Conclusion: The average PSNR and SSIM of this method are 11.37 dB and 0.46, respectively, which effectively improves the image enhancement effect of the under-sampling problem caused by the large sampling interval.

Key words: millimeter wave imaging, image enhancement, CycleGAN

ID 688

Recovering the Elevational Resolution and SNR of Ring Transducer Array-based PACT Using the Technique of SAFT

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Objective: The imaging quality of ring transducer array-based photoacoustic computed tomography (RT-PACT) is generally limited by the poor elevational resolution, in which case the sectioning capability for slice-stacking 3D imaging of RT-PACT is largely deteriorated. In addition, the trade-off relationship between the elevational resolution and focal range also restricts the image quality within the out-of-focus region. The purpose of this study is to tackle this challenge and recover the elevational resolution and SNR outside the focal zone.

Methods: We propose a reconstruction method based on the concept of the synthetic aperture focusing technique (SAFT) to restore the elevational image quality in the out-of-focus region for the RT-PACT system. In our strategy, the SAFT-based scheme were incorporate with the universal back-projection algorithm to separately deal with the time delays of PA signals between the source and the detectors in both the imaging-plane and the elevational direction. The proposed SAFT method integrates signal coherence weighting and the spatial impulse response, and was made suited for ring arrays to manifest a 3D slice-stacking tomographic imaging.

Results: The proposed approach substantially increases the elevational resolution and SNR for RT-PACT. The performances of this proposed algorithm scheme were evaluated through phantom and human rib model experiments. In the phantom study, the elevational resolution and SNR were improved by 7-fold and 14 dB. Similar Results were obtained in the human rib model imaging, wherein the elevational resolution and SNR were respectively improved by 3.5 times and 10.8 dB.

Conclusion: This method opens up new opportunities for the RT-PACT system because (1) It regains the sectioning ability for the RT-PACT system outside the focal zone, and (2) it overcomes the trade-off relation between the elevational resolution and focal zone for RT-PACT, thereby enabling high resolution, high penetration, and large focal zone to be simultaneously achieved.

Key words: Ring transducer array, Photoacoustic computed tomography, Elevational resolution, SNR, Synthetic aperture focusing

ID 708

Development on Improving LYSO Array Performance through Photonic Crystal Structure

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Objective: Scintillation crystals are widely used in various radiation detec-tion fields. The properties of scintillation crystals determine the performance of equipment.

Methods: We proposed a V-slot structure array and machined it to the 6×6 LYSO crystal arrays using femtosecond laser, the size of single crystal is 3×3 mm2.

Results: The Results show that femtosecond laser can achieve the processing accuracy of LYSO nanoscale, and the light output and energy resolution performance of LYSO photonic crystal can be im-proved by 20%, which is conducive to the improvement of decoding accuracy and imaging effect.

Conclusion: Femtosecond laser can realize high-precision and high- efficiency processing of LYSO crystal and obtain V-groove photonic crystal structure. Avoid combining SI and CGS units, such as current in amperes and magnetic field in oersteds. This often leads to confusion because equations do not balance dimensionally. If you must use mixed units, clearly state the units for each quantity that you use in an equation.

LYSO crystal array with photonic crystal structure has better light output performance and energy resolution performance, and the decoding is clearer.

Key words: Scintillation crystal, photonic crystal, femtosecond laser

ID 790

Semantic Segmentation of Medical Images based on Knowledge Distillation Algorithm

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Objective: Background: Since the advent of convolutional neural networks, they have been employed in various fields. Nevertheless, the calculation cost must be considered for the automatic deep learning analysis. A novel strategy was proposed to improve the segmentation performance without adding additional parameters by transferring pre-trained prior knowledge information in certain medical scenes.

Methods: Methods: We accessed knowledge distillation to train a teacher and a student network simultaneously, then introduced the best weight of the teacher to distill the student network, contributing to the distillation loss function. The effectiveness was verified with two segmentation convolutional neural network structures.

Results: Result: the mean Acc, mIoU, Dice, and Kappa of the distilled network in three different medical datasets were in-

creased by 0.18 percent, 1.25 percent, 1.62 percent, and 0.79 percent, respectively.

Conclusion: Conclusions: the dark knowledge was transformed from a deeper network to another lightweight one that can enhance the segmentation performance significantly without additional elements.

Key words: Semantic Segmentation; Knowledge Distillation; Ultrasonic image; Deep learning

ID 872

Liver Segmentation with MT-UNet++

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Objective: The liver is the largest organ in the human body, located on the right side of the abdomen and under the chest, and is the key center of many physiological processesIn order to reduce the amount of tasks for doctors to label liver CT images and improve the efficiency of diagnosis and treatment.

Methods: We designed MT-UNet++for liver segmentation of LITS2017 data set. It is a semi-supervised method. Two improved UNet++act as students and teachers to correct themselves, and integrate data enhancement and confidence denoising modules.

Results: The DSC of MT UNet++proposed by us for liver segmentation is 95.80%, IOU is 90.57%, and HD is 4.26mm. The proportion of labeled data in this method is only 30%, which is superior to most of the better performing full-monitoring Methods than liver segmentation, such as UNet++, UNet, etc. In addition, it is 2.5% higher than the semi-supervised method.

Conclusion: In this paper, we explore the advantages of our meth-od compared with the recent fully supervised and semi-supervised methods. MT-UNet++ is based on the aver-age teacher-assisted learning mechanism, uses two improved UNet++ models as teachers and students, rotates, mirrors and adds noise to the input data, and combines confidence learning to remove noise. Compared with the full supervision method, the model we designed achieves the same or even higher segmentation accuracy with less labeled data, which has foreseeable value in solving the cost of data labeling and improving the efficiency of doctors' diagnosis and treatment; Compared with semi-supervised method, this method improves the segmenta-tion accuracy by 2.5%.In the future work, we will focus on dealing with smaller segmentation targets and seek to integrate condi-tional random fields, attention mechanisms or other in-depth learning Methods to further improve segmentation accuracy. Please look forward to it.

Key words: liver segmentation, diagnosis and treatment, MT-UNet++, data augmentation, confide

ID 936

Sex Differences in Episodic Memory and Structural Covariance Network

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Objective: Episodic memory (EM) is a mental system, which enables humans to remember past experiences. Sex differences in EM performance have been widely reported, but the neural mechanisms are largely unknown.

Methods: Here, we constructed structural covariance networks (SCN) based on cortical surface area (CSA) in females and males using surface-based morphometry and structural covariance (SC) analysis in 172 participants aged 20-65 years old from the Dallas Lifespan Brain Study (DLBS), and we calculated the global efficiency to characterize network integration of the SCN. The relationship between SCN and EM was examined by SC analysis among the top-n brain regions that were most relevant to EM performance.

Results: We found the number of SC connections (Females: 9375; Males: 1350, p=0.0214) and global efficiency (Females: 0.2503; Males: 0.1743,p=0.0498) of SCN in females were higher than those in males, SC analysis among the top-n brain regions that were most relevant to EM performance revealed that the top-n brain regions with the strongest SC in females were mainly located in frontal cortex, parietal cortex and temporal cortex, and in males were mainly located in frontal cortex.

Conclusion: These Results confirmed that the ability of network integration (global efficiency) of females is better than males, and sex differences in EM performance may be related to the differences in SCN between females and males. Our study highlights the role of sex as a research variable in brain science.

Key words: episodic memory, structural covariance network, cortical surface area, sMRI, sex

ID 1010

True-FISP Line-scan Sequence: A Better Choice for High Temporospatial Resolution T2 Changing

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Objective: Recently, line-scan technology has been widely used in magnetic resonance imaging (MRI) applications. Researchers have successfully imaged the neuronal activity at high temporospatial resolution using a fast low-angle shot (FLASH) line-scan sequence, but the changes in the MRI signal are very small (about 0.2 percent). We proposed a True-FISP line-scan sequence with better sensitivity when facing variable T_2.

Methods: Imaging was performed on a 3T MRI system (MAGNETOM Prisma; Siemens Healthcare, Germany) with a Head/Neck 64-channel coil. Different concentrations of agarose gels were manufactured and used to build four cylindrical phantoms. A spin echo (SE) pulse sequence with a TR of 3000ms and variable TE values (15-800ms) were used for T2 measurements.

In the FLASH sequence, the T_{2*} dominates the signal intensity when TE is large. In the True-FISP sequence, the signal intensity is dominated by T_2.

The True-FISP sequence is more sensitive to T_2 than the FLASH sequence and can achieve higher SNR at the same spatial and temporal resolution. In this study, a True-FISP sequence was modified for line-scanning and compared to the current FLASH line-scan sequence.

The imaging parameters of the traditional FLASH line-scan sequence and the proposed True-FISP line-scan sequence were the field of view=256 * 180mm^2, matrix size=256 * 180, TR=4ms, TE=2ms, flip angle=15° (FLASH line-scan) or 28° (True-FISP line-scan), bandwidth=1200 Hz/pixel.

Results: The T_2 values of four phantoms are 170, 220, 670, and 1130, the mean image signals are 296, 334, 362, and 380 for the FLASH line-scan sequence and 455, 667, 722, and 1070 for True-FISP line-scan sequence, respectively. The mean signal-to-noise ratio (SNR) of four phantoms is 40 (FLASH line-scan) and 110 (True-FISP line-scan).

Conclusion: In conclusion, the True-FISP line-scan sequence produces more sensitive T_2 corresponds and can obtain images with better SNR, thus being more suitable for direct neuronal activity imaging.

Key words: MRI; MRI sequence; Line-scan; True FISP

ID 1020

Automated Segmentation of Nasopharyngeal Carcinoma Based on Dual-sequence Magnetic Resonance Imaging Using Self-supervised Learning

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Objective: Background and purpose: Radiation therapy is one of the most effective treatments for nasopharyngeal carcinoma. For radiotherapy planning, contouring of the tumor region is usually done manually by oncologists, a process that is time-consuming and subjective. Fully automated deep-learning models can be helpful for this application. However, the segmentation performance is limited by the scarcity of data annotations.

Methods: Materials and methods: We retrospectively collected the image data of 116 nasopharyngeal carcinoma patients, of which 44 patients' lesions were labeled while 72 were not. Then, we proposed a fully automated method to manage the limitations of scarce data annotations and to achieve accurate segmentation of nasopharyngeal carcinoma lesions from dual-sequence magnetic resonance images by using a self-supervised learning and saliency transformation module.

Results: Results: The mean dice similarity coefficient in the ten-fold cross-validation was 0.77, comparable to the Results using 4100 annotated cases for training, whereas we only used 44 annotated cases. Upon examining the Results of the proposed method, we showed that our method does not require much modification (primarily less than 20%, measured by using the Dice score) to meet the need for clinical application.

Conclusion: Conclusions:We proposed a fully automatic segmentation method for nasopharyngeal carcinoma with accurate and stable performance. The method, constructed with few labeled data and improved with unlabeled data, could positively impact on the automated segmentation of tumor lesions, reducing the annotation burden and oncologists' subjectivity while increasing trustworthiness for lesion delineation.

Key words: Nasopharyngeal carcinoma; deep learning; self-supervised learning; automatic segmentation; saliency transformation module

ID 1117

An Angle-Independent Three-dimensional Ultrasound Velocimetry Using a One-dimensional Transducer Array

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Objective: Ultrasound-based velocimetry possesses the capability of estimating flow speeds in a non-invasive, high-speed, and contrast-free manner, making it an attractive diagnostic tool for the blood circulation assessment. However, the flow measurements are constrained to resolve the in-plane two-dimensional (2D) flow components when using a one-dimensional (1D) transducer array, and it requires well trained operators to obtain accurate measurement.

Methods: In this work, we propose an angle-independent three-dimensional (3D) ultrasound velocimetry using a 1D transducer array. By applying a two-step nonlinear fitting procedure based on the ultrasound speckle decorrelation analysis, the proposed approach enables us to resolve not only the 2D in-plane velocity components of v_x and v_z, but also the through-plane velocity component of v_y.

Results: We validated our method with numerical simulation and phantom experiments, and further demonstrated its superiority for the 3D flow components measurement of human carotid artery using a clinic 1D array transducer probe. Results indicates that the total velocity measured at different probe-to-vessel angles have the same speed value throughout the cardiac cycles, demonstrating its robustness and angle-independency in carotid blood flow assessment.

Conclusion: With the angle-independent 3D imaging ability, this method would reduce the requirement of the operators and can potentially be applied for disease screening of the circulation system.

Key words: Ultrasound based velocimetry; 3D velocimetry; Angle independent; Carotid artery

ID 1191

UtransNetPlus: 基于 Transformer 和 CT 影像的 COVID-19 病灶分割网络

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目的：如今仍然处于新冠肺炎时期，计算机断层扫描 (CT) 影像可辅助新冠肺炎 (COVID-19) 病例诊断。本文结合 Transformer 提出了一种面向 CT 图像的分割模型 UtransNetPlus，旨在解决新冠肺炎病灶区域呈病灶区域面积差异大以及病灶相对位置不定等难点，利用计算机自动准确分割出 CT 图像中新冠肺炎病灶区域，辅助医生对病情的后期治疗同时降低标注成本。

方法：通过在编码器阶段设计的残差卷积块捕获纹理，边界等细节信息。利用 Transformer 结构设计特征融合模块代替 U-Net 中原始跳跃连接，最大化融合编码器提取的特征信息并建立长距离依赖关系，最后在解码器阶段设计全尺度连接与分割引导模块从而提高新冠肺炎病灶分割效果。

结果：实验结果表明 UtransNetPlus 在 COVID-19 CT 分割数据集上 Dice 系数和 IoU 指标分别达到 83.61%、73.90%，性能优于其它一些主流方法。此外还有效解决了数据集的数据量少、病灶分割难度大等问题。

结论：证明了引入 Transformer 结构，与 CNN 有效结合可以应对新冠肺炎病灶分割的复杂性和多样性。

关键字：分割；Transformer；CT；新冠肺炎；COVID-19

ID 1199

可视化钆离子交联双网络磁共振成像微球动态监测软组织愈合

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目的：采用一种无创、连续的方法，同时实现支架材料与再生组织的实时监测

方法：通过气流控方法，将磁共振 T1 加权成像造影剂——钆离子，通过共价交联的方法与修饰了甲基丙烯酸酐的海藻酸钠共价交联，制造出一种可磁共振成像的双网络交联水凝胶微球，同时实现支架材料降解和组织修复再生的无创实时监测。

结果：弛豫率实验表明，海藻酸钆微球的纵向弛豫率为 33.113M-1s-1，是临床用磁共振 T1 加权成像造影剂钆喷葡胺（Gd-DTPA）的 3 倍，体外和体内实验均表明，海藻酸钆微球的 T1 信号值随着微球的降解而逐渐降低（R2=0.95），而在大鼠腹部肌肉缺损模型中，患处磁共振信号值也与其对应的组织病理切片中的组织修复程度呈线性相关（R2=0.91）。另外，海藻酸钆微球表现出良好的生物安全性，没有发现重要器官有不良反映，降解的钆离子经肝、肾代谢后排除体外。

结论：该双网络交联水凝胶微球可利用磁共振信号值较好地反映出材料的在体情况，支持使用 MRI 以无创方式监测生物材料降解和组织再生程度，为进一步优化支架材料与再生过程的匹配提供了支持。

关键字：气流控，微球，磁共振成像，软组织再生

ID 1257

The Research of Biological Pathway of Imaging Features with Lymph Node Metastasis in Bladder Cancer

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Objective: Image features had shown potential in the prediction of lymph node (LN) metastasis in bladder cancer(BCa), but the biological significance of radiomics features remains an open issue to date.To develop a biologically interpretable deep radiomics model using preoperative CECT images and paired transcriptome data for the prediction of LN metastasis in BCa.

Methods: Preoperatively CECT images and the corresponding transcriptome data of BCa patients were collected from TCIA and TCGA databases, which were provided by four clinical centers. A prediction model integrating radiomics with deep learning features was established for LN metastasis discrimination. WGCNA and GSVA were used to unearth the pathway enrichment of driven pathways, and correlation analysis between features and pathways to reveal the biological pathway of deep radiomics features in characterizing LN metastasis of BCa.

Results: A total of 80 patients with an average age of 68 years were included in this study. 1497 radiomics features were extracted from intratumoral and peritumoral regions by using the Pyromics-packages, respectively. After screening the features by variance and SVM-RFE, a total of 39 radiomics features were finally obtained. In addition, 39 deep features were

extracted from the global images by using the fine-tuned Resnet18 network. The prediction model using these optimal features and SVM classifier with 5-fold cross-validation achieved favorable performance, with average sensitivity, specificity, accuracy, and AUC of 92.3%, 92.7%, 92.5%, and 96% (95% CI: 0.884, 1.000). In addition, two key modules were screened by WGCNA analysis, which was further enriched and analyzed by the GSVA. Pearson's correlation analysis between deep radiomics features and pathways eventually found six types of related biological pathways, including metabolism, immunity and inflammation, cell function, tumor transformation and lymphatic metastasis, angiogenesis, and biosynthesis.

Conclusion: Image features that can predict LN metastasis in BCa patients may be driven by different key pathways.

Key words: Bladder cancer, Lymph node metastasis, Imaging features, Driven pathway, Biological significance

ID 1345

Targeted Cyclo[8]pyrrole-based NIR-II Photoacoustic Tomography Probe for Pancreatic Cancer Therapy

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Objective: Photoacoustic (PA) imaging is a relatively non-invasive diagnostic modality that is based on the principle of "light in, sound out". However, to reach its full potential the use of appropriately designed small molecule probes is necessary. So-called expanded porphyrins are particularly interesting in this regard since many absorb well into the NIR spectral region where interference from natural pigments is minimal.

Methods: We report here that an expanded porphyrin, cyclo[8]pyrrole (CP), with a high extinction coefficient (89.16 L/g•cm) within the second near-infrared window (NIR-II) may be formulated with an αvβ3 specific targeting peptide, cyclic-Arg-Gly-Asp (cRGD), to form cRGD-CP nanoparticles (cRGD-CPNPs) with promising NIR-II photothermal (PT) therapeutic and photoacoustic (PA) imaging properties.

Results: Studies with a ring-array PA tomography system, coupled with analysis of control nanoparticles lacking a targeting element (CPNPs), revealed that cRGD conjugation promoted the delivery of the NPs through abnormal vessels around the tumor to the solid tumor core. This proved true in both subcutaneous and orthotopic pancreatic tumor mice models, as confirmed by immunofluorescent studies.

Conclusion: In combination with NIR-II laser photoirradiation, the cRGD-CPNPs provided near-baseline tumor suppression through PTT both in vitro and in vivo. They also displayed good biosafety profiles as inferred from PA tomography, blood analyses, and H&E staining. They thus appear promising for use in combined PA imaging and PT therapeutic treatment of pancreatic cancer.

Key words: Expanded porphyrins; Photoacoustic tomography; Pancreatic cancer; Biocompatibility; Imaging guided photothermal therapy

ID 1349

基于超短回波时间序列的磁纳米颗粒标记干细胞定量 MRI 成像

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目的：基于磁纳米颗粒的干细胞标记试剂 T2* 会随浓度的增加而减小，所以高浓度的经 ferumoxytol 标记的干细胞需采用超短回波序列（Ultrashort Echo Time, UTE）进行磁共振成像。本研究采用基于 UTE 序列的 MRI 方案对磁纳米颗粒标记的干细胞进行定量成像。

方法：细胞水模在 3T GE-MR750 磁共振系统进行扫描。T1 定量采用基于 UTE 的多翻转角 (VFA-UTE) 法；T2 定量采用 CPMG 方法；T2* 和 QSM 定量采用 UTE 序列采集多组 TE 下的数据。

T1 和 T2* 的计算采用 Levenberg-Marquard 算法进行非线性拟合；QSM 基于 MEDI 算法进行重建，T2 图由 GE 磁共振系统自带的计算软件生成。

结果：不同浓度的标记干细胞在 QSM、T1、T2 和 T2* 定量图上有很高对比度，T1、T2 和 T2* 值随浓度增加而减小，QSM 值随浓度增加而增加。标记干细胞的浓度与 R1（1/T1），R2（1/T2），R2*（1/T2*）和 QSM 值之间呈显著相关性。

结论：基于 UTE 的成像方案可被用于准确定量不同浓度磁纳米颗粒标记的干细胞的 T1、T2* 和 QSM，这些磁共振参数有可能成为非常有潜力的干细胞示踪生物标记。

关键字：超短回波时间序列，磁纳米颗粒，定量 MRI

ID 1409

tDKI-Net: A Joint q-t Space Learning Network for Diffusion-time-dependent Kurtosis Imaging and Karger's Model Fitting

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Objective: Time-dependent diffusion MRI[1] acquires signals in both q-space and t-space for microstructual mapping, and is often time-consuming. We presented a tDKI-Net to fit the Karger's model with downsampled time-dependent diffusion kurtosis measurements.

Methods: Network: tDKI-Net has two parts: q-space network and t-space network. Due to the superior performance of extra-gradient-Unit in q-space learning[2], here, we chose extragradient-Unit as q-Encoders to encode signals in q-space. We also adopted the extragradient-based network[3], as t-Encoder, and it can be constructed as:

$X^{n+1/2=}H_M(S^1X^{n+}W^1Y_t)(1)$

$Xn+1_=H_M(X^{n+}W^1W^2Y_{t+}S_2X^{n+1/2})(2)$

Where, H_M denotes a nonlinear operator, $S^{1,}S^{2,}W^{1,}$ and W^2 are learnable weights.

Materials: Dataset was collected on a 7T Bruker scanner from 3 normal rats and 10 rats that underwent a model of transient Middle Cerebral Artery Occlusion (MCAO). Diffusion gradients were applied in 18 directions per b-value with 6 td (20, 50, 80, 100, 150, and 200 ms) at 3 b-values (0.8, 1.5, and 2.5 ms/μm^2). To get gold standards, DKE[4] and Bayesian fitting[5] were used. The dataset was downsampled with randomly selected 9 gradient directions for b = 0.8 and 1.5 ms/μm2 in 4 td (20, 50, 100, and 200 ms).

Results: Normal rat brains: We compared our method with DKE and q-DL in estimating kurtosis at each t_d with downsampled q-space data. tDKI-Net achieved the lowest estimation error. Then, we compared tDKI-Net with Bayesian method and q-DL for Karger model(KM) fitting. Our proposed method kept the highest fidelity with the ground truth and least fitting error in both K_0 (5% lower MSE than q-DL) and tm (4% lower MSE than q-DL).

MCAO-injured rat brains: In MCAO rats, tDKI-Net better preserved the injury information, especially at the long td. The improvement was more evident in KM's fitted parameters, e.g., MSE of tm were 12% lower than q-DL.

Conclusion: This work presented a tDKI-Net to estimate diffusion-time-dependent kurtosis and KM parameters, which demonstrated superior performance.

Key words: Time-dependent diffusion MRI; deep learning; diffusion kurtosis imaging; Karger model

ID 1504

肺部影像精细结构分割及其在辅助手术引导中的应用

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目的：胸腔镜肺段切除术是一种微创、精准的早期微小肺癌治疗方案，单纯通过肺实质、病灶组织分割提取的分析技术已不能对医生提供有效引导信息。如何有效降低胸腔镜肺段切除手术的难度，提供客观、准确的术前组织结构定位和变异信息已成为临床迫切需求。

方法：本工作针对肺部组织结构复杂、相邻组织区分度低、特征相近、结构边界不清晰等问题，提出了保持三维连通性和拓扑结构一致性的细小支气管分割方法，设计了基于拓扑关系高阶能量函数最小化的肺动静脉分离方法，实现了解剖结构相关性知识引导、形状聚类约束的肺叶 / 肺段实质分割及段间平面构建技术。同时，构建了精细肺组织结构分割标准数据集，供国内外研究者免费开放使用。

结果：通过对关键技术的集成优化，构建满足临床需求、功能完善、方便易用的肺部辅助手术系统，已在国内 200 多家医院的胸外科、呼吸科免费推广应用，累计辅助实施肺部手术 3000 余例，取得了良好的应用效果，临床医生采用本技术在 Thoracic Cancer 等领域期刊发表多篇论文。

结论：临床应用结果表明，该技术有效降低了肺部精准手术的实施难度，对精准、微创、个性化肺部手术治疗方案的普及推广起到重要的促进作用。

关键字：肺部影像，辅助手术，图像分割

ID 1761

Study on Semi-automatic Fine Delineation of Pancreatic Tumors

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Objective: Automatic and accurate delineation of pancreatic tumors target volume is the basis for assisting doctors in formulating high-quality radiotherapy plans and determining radiotherapy doses. However, the differences between patients and the large number of medical images to be delineated bring great challenges for doctors to draw by hand. Although automatic segmentation models are currently widely adopted to address this challenge, the segmentation accuracy of pancreatic tumors still needs to be improved. For this reason, this study proposes a method for predicting the target area of pancreatic tumors in blocks according to a certain number of CT image layers, and designs a semi-automatic delineation scheme for target area, which is used to assist doctors to accurately and quickly delineate tumor target areas and improve the efficiency of diagnosis and treatment.

Methods: Specifically, several layers of the patient's CT image are divided into a block, which and the corresponding label of the head and tail layer are used as the two channels of the model respectively. After the training of the improved model such as 3D Res U-Net, the outline of each block is predicted. In addition, a joint index was introduced to classify the predicted Results of each patient.

Results: On the test data set of 11 patients provided by Sun Yat-sen University Cancer Center in Guangdong Province, the DSC coefficient of pancreatic tumors target area delineated in this study is 89.42%, the NSD coefficient is 96.85%, and the HD95 coefficient is 3.4650. The delineation result is better than most existing methods.

Conclusion: It takes an average of 4.5 minutes to delineate the target area of a patient. Compared with the manual delineation of one patient every 61 minutes, this study has a significant advantage in reducing the workload of doctors. In clinical application, it is expected to help doctors improve work efficiency.

Key words: semi-automatic delineation; block prediction; deep learning; pancreatic tumors

ID 1840

0.1 mT 极低场磁共振成像技术

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目的：极低场核磁共振成像（ULF-MRI）通常是在几十至几百 mT 静磁场 B0 下获得图像。与传统的高场（B0>1 T）MRI 系统相比，ULF-MRI 系统具有结构简单、移动性强、成本低廉、对金属不敏感、可与其他影像手段融合开发多模态成像技术等优点。同时，诸如前列腺癌、乳腺癌等疾病组织在超低场下与正常组织具有更好的对比度差异，因而可以更好的实现癌症诊断。然而，ULF-MRI 由于磁场强度低而面临信噪比差的挑战。

方法：我们引入了预极化技术并使用灵敏度达 10^{-15} T 量级的低温超导量子干涉仪（SQUID）作为探测手段来提高 ULF-MRI 系统信噪比。同时引入深度学习技术开展多通道极低场磁共振图像重建与降噪处理。

结果：我们已完成五通道 0.1 mT 极低场磁共振原理样机，系统噪声水平 1~3 fT/sqrt(Hz)，预极化场 80 mT，并基于 CNN、U-net 等多种深度学习方法开展图像重建保真与降噪研究，显著提升图像信号比，缩短成像时间。

结论：通过上述优化技术，我们证明极低场磁共振可以对脑组织进行成像，成像分辨率与低场强磁共振相当，这

为后续临床研究奠定重要基础。

关键字： 极低场磁共振、深度学习、信噪比

ID 1878

A Novel Parallel Residual Neural Network Model for Classification of COVID-19 Chest X-ray Images

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Objective: The 2019 novel coronavirus pneumonia outbreak rapidly spread across the globe. This resulted in a significant increase in the number of cases, leading to a shortage of medical resources and personnel in many regions. Chest X-ray imaging, characterized by its low cost and fast results, is crucial for diagnosing COVID-19 patients. However, interpreting these images requires professional expertise and significant amounts of time, posing experts with a challenge. Therefore, there is an urgent need for a technology that can quickly and accurately classify chest X-rays of COVID-19 patients. Chest X-ray image recognition technology based on deep learning is a critical auxiliary diagnostic tool in clinical medicine.

Methods: In order to reduce the burden of experts in diagnosing COVID-19 patients with chest X-ray images, this paper proposes a novel parallel residual neural network model for fast and accurate classification of novel coronavirus pneumonia images. To address the small target detection problem in chest X-ray image detection, we propose to adopt a parallel structure with different size convolutional filter structures on the basis of the existing residual network to extract local and global features of pneumonia images. To address the noise interference problem, we added a soft thresholding module in the neural network structure and optimized the module through backpropagation algorithms. The channel attention module automatically learns the weights of each feature map channel and assigns values accordingly.

Results: We trained and tested our proposed model on the publicly available Kaggle COVID-19 Radiography Database. The training set accuracy reached 100% and the test set accuracy reached 98.5%, and the model AUC value reached 99.7%.

Conclusion: Our proposed parallel residual neural network model demonstrates improved performance in classifying COVID-19 chest X-ray images using the same dataset. Future prospects could explore the possibility of implementing real-time classification of pneumonia images to maximize the potential of this research.

Key words: ResNet; Parallel Structure; Soft Thresholding; Attention Mechanism

ID 1917

Development and Validation of a Deep Learning Radiomics Method for Preoperative Diagnosis of Occult Peritoneal Metastasis in Patients with PDAC

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Objective: Computed Tomography (CT) is widely used as the preferred imaging modality for preoperative diagnosis of pancreatic ductal adenocarcinoma (PDAC). Nevertheless, unclear CT indications can lead to underdiagnosis of occult peritoneal metastasis (PM). Therefore, we aimed to develop and validate a deep learning radiomics (DLR) model combined with clinical information for preoperative diagnosis of occult PMs in patients with PDAC.

Methods: A total of 253 PDAC patients with preoperative CT images (134 for training and 56 for internal validation, center 1; 64 for external validation, center 2) were retrospectively included. Deep semantic segmentation features and radiomics features were extracted from CT contoured lesions, contributing to the construction of radiomics signature (RS) 1 and RS2, respectively. The least absolute shrinkage and selection operator regression was used for feature selection. Then, a DLR model was developed based on RS1 and RS2, and it was incorporated with clinical information to establish a DLR-C model. The performance of models was evaluated using the area under the receiver operating characteristic curves (AUC) with 95% confidence interval (CI) .

Results: After feature selection, 13 deep semantic segmentation features in RS1, 20 radiomics features in RS2 and 3 clinical factors remained . The AUCs of the DLR model were as follows: in the internal validation set, 0.775 (95% CI, 0.666-0.885); in the external validation set, 0.767 (95% CI, 0.663-0.872) . The DLR-C model achieved better performance than the DLR model with AUCs of 0.825 (95% CI, 0.726-0.925) and 0.800 (95% CI, 0.702-0.899) in the internal and external validation set.

Conclusion: CT-based DLR model had a good prediction ability of occult PM, and clinical information further improved the performance.

Key words: Occult peritoneal metastasis, pancreatic ductal adenocarcinoma, deep learning, radiomics, Computed Tomography

ID 1954

Contrast Free Endovascular Aortic Repair Guided by Intraoperative Cone-beam Computed Tomography

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Objective: The indications for endovascular repair of abdominal aortic aneurysm (EVAR) have been rapidly expanded due to the improvement and innovation of devices and technology. However, the use of iodinated contrast agents limits its application in patients with severe contrast allergy or renal dysfunction. Our study reported a contrast free EVAR case through intraoperative cone-beam CT (CBCT) guidance and evaluation.

Methods: A 76 year-old female patient was diagnosed with abdominal aortic aneurysm by MRA. The patient had severe allergic history of iodine contrast medium. After general anesthesia, CBCT (syngo DynaCT 360) was acquired with projection angle range of 360 degrees around the abdomen. Based on the calcified plaques confirmed in MRA and CBCT, the orifice of each branching artery and its corresponding spinal position were marked on the sectional images. The stent-graft alignment was guided by the markers on the fluoroscopy screen. After deployment, another CBCT was acquired to evaluate the stent position and shape.

Results: No contrast medium was used during the whole procedure. The calcified plaques found in CBCT corresponded well with that in MRA. With the guidance of the anatomy markers on fluoroscopy screen, anchoring zones for stent-graft can be quickly localized. Two stent-grafts were deployed and the whole procedure took only 77 min. The postoperative CBCT images showed that all the stent-grafts were well aligned and attached to aorta wall. The patient recovered well and discharged after 7 days. A 3-month follow-up MRA demonstrated total thrombosis of the aneurysm with stent-grafts patent.

Conclusion: The intraoperative CBCT guidance provides a new and effective option for contrast free EVAR. In this condition, accurate intraoperative localization could be achieved without any extra equipment, registration error or patient position variance during overlapping.

Key words: Endovascular aortic repair; Contrast-free; Cone-beam computed tomography

ID 2090

Cone-Beam Computed Tomography-Based Delta-Radiomics Analysis for Predicting Radiation Pneumonitis in Patients with Thoracic Cancer after Radiotherapy

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Objective: To construct a cone-beam computed tomography (CBCT)-based delta-radiomics nomogram for individualized predicting of radiation pneumonitis (RP) in patients with thoracic cancer after radiotherapy.

Methods: 92 thoracic cancer patients treated with image-guided-radiotherapy at Peking University Cancer Hospital were retrospectively included. KV CBCT images before the treatment (CBCT), after the first, second and third week of the course (CBCTi, i=1,2,3) were obtained. 560 radiomics features were extracted from each CBCT. The longitudinal feature changes from CBCT to CBCTi were calculated and defined as delta-radiomics features (Delta-RFi, i=1,2,3). In addition, accumulative CBCT delta-radiomics (Delta-RFaccu) was proposed which stacked the temporal changes of lung tissues over the treatment course. For each Delta-RFi (i=1,2,3,accu), significance tests of difference and principal component analysis (PCA) were sequentially conducted to reduce dimension. Then the first principal component of PCA was taken as the signature of the corresponding Delta-RFi. 92 patients were randomly divided into 7:3 training and validation cohort to fit the predicting model. Finally, the best delta-radiomics signature along with important clinical and dosimetric predictors were used in multivariate Logistic regression to predict RP, and a delta-radiomics based nomogram was established correspondingly.

Results: The AUC of signatures from Delta-RFi (i=1,2,3,accu) were 0.70 ± 0.09, 0.66 ± 0.15, 0.70 ± 0.13 and 0.82 ± 0.09, respectively in the validation cohort. In the Delta-RFaccu based model that integrated important clinical and dosimetric predictors, AUC increased to 0.85 ± 0.10. Calibration curves and decision curves exhibited a precise prediction and satis-

factory clinical utility of our final model.

Conclusion: CBCT-based delta-radiomics has good performance in predicting RP, and the accumulative delta-radiomics strategy we proposed performs better than conventional methods. The developed multivariate nomogram has better predicting ability than delta-radiomics signature or models composed by dosimetric factors alone, and can be used as a quantitative tool for individualized RP prediction.

Key words: radiomics; radiation pneumonitis; cone-beam computed tomography; thoracic cancer; prediction model

ID 2154

Dual-modality System Based on Dynamic Blood Perfusion and Temperature for Early Detection of Pressure Ulcers

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Objective: The formation of pressure ulcers poses a significant clinical and economic burden. However, there is a lack of reliable Methods for the Objective detection of early-stage pressure ulcers. This study aimed to develop and validate a system for the early detection of pressure ulcers.

Methods: A system was developed to perform cooling stimulation on the skin and acquire dynamic image data of blood perfusion and temperature. The dynamic perfusion and temperature parameters were obtained and processed to provide dynamic synthesis parameters for the early detection of pressure ulcers. The system was tested on a rabbit ear pressure ulcer model.

Results: The Results showed that the use of dynamic synthesis parameters was able to distinguish between normal and early pressure ulcer skin with better accuracy than dynamic or static parameters alone. The system was also able to detect minor pressure injuries that precede early-stage pressure ulcers.

Conclusion: The Results of this study demonstrate the feasibility of the proposed system for early pressure ulcer detection and the potential for early warning of areas where early pressure ulcers may occur. This system provides a promising solution for the early detection of pressure ulcers and has the potential to reduce the clinical and economic burden associated with these sores.

Key words: pressure ulcers; laser speckle; dual-modality; dynamic detection

ID 2157

Optical Coherence Tomography-based Fluid-structure Interaction Models for Human Coronary Vulnerable Plaque Rupture: A Biomechanical Modeling Case Study

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Objective: Acute myocardial infarction (AMI) is mainly caused by vulnerable plaque rupture and subsequent coronary artery occlusion. Previous studies have revealed that multiple factors can lead to vulnerable plaque rupture (lipid necrotic core expansion, accumulation of foam cells, etc.). However, it's still not well established whether biomechanical factors could increase the risk of plaque rupture.

Methods: In vivo optical coherence tomography (OCT) data of a vulnerable plaque on baseline and 1-month follow-up were acquired from an AMI patient with consent obtained and the unexpected plaque rupture was detected at 1 month. OCT and angiography data at baseline were acquired to construct 3D fluid-structure interaction (FSI) coronary plaque model to obtain plaque wall stress (PWS), plaque wall strain (PWSn), wall shear stress (WSS) and flow velocity of the plaque at a mid-cut plane for analysis. The quantitative and qualitative analyses of OCT imaging were based on the established criteria.

Results: The minimum fibrous cap thickness and largest lipid arc of the plaque were 30 μm and 171.3° respectively, which was eligible for OCT-defined criteria for vulnerable plaque. The local maximum WSS and flow velocity were 255.4 dvn/cm2 and 104.4 cm/s, which were located at the minimum blood flow area with relatively small PWS (52.0 kPa) and PWSn (0.1262) for all 41 slices. The plaque rupture appeared at the site of maximum PWS (165.0 kPa) with relatively large PWSn (0.1823) rather than the location of maximum PWSn (0.1945) with relatively small PWS (102.0 kPa).

Conclusion: Our study demonstrated that biomechanical conditions quantified by computational modeling could be used to predict which vulnerable plaque was prone to rupture. More patients with follow-up data are needed to investigate and verify the mechanisms of biomechanics in vulnerable plaque rupture.

Key words: acute myocardial infarction; plaque rupture; fluid-structure interaction; optical coherence tomography

ID 2570

Deep Learning-based Detection of Dental Caries and Fissure Sealant in RGB Photos: A Multi-task Study

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Objective: The purpose of this study is to develop and evaluate a deep learning-based multi-task model (ToothNet) for

caries and sealant detection from oral photographs.

Methods: 1020 oral photographs obtained from 762 volunteers were included for the development and evaluation of model. A multi-task deep learning detection model ToothNet was developed by adapting from YoloX Detector. The performance of the model was evaluated at image-level and tooth-level: (i) classification accuracy for telling the existence of dental caries and sealant from a photograph and (ii) localization accuracy for locations of predicted dental caries and sealant. The area under curve (AUC) under the receiver operating characteristic curve (ROC) and free-response receiver operating characteristic curve (FROC) were calculated to evaluate the performance of the model.

Results: At image-level, the AUC of the model was 0.925 (95% Confidence Interval: 0.880 to 0.958) for caries detection and 0.902 (95% Confidence Interval: 0.853–0.940) for sealant detection. At tooth-level, at a confidence threshold of 0.5, the sensitivity and precision of the model were 0.807 and 0.814 for caries detection and 0.714 and 0.750 for sealants detection, respectively.

Conclusion: The multi-task ToothNet model can accurately locate teeth, and show good performance in the detection of caries and fissure sealants, which can indicate the potential for detection and localization of caries and sealant on photographs.

Key words: Dental caries; Fissure sealant; Detection and Localization; Deep learning

ID 2672

人体血流灌注生物电阻抗断层成像关键技术研究进展

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目的：重要脏器的血流灌注状态的实时成像，对于研究其功能状态，探索其内部交互机制，实现损伤预警均有着重要的应用价值。电阻抗断层成像 (EIT) 技术是一种以组织电阻抗特性为成像目标的新型成像技术，具有敏感、无创、廉价、便捷等突出优势，有望基于血液与相关组织的电阻抗差异实现灌注成像。但这种因血流灌注导致的阻抗变化信号极弱，如何准确采集这一信息并进行成像一直是本领域的突出难点问题。

方法：采用高精度数字信号合成、宽频带信号调理、并行化模数转换、正交序列数字解调等系列关键技术，研制了一套全新的高速、高精度 EIT 系统。系统具有 40 帧 / 秒以上的采集速度、80dB 以上的测量精度和 1kHz~500kHz 的工作频率范围。主要性能指标达国际领先水平。

结果：将灌注成像 EIT 系统应用于正常志愿者与重症新冠肺炎患者的图像监护过程。通过监护实验，我们首次观察到正常志愿者瓦氏动作过程中脑血流存在特异性的反应调节过程；同时我们还通过盐水增强造影法与呼吸保持期间的肺血流灌注成像的对照，证实灌注成像 EIT 系统能够实时获取肺每搏血流灌注信息，并能反应呼吸机参数变化的影响。

结论：EIT 技术可用于组织血流灌注过程的无创实时成像，具有较好的临床应用推广价值。

关键字：电阻抗断层成像，灌注成像，图像监护

ID 2944

A Weber-Fechner Law Based Contrast Enhancement Algorithm for Bone ECT images

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Objective: Clinically, the bone ECT image has the problem of low contrast caused by the small difference between the bone and the background gray level, which will greatly affect the diagnosis and analysis of doctors.Weber-Fechner Law points out that the perceived brightness is proportional to the logarithm of physical brightness,therefore, this paper proposes an algorithm based on Weber-Fechner Law to improve the contrast between bones and background in bone ECT images. Thereby achieving a better enhancement effect than traditional enhancement algorithms. The enhanced image is easier to observe and has higher contrast.

Methods: In order to improve the contrast between bone and background in bone ECT images, this paper uses the improved Laplacian enhancement operator for sharpening processing, and calculates the threshold value through the Otsu threshold method. The exponential function of Fechner Law increases the gray value of the pixel, whereas the Softplus function reduces the gray value of the pixel.

Results: In this paper, structural similarity (SSIM) and peak signal-to-noise ratio (PSNR) are used as quantitative evaluation indicators of the algorithm, and the Results are 0.95 and 20.30, respectively, which are 10% and 9.3% higher than the enhancement effect of MicroDicom software. Compared with traditional algorithms, bone ECT images enhanced by this algorithm have higher contrast and are easier to observe and analyze.

Conclusion: The algorithm based on Weber-Fechner Law proposed in this paper has good performance in enhancing bone ECT images, and is expected to achieve good Results in image enhancement of other modalities.

Key words: Bone ECT image;Weber-Fechner Law; Image enhancement;

ID 2968

基于循环生成对抗网络提高锥束 CT 影像组学预测放射性肺炎效果

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目的：基于循环生成对抗网络（CycleGAN）和锥束 CT 合成伪 CT 图像（sCT），提高胸部放疗患者放射性肺炎的预测精度。

方法：回顾性收集 92 例胸部肿瘤患者的计划 CT（pCT），放疗前 CBCT（CBCT）以及放疗后第一周 CBCT（$CBCT_1$）图像数据。利用 pCT 和 CBCT 训练 CycleGAN 网络合成 sCT，利用该网络将 $CBCT_1$ 转化为 sCT 图像（$CBCT_1$-plus）。将病人按 7：3 比例随机分为训练和测试集，提取对应图像中的影像组学特征。构建四个影像组学模型：分别以 pCT，$CBCT_1$，pCT 和 $CBCT_1$，$CBCT_1$-plus 的影像组学特征训练和测试，并在训练集中通过统计学检验与 lasso 回归筛选特征。最终采用受试者工作特征（ROC）曲线评价模型的预测能力。

结果： 使用 $CBCT_1$-plus 的模型对放射性肺炎的预测能力最强，其 ROC 曲线下面积（AUC）为 0.745。基于 pCT，CBCT1，pCT 和 $CBCT_1$ 联合的模型只有有限的预测能力，其 AUC 分别为 0.612，0.607，0.612。

结论： 本研究通过 CycleGAN 网络，使用 pCT 和 CBCT 图像改进了 sCT 图像质量和影像组学模型对于放射性肺炎的预测效果。

关键字： 影像组学、放射性肺炎、循环生成对抗网络、伪 CT

ID 3165

全面性癫痫瞬时相位依赖的时空模式研究

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目的： 探讨全面性癫痫（强直阵挛发作，GTCS）默认模式网络 (DMN) 与任务正网络 (TPN) 周期性反相关关系的瞬时相位依赖时空模式。

方法： 本研究收集 100 例 GTCS 和 104 例健康对照 (HC) 的静息态 fMRI 数据。首先，定义 DMN 与 TPN 周期性反相关关系的时空模式。然后对该模式进行希尔伯特变换，通过瞬时锁相计算功能连接。随后进行主导特征向量分析 (LEiA)，即每个时间点瞬时锁相的最大特征值对应的特征向量。为识别锁相模式，对 LEiA 进行了 k 均值聚类。最后比较组间瞬时相位依赖时空模式的时间分数、停留时间和转移概率。

结果： LEiA 聚出 6 个状态。其中，状态 1 与健康被试的静态功能连接很相似，表现出 DMN 正相位，TPN 反相位；状态 2 表现为 TPN 正相位；状态 3 和 6 均有 DMN 与腹侧注意网络（VAN）反相。与 HC 相比，GTCS 的状态 2、3 的时间分数显著升高，状态 1、6 显著降低。而且，除状态 2 外，组间停留时间与时间分数的结果相似。此外，GTCS 状态 2、3 向自身状态转移概率和状态 6 到状态 3 的转移概率增加。

结论： 研究发现 GTCS 中异常动态变化主要是 VAN 高度活跃和 TPN 与 DMN 间反相依赖减弱，为 GTCS 潜在的病理生理机制提供了重要见解。

关键字： 动态功能连接；时空模式；主导特征向量分析；全面性强直 - 阵挛癫痫

ID 3174

经颅聚焦超声衰减数学模型研究

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天津大学

目的： 近年来，经颅聚焦超声在神经调控和神经成像方向上展现了广阔的前景和潜力。在脑科学研究中，经颅聚焦超声受头部生物组织头皮、颅骨和脑组织的影响，声场特性发生变化，经颅聚焦超声的精准聚焦对其发展至关重要。由于头部组织尤其是颅骨的影响，其衰减是影响精确聚焦的关键问题。

方法： 本研究的目的是建立一个随颅骨厚度变化超声衰减数学模型。结合真实颅骨体模实验和仿真实验，研究不同头部组织的经颅聚焦超声衰减情况。基于系统辨识方法，建立经颅聚焦超声颅骨厚度的声压衰减数学模型。最后，

对数学模型的性能进行测试，并对其潜在的应用进行研究。

结果：对于不同的头部生物组织，包括头皮、颅骨和脑组织，发现颅骨是影响超声衰减的最大因素，其造成的衰减分别是脑组织和头皮的 4.70 倍和 7.06 倍。与仿真和模体实验的结果一致，数学模型中的超声衰减随颅骨厚度的增加而增加。对比体模实验，数学模型的平均误差为 1.87%。

结论：实验结果表明，本研究提出的数学模型能够准确计算经颅聚焦超声的衰减，对经颅聚焦超声进一步研究和应用具有重要意义。

关键字：经颅聚焦超声，声压衰减，数学模型

ID 3182

Molecular Imaging of PSMA-targeted Nanobubbles by Modeling the Second-wave Phenomeno

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Objective: With a diameter 10 times smaller than microbubbles (MBs), nanobubbles (NBs) have been developed as a new-generation ultrasound contrast agent (UCA) that can extravasate to access receptors overexpressed in extravascular cells. In particular, NBs targeted to the prostate-specific membrane antigen (PSMA), which is over-expressed in prostate cancer (PCa), can be used for ultrasound molecular imaging of PCa.Previously, we have shown the feasibility of pixel-level modeling of PSMA-NBs. We have also observed for the first time the second wave phenomenon, which is unique to the pharmacokinetics of NBs. Here we aim to improve the modeling of PSMA-NBs pharmacokinetics by explicitly incorporating this phenomenon into the model.

Methods: PSMA-expressing (PSMA+) and a PSMA-negative (PSMA-) tumor were subcutaneously implanted in 7 mice. After injecting a 200-µL bolus of untargeted NBs or PSMA-NBs, contrast-enhanced ultrasound loops were acquired using a PLT-1204BT probe for 30 mins. Measured TICs from each pixel were fitted by a dedicated model that includes one wave and two waves, respectively. After estimating the parametric maps, the difference between the pixel-level parameter values in PSMA- and PSMA+ tumors was assessed by the Mann-Whitney U test [37] with pooled data.

Results: When using the two-wave model, two parameters, the peak time and residual factor of the second wave are significantly different between PSMA+ and PSMA- when using PSMA-NBs. Six out of seven mice present critical one-quartile differences when using PSMA-NBs. By taking the unique second-wave phenomenon into account, the two-wave model outperforms the one-wave model, n terms of both fitting accuracy and the ability to differentiate between PSMA and PSMA tumors.

Conclusion: The estimation of relevant parametric maps allows the estimation and visualization of specific binding of PSMA-NBs in PCa.

Key words: Nanobubbles, Contrast-enhanced ultrasound, Pharmacokinetic modeling

ID 3241

精神分裂症信号和噪声成分对全局信号贡献的变化

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目的：利用 rs-fMRI 研究大脑活动信号和噪声信号成分对全局信号 (GS) 的影响及其在精神分裂症 (SZ) 患者中的变化

方法：收集了 91 例 SZ 患者和 109 例健康对照 (HC) 的数据。首先，使用 ICA 方法识别信号和噪声成分。然后，通过计算 GS 时间序列与各灰质体素时间序列之间的 Pearson 相关系数，得到 GS 相关图，再进行组间对比。首先建立多元线性回归模型，以因变量为 GS 时间序列，各成分的时间序列为自变量。另外，以 GS 相关图为因变量，为各成分的空间模式为自变量建立回归模型。分别对两个回归模型同一成分的回归系数 β 值进行组间统计对比。

结果：首先，对于 GS 相关图，与 HC 相比，SZ 在额顶网络和基底节的 GS 相关值较高，而在视觉、听觉和运动网络的 GS 相关值较低。其次，对于时间序列回归模型，SZ 在视觉、听觉、运动网络和磁化率成分的贡献降低，脑脊液波动成分的贡献增加。最后，对于空间模式回归模型，SZ 也在视觉、听觉、运动网络和磁化率成分的贡献降低，在额顶网络、基底节、白质和血管噪声的贡献增加。

结论：总的来说，SZ 与 HC 相比，GS 相关和贡献值在初级感觉区域降低，而在高级联合区域增加。噪声成分中脑脊液波动的贡献值增加，磁化率成分的贡献降低。

关键字：全局信号 ; 精神分裂症 ; ICA; 多元线性回归模型

ID 3246

频率特异白质功能活动：在服药和未服药全面性特发性癫痫中的研究

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目的：从白质功能活动出发，在全脑体素水平上进行功能结构耦合，揭示全面性特发现癫痫（IGE）脑网络特征。

方法：我们总共招募了 85 名 IGE 患者（包括 50 名未服过抗癫痫药物（DNP）和 35 名服用抗癫痫药物患者（DRP））和 93 名年龄性别匹配的健康被试（HC）。计算了 5 个频段（0-0.01Hz，0.01-0.027Hz，0.027-0.073Hz，0.073-0.198Hz，0.198-0.25Hz）的低频振幅（ALFF）、动态 ALFF 以及部分各项异性（FA），采用基于骨架的统计分析方法将 FA 和功能指标投射到骨架上。利用置换检验统计 DNP、DRP 和 HC 之间的差异（p<0.01，TFCE 校正）。

结果：相较于健康被试，所有患者的 FA 在胼胝体、内囊等区域显著降低。此外，所有患者 ALFF 在胼胝体、内囊、中央前后回、额上回等区域升高。在 0.01-0.027Hz 和 0.027Hz-0.073Hz 频段，DNP 的小脑 ALFF 升高。IGE 的动态 ALFF 在胼胝体、小脑、脑干等区域降低，在胼胝体膝、中央前后回、额上回等区域升高。

结论：本研究发现了 IGE 患者白质通路上的结构功能紊乱，揭示了未服药患者存在频率特异的小脑功能紊乱。

关键字：全面性特发性癫痫；白质；频率特异功能活动；基于骨架的功能分析

ID 3259

低频 rTMS 改变闪光刺激引起的大脑激活

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目的：在健康被试中探讨闪光刺激诱发的皮层激活机制，以及低频 rTMS 对其干预作用。

方法：本研究共纳入 73 名健康被试，分为两组，分别用 1Hz rTMS 干预外侧枕叶和顶点 Vertex，两组都施加 900 个脉冲，刺激强度为静息运动阈值的 90%。在 rTMS 前后进行 fMRI 图像采集，于扫描中以伪随机的方式呈现 5/10/20Hz 的黑白闪光刺激，每次闪光持续 20s，每个频率的刺激呈现 3 次。用一般线性模型计算闪光任务时的大脑激活，进行两因素混合设计方差分析，比较刺激位点间以及刺激前后的差异。

结果：与以往研究相一致，刺激前，被试注视闪光屏幕时初级视觉皮层的 BOLD 激活为正，同时，左侧梭状回、海马旁回以及颞下回在闪光刺激时激活为负。低频 rTMS 干预外侧枕叶后左侧梭状回、海马旁回以及颞下回的负激活被减弱，而初级视觉皮层的正激活并无显著变化。

结论：研究结果表明 1Hz rTMS 削弱了闪光刺激对左侧梭状回、海马旁回以及颞下回的抑制作用，而并未对初级视觉皮层产生显著影响，提示了 rTMS 对高级视觉皮层与初级视觉皮层的平衡抑制关系的调控，为进一步探究视觉信息的传递机制提供了重要参考。

关键字：闪光刺激；低频经颅磁刺激；枕叶 rTMS 干预；fMRI

ID 3342

一种适用于 0.5 T 磁共振成像系统的空间正则化多组分成像方法

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目的：多组分成像可以捕获与损伤或病理变化相关的微结构信息。因为这种成像方法依赖于较高质量的成像数据，所以目前大多数多组分成像方法只在高场磁共振成像（MRI）系统应用研究。本文提出了一种适用于在低场磁共振系统中的多组分成像方法。

方法：该方法包括低场 T1-T2 MRI 数据采集方法和优化的拉普拉斯逆变换（ILT）算法。T1-T2 MRI 数据采集方法可以提高测量效率，避免低场 MRI 系统中的伪影。优化后的 ILT 算法结合了每个体素内的平滑约束和体素间的空间正则化约束，旨在提高对低质量 MRI 数据的弛豫分布估计的鲁棒性。

结果：本研究进行了数值模拟验证实验，同时在自制的 0.5 T MRI 系统中进行了成像实验。数值模拟和模型样本的磁共振成像结果表明，优化后的 ILT 算法比没有空间正则化的 ILT 算法具有更好的收敛特性和鲁棒性。蓝莓和秋葵切片的多组分成像结果给出了与组织内在水分子状态相对应的弛豫分布特征，这是常规 MRI 方法无法观察到的。

结论：这种多组分成像方法可以提供亚体素分辨率，并应用于低场磁共振的众多使用场景当中。在未来，该方法可以进一步优化应用于便携式的磁共振成像系统，服务于早期疾病的筛查。

关键字：空间正则化，多组分建模，T1-T2 磁共振成像，低场磁共振成像

ID 3456

关于视网膜 OCT 图像自动分层技术研究的综述

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目的：白内障、青光眼和糖尿病性黄斑水肿等眼科疾病成为眼健康的关键问题，通常会对视网膜层的厚度和结构产生影响，通过光学相干层析技术（OCT）对眼底视网膜进行成像可以观测到这些变化，对视网膜各层次进行分析从而进行眼健康状况评估。光学相干层析成像技术（OCT）的飞速发展和临床需求对处理技术提出了更高的要求。

方法：本文通过对视网膜自动分层技术的发展进行详细阐述，介绍了从经典图像处理方法到基于深度学习的分层技术的历程，直观展示了视网膜分层从层数、时间和精度方面上的进步。

结果：经典的视网膜分割模型从基于经典边缘像素特征逐步发展到以卷积神经网络为主流，基于深度学习视网膜分层经历了从 CNN 到 FCN 到 U-Net 的过程，在之前的基础上不断改进。

结论：视网膜分层思想从早期的根据边界灰度梯度划分到提取特征聚集属于这一层的所有的像素点。

关键字：OCT 视网膜分层 深度学习

ID 3531

Sensitive Magnetic Particle Imaging Visualizes Intraplaque Hemorrhage for Detecting and Monitoring Atherosclerotic High-risk Plaques

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Objective: Intraplaque hemorrhage (IPH), which arises from leaky neovessels, is an imaging predictor of stroke and myocardial infarction. However, non-invasive and sensitive monitoring of IPH is challenging due to the compositional complexity and dynamic nature of atherosclerotic plaques. Magnetic particle imaging (MPI) is a highly sensitive, radiation-free, and no-tissue-background tomographic technique that detects superparamagnetic nanoparticles. We aimed to investigate whether MPI can image IPH for identifying and monitoring high-risk plaques.

Methods: Thirty human carotid endarterectomy samples were collected and scanned with MPI. The tandem stenosis (TS) model was employed to establish unstable plaques with IPH in ApoE-/- mice. MPI and 7 T T1-weighted magnetic resonance imaging (MRI) were performed on TS ApoE-/- mice. Ex vivo light-sheet microscopy (LSM) was performed to quantify neovessel permeability after administering FITC-dextran. Plaque specimens were analyzed histologically.

Results: Human carotid endarterectomy samples exhibited endogenous MPI signals, which histologically colocalized with IPH. In vitro experiments identified haemosiderin, a haemoglobin degradation product, as a potential source of MPI signals. MPI/CTA identified IPH in high-risk plaques of right carotid artery, of which MPI signals increased from 3.05 ± 1.45 (4 weeks) to 7.29 ± 4.47 (7 weeks) and then reduced to 2.59 ± 0.84 (11 weeks) ($P < 0.05$). In contrast, 7 T T1-weighted MRI did not detect the small-size IPH (329.91 ± 226.82 μm2) at four weeks post-TS. Ex vivo LSM imaging of right carotid artery

found a dynamic change of neovessel permeability, measured by FITC-dextran fluorescence intensity, which increased from 0.84 ± 0.24 × 1011 (4 weeks) to 2.91 ± 0.57 × 1011 (7 weeks), and reduced to 1.70 ± 0.39 × 1011 (11 weeks) ($P < 0.05$).

Conclusion: MPI enabled IPH detection via imaging of endogenous hemosiderin, which allows identification of high-risk plaques and longitudinal monitoring of IPH dynamics.

Key words: atherosclerosis, magnetic particle imaging, intraplaque haemorrhage, endogenous component, haemosiderin

ID 3546

A unified CNN-ViT Network with a Feature Distribution Strategy for Multi-modal Missing MRI Sequences Imputation

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Objective: Multi-modal magnetic resonance imaging (MRI) is of great clinical use for disease assessment and diagnosis, as it provides comprehensive and complementary information through multiple contrasts. However, due to potential obstacles of the scanning process and the patient's physical condition, the available scans of each subject may vary.

Methods: Here, we propose a unified adversarial network based on the convolution neural network (CNN) and vision transformer (ViT) for missing MRI image synthesis in any input-output image configurations. The purpose of our network design is to develop a robust and efficient way to integrate the local information capturing ability of the convolutional operation and global contextual sensitivity of the multi-head self-attention (MSA) mechanism. Specifically, we employ a u-shape network as our generator and mix the convolutional path and the MSA path in a parallel manner at each network stage, the mixer is in place of the original MSA block of the canonical transformer, this design enables each layer to learn both global and local information simultaneously and takes advantage of the general ViT architecture. Furthermore, since these two branches have different frequency information preference, possessing all channels in each branch inevitably renders feature redundancy and introduces extra artifacts, accordingly, we adopt a channel splitting strategy that splits input features channel-wise and feed to each branch separately, meanwhile, considering each network stage has different desire of the high- and low-frequency information, we also explore various channel distribution ratios at each network stage.

Results: Our proposed method demonstrates reliable synthesis for healthy tissues and heterogeneous enhancement on BraTS2021 dataset. Furthermore, compare with four state-of-the-art Methods including convolution-based, MSA-based and hybrid models in the MRI sequence synthesis field, our approach outperforms these Methods quantitatively and qualitatively.

Conclusion: Therefore, our method has the potential to be used as a candidate for medical image synthesis.

Key words: Image synthesis, multi-modal MRI, visual transformer, convolutional neural network, deep learning

S03
脑器交互（含脑机接口）与神经工程
Brain-Apparatus Communication and Neural Engineering

ID 544

首发精神分裂症患者在 40 Hz 听觉稳态响应时的异常相位 - 幅值耦合

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目的：本研究想探索首发精神分裂症患者的 40 Hz 听觉稳态响应时的动态相位 - 幅值耦合模式，及其与临床症状的联系。

方法：67 名未服药的首发精神分裂症患者和 84 名健康对照参与听觉稳态响应任务，记录脑电信号。首先，计算声音刺激出现前、中、后时间窗口内的 PAC。接着，比较 PAC 在声音刺激前中后的变化与两组人之间的差异。最后，评估患者 PAC 值与临床量表 PANSS 的相关性。

结果：theta/alpha/beta-40 Hz PAC 在声音出现时下降；theta/alpha/beta-30 Hz 和 -50 Hz PAC 随声音出现而升高，且与阴性症状显著正相关。Beta-80 Hz PAC 在声音出现时下降；beta-70 Hz 和 -90 Hz PAC 随声音出现而升高；患者组的 beta-80 Hz PAC 在 T1、T2、T3 都显著高于健康组，且与 PANSS 量表总分、一般症状分呈显著正相关。

结论：听觉稳态响应任务中不同且异常的 PAC 模式可能为精神分裂症损伤环路和临床症状机制提供新的视角。

关键字：精神分裂症、听觉稳态响应、相位 - 幅值耦合

ID 623

EEG Studies of The Effects of Music Training on Rhythm, Music Phrases and Syntax Perception

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Objective: The effects of music training are reflected in auditory perception. Behavioral, brain structural and functional changes were found in musicians and nonmusician controls, demonstrating the effects of music training.

Methods: Rhythm, music phrases and syntax are complex music elements, which involve higher level of auditory processing. EEG studies of the perception of these music elements and the effects of music training were summarized and discussed in this review.

Results: The ERP early and mid-latency components, P3a, P3, N5, ERAN (early right anterior negativity), CPS (closure positive shift) and neural entrainment to beat frequencies were EEG features to study complex music perception between musicians who received music training and nonmusician controls. Musicians showed more complex ERP components related to rhythm, music phrases and syntax features and stronger neural entrainment to music beats.

Conclusion: These Results showed different cortical processing of rhythm, music phrases and syntax in musicians and nonmusicians and explained the effects of music training on auditory perception on a deeper level.

Key words: EEG, Music Training, Rhythm, Music Phrases, Music Syntax

ID 661

基于多时段脑电数据的源定位方法重测可靠性评估

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目的：现有脑电源定位方法的评估通常基于模拟数据，而非真实脑电数据。本研究基于多时段的真实的脑电数据从重测可靠性的角度对多种脑源定位方法进行评估和比较。

方法：本研究用五种主流源定位方法，包括加权最小范数估计 (WMN)、动态统计参数映射 (dSPM)、标准化低分辨率脑电磁层析成像 (sLORETA)、偶极子建模 (dipole modeling) 和线性约束最小方差 (LCMV) 波束形成器，对 16 名受试者重复执行同一人脸识别任务的六次 EEG 数据进行源重建，并对重建的源信号从峰值定位可靠性和振幅可靠性进行评估。

结果：在负责静态人脸识别的两个脑区（枕叶面孔区和梭状回面孔区）所有方法都具有峰值定位可靠性，其中 WMN 得到了不同时段之间最小的峰值偶极子距离；在右半球的人脸识别区域，熟悉面孔条件下源定位在空间稳定性上优于陌生面孔和混乱面孔条件下的；在熟悉面孔条件下，各种方法的源振幅重测信度均为良好至优秀（大于 0.6）。

结论：在存在明显脑电效应的情况下，脑电源定位方法可以获得稳定可靠的源定位结果。由于先验知识不同，各种源定位方法有不同的适用场景。这些发现为源定位分析的有效性提供了新的证据，也为在真实脑电数据上比较源定位方法提供了新视角。

关键字：脑源定位，脑电，类内相关系数，重测可靠性

ID 733

Review of EEG Responses in Patients with Vestibular Related Diseases using Different Stimulation Methods

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Objective: Understanding the degree of damage to the vestibular nervous system is a necessary means for diagnosing and treating dizziness, balance disorders, and other vestibular-related diseases and selecting special occupational groups. In recent years, the electroencephalography (EEG) technique has been increasingly applied to assess vestibular function at a neurophysiological level, due to its advantage of not strictly limiting head movements and is a non-invasive, inexpensive, and high temporal resolution. Some studies have been done to differentiate between patients with vestibular-related disorders and healthy controls, and different stimulation Methods have been selected for these studies. This review aims to help novices quickly understand the current state of the research field and provide guidance for selecting appropriate stimulation for their own studies.

Methods: This article collects literature from the Web of Science-Clarivate Analytics, Google Scholar, and Pub-Med databases. Key words were defined as vestibular function, Electroencephalogram (EEG), vestibular vertigo, auditory evoked potential, visual evoked potential, vestibular stimulation, and vestibular evoked potentials. Articles matching the defined Key words were selected and reviewed.

We mainly focus on studies that differentiate between patients with vestibular-related disorders and healthy controls using different stimulation methods.

Results: This paper summarizes the findings of relevant studies and discusses the main aspects that researchersshould beconsidered when choosing a stimulation method, such as the feasible principle of stimulus, the feasibility of the experiment, the difficulty of subsequent processing, etc.

Conclusion: EEG technology has a good application prospect in evaluating the vestibular function, especially using natural vestibular stimulation. Stimulation method should be properly selected according to the Objective of study.

Key words: EEG, Vestibular function, auditory evoked potentials

ID 802

高通量侵入式脑机接口有效通道帅选

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目的：近几年发展起来的高通量 BCI，使得记录大量神经活动成为可能。这些高通量 BCI 通常可以同时记录成千上万个神经元的活动，因此可以获得更高质量的解码效果。但是这类设备也带来了一些挑战，比如在侵入性和计算压力上。所以 本文提出使用通道选择方法来解决高通量带来的植入安全隐患和信号处理压力。通道选择通过一定的电极筛选算法选择出和解码任务相关的特定通道，从而降低所需要记录和解码的通道数量。

方法：本文将使用两种基于深度学习的自动通道选择方法，这里称其 Gumbel 和 STG 方法。这两种方法通过对 Bernoulli 分布的不同处理，进而可以整合到深度学习网络中学习。这里使用立体脑电（SEEG）数据来验证该两种算法。

结果：在没做通道选择之前（使用所有通道），平均的分类精度为 59%，而当选择其中 10 个通道时，Gumbel 和

STG 的解码精度可以达到 65% 和 60%。该结果表明使用这两种基于深度学习的通道选择算法，可以使用更少的通道并获得更好的解码效果。

结论：所提出的基于深度学习的方法可以有效的帅选出对解码有效的通道。

关键字：脑机接口（BCI），立体脑电（SEEG），运动解码，深度学习，通道选择

ID 1095

刺激和促进昏迷病人大脑苏醒的一种很有潜能的方法——刺激膀胱充盈、苏醒、排尿神经反射通路，促进昏迷病人大脑苏醒

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目的：为了促进昏迷病人苏醒，提高病人生存生活质量，研究创新一套新的出新方法。

方法：本研究通过总结作者长期、反复的临床实践和观察，结合相关生理和病理生理知识和原理，诱发了新的创新和设想，就是刺激膀胱充盈、苏醒、排尿神经反射通路，促进昏迷病人大脑苏醒的一整套方法。

结果：结果：在作者长期、反复的临床实践中，一种特别的病理生理现象被发现，就是，很多昏迷病人，在无尿时，总是一直处于昏迷状态，肢体常静止不动，当随着病人膀胱充盈、尿储留，并且尿储留逐渐加重时，病人会出现躁动，或由昏迷好转转变成昏睡或嗜睡，甚至能短暂苏醒，呼喊排尿，排尿后会再次进入排尿前的状态。

这种创新和设想，以刺激排尿反射整个通路神经为切入点，通过物理手段、药物手段、中医中药手段、外科手段，等手段，刺激膀胱周围副交感传入神经或其感受器、骶部脊髓的初级排尿中枢、脊髓的传入神经、脑干中枢调节系统及大脑皮层高级中枢，从而产生苏醒或（和）小便意感，从而达到临床治疗昏迷病人的目的。

结论：经国内外检索证实截至目前，在国内外还没有类似的研究报道，因此本研究论文值得参考应用。

关键字：膀胱充盈；尿储留、排尿反射；昏迷；苏醒；治疗方法。

ID 1597

A Channel Selection Method for Motion Imagination Brain-computer Interface Based on Multi-frequency Channel Correlation

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Objective: Motor imagery(MI) based brain-computer interface technology can decode motor intent from the subject's EEG signal and convert it into control signal for application in BCI system. EEG acquisition usually uses a larger number of EEG channels to improve the overall information and classification accuracy. However, it may contain channels unrelated to MI tasks or redundant channels, affecting the performance of the BCI system.

Methods: Aiming at the channel selection problem of MI-BCI system, this paper proposes a correlation-based multi-frequency EEG channel selection method (FB-CCS-CSP), which combines multi-band signal decomposition filtering and correlation-based channel selection method (CCS) to select the optimal channel in different frequency bands. The common space pattern (CSP) method was used to extract the EEG features of selected channels in each frequency band, and the features were splicing to form the feature vector. Finally, the SVM classifier was trained to recognize and classify tasks.

Results: The experimental data set collected in this paper is used for research. The Results show that compared with the method of extracting all EEG features using CSP, the classification accuracy of FB-CCS-CSP method is better (82% vs. 70%). Compared with CCS-CSP method to extract EEG features of specific channels in all frequency bands, FB-CCS-CSP method also achieved better classification accuracy (82% versus 78%), and used fewer channels (29 versus 40).

Conclusion: The proposed method of FB-CCS-CSP can provide a useful tool for further personalized BCI system design and improvement of BCI performance.

Key words: brain-computer interface; motor imagery; channel selection;

ID 1716

单次校准下稳态视觉诱发电位的解码算法研究

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目的：基于稳态视觉诱发电位的脑机接口（SSVEP-BCI）信息传输速率高，具有广阔的应用前景。在其解码研究中，无训练方法无需繁琐的校准过程，但识别性能差；有训练方法识别效果显著，但大多在校准试次≥ 2 时才能正常工作。单次校准相较于无训练方法能够捕获个体脑电差异，相较于有训练方法能够最大程度降低校准负担，或为未来 SSVEP-BCI 模型构建的最佳模式。

方法：本文提出了一种数据增强方法，即跨刺激源混叠矩阵估计（msSAME）。该方法利用邻近频率下源混叠矩阵的相似性来提高其估计的鲁棒性，进一步通过重建 SSVEP 的源成分来扩增校准数据。与任务判别成分分析相结合后，能够实现单校准试次下的 SSVEP 高效解码。

结果：结果表明，在仅单次校准下，所提出的方法在 1s 时长下准确率达到 94.7%，相较 eCCA 和 ms-eCCA 方法分别提高了 22.5% 和 3.3%；最大信息传输速率达到 214.2bits/min，相较 eCCA 和 ms-eCCA 方法分别提高了 86.3bits/min 和 23.2bits/min。

结论：msSAME 有效增强了单次校准下 SSVEP 的解码性能，能够显著降低系统的校准负担，相关研究成果在实用型脑机接口方面具有潜在的应用价值。

关键字：脑机接口；脑电；稳态视觉诱发电位

ID 1800

Convolutional Neural Networks with Separated Frequency Bands for Motor Imagery Classification

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Objective: Motor imagery (MI) based brain-computer interfaces (BCIs) allow for practical applications by decoding neurophysiological phenomena recorded by electroencephalography (EEG). The traditional machine learning algorithms have been widely used in EEG analysis, but they often lack the ability to capture complex patterns in EEG data, leading to a suboptimal performance. As an important research field, deep learning has been widely used in the field of neuroscience research to study the functions and activities of the brain. To overcome the problem of small sample size and low signal-to-noise ratio of motor imagery EEG, we constructed a convolutional neural network model with separated frequency bands.

Methods: In this work, we propose a novel separated frequency bands convolutional neural networks (CNNs) to decode MI tasks in the BCI Competition IV-2A dataset. Firstly, the EEG data are preprocessed and normalized, targeting four types of tasks in specific nine frequency bands. Then, we construct a CNN model to capture the joint features of multiple frequency bands. Furthermore, we introduce a parallel channel-spatial attention mechanism to adaptively improve the discriminability of the joint features. Finally, the fully connected layers are used for our classification. The performance of our proposed model was evaluated within subjects by using 10-fold cross-validation classification strategy.

Results: The Results show that our proposed deep learning model achieves high performance in decoding MI-EEG four-category tasks, with the highest subject accuracy (kappa) of 97% (95%), and the within-subject average accuracy (kappa) of 81.56% (75.00%). Furthermore, our Results are improved compared to several machine learning Methods and state-of-the-art deep learning algorithms.

Conclusion: In conclusion, our proposed deep learning approach improves accuracy and performance for EEG decoding, while providing a promising solution to the limitations of traditional machine learning algorithms.

Key words: motor imagery; joint features; CNN; attention

ID 1817

多种干扰因素对虚拟现实注意力测试结果影响的研究

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目的：背景 / 目的：基于虚拟现实的持续执行注意力测试能够评估儿童注意力水平。课堂是儿童学习生活重要组成部分。本研究提出一个虚拟现实课堂情境的注意力测试方法，并设计了多种教室内外干扰物。采集多种行为学数据，头动数据和脑电数据，对比传统测试结果，探讨提出的注意力测试的多种参数反映注意力水平的优越性。

方法：利用 unity 实现虚拟现实的课堂注意力测试系统，以及视听觉多种干扰物。邀请 30 名 ADHD 儿童和 30 名健康儿童（8-15 岁），完成韦氏量表和临床诊断评估，并分为实验组和对照组。分析任务反应时和正确率等行为学数据，分析头转动角度信息，分析脑电数据时频特征。

结果：结果：（1）实验组反应时与干扰物强度成正相关，正确率与干扰强度负相关。对照组无明显规律。（2）与头动数据结合的注意力商数与韦氏智力量表和临床判断的相关性增强。（3）实验组脑电图中事件相关电位如 N1，P1

的潜伏期和峰值与干扰物的出现同步性高于对照组。（4）相比于对照组，实验组 theta 波在干扰物出现后的激活持续时间更长，能量更高，但在任务目标出现后能量下降。

结论：结合多种类型不同强度干扰物的虚拟现实课堂情境下注意力测试能够更准确的反映儿童注意力水平。

关键字：持续执行注意力测试；虚拟现实；脑电；课堂情境注意力缺陷多动障碍

ID 2014

SKDCPM Algorithm Can Improve the Single-trial Decoding Performance of Very Similar Error-related Potentials

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Objective: Error related potential (ErrP) is an effective control signal for the brain-computer interface (BCI). Current ErrP decoding Methods can only distinguish right and wrong mental states. However, in real scenarios, error conditions often contain more detailed information, such as the degree of error, which would induce very similar ErrPs. Distinguishing such ErrPs effectively is of vital importance to provide more detailed information for optimizing BCIs. Hereto, a major challenge is the EEG differences of very similar ErrPs are very small. Thus, it is necessary to develop new efficient method for decoding very similar ErrPs.

Methods: This study newly proposed an algorithm named shrinkage discriminant canonical pattern matching (SKDCPM), which innovatively applied the shrinkage estimation method of covariance matrix to the construction of discriminative spatial patterns (DSPs). In this way, the anti-interference ability of DSPs in small sample size was improved. Therefore, SKDCPM could have a great decoding performance. This study compared the decoding Results of SKDCPM with linear discriminant analysis (LDA), shrinkage LDA (SKLDA), stepwise LDA (SWLDA), Bayesian LDA (BLDA) and the DCPM, which were algorithms commonly used for ErrP decoding. A data set of 18 subjects was built for the decoding performance comparison of the six algorithms. The data set had four conditions, i.e., right (0 °), errors with varying degrees, i.e., 45 °, 90 °, 180 °deviation from the predicted direction.

Results: As a result, the SKDCPM had high balanced accuracy (BACC) in right-wrong classification (0° vs. others). More importantly, it achieved a grand averaged BACC of 69.54% with the highest up to 74.25%, which outperformed all the other algorithms in very similar ErrPs decoding (45 ° vs. 90 ° vs. 180 °) significantly.

Conclusion: This study could provide new decoding Methods for developing the ErrP-based BCI system.

Key words: Error-related Potentials (ErrPs)；Brain-computer interface (BCI)；Shrinkage Discriminative Canonical Pattern Matching (SKDCPM)

ID 2211

适用于低像素密度 SSVEP-BCI 的编码方法研究

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目的：基于稳态视觉诱发电位的脑 - 机接口由于信息传输率高、反应速度快等优点得到了广泛应用。然而，现有的 SSVEP-BCI 多采用高强度闪烁刺激，易引起用户疲劳，制约了其进一步发展。因此，研究如何兼顾其系统的高效性和舒适性，具有重要的实用价值。

方法：本文设计了用于提升 SSVEP-BCI 舒适度的新型低像素密度编码范式，首先从刺激形式（方块与棋盘格）、像素密度（20%、40%、60%、80%、100%）以及像素排布方式（随机分布与均匀分布）三个方面设计并开展离线实验，探究最优刺激参数。随后根据离线结果搭建低像素密度 SSVEP-BCI 在线系统验证系统性能。

结果：离线实验结果显示：相较于其他刺激模式，方块范式 - 随机分布在像素密度为 60% 时显著提高了用户舒适度，分类正确率（95.05±5.78%）与 100% 时（94.58±7.06%）没有显著差异。在线实验像素密度 60% 分类正确率略高于 100%，分别为 85.73±10.94% 和 85.21±11.94%，进一步验证了离线实验的结果。

结论：综上所述，本文提出的低像素密度 SSVEP 刺激范式兼顾了系统高效性和用户舒适性，为进一步优化 SSVEP-BCI 系统的性能提供了新的思路。

关键字：稳态视觉诱发电位，脑 - 机接口，像素密度，舒适度，在线系统

ID 2620

稳固的高性能神经界面的构建

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目的：基于现有的柔性器件结构的设计优化，针对神经电极的不同应用场景（脑皮层电极、坐骨神经），构建了高性能的神经电极界面材料，并解决电极材料与电极衬底、动态组织之间粘附力较差的问题，从而实现稳固的高性能神经界面的构建。

方法：①针对脑皮层应用场景，通过微加工工艺，制备了 64 通道的超薄网格状 ECoG 器件，并利用电活性聚 5- 硝基吲哚（PIN-5NO_2）作为活性中间层，在器件的金电极上，电化学法稳固地修饰了导电聚合物 PEDOT（Au/PIN-5NO_2/PEDOT）。

②针对坐骨神经应用场景，为提升电极材料与动态组织之间的粘附力，利用两性离子单体和 PEDOT：PSS，设计制备一种可图案化、类组织弹性、导电性能良好、抗污染的多功能水凝胶电极涂层材料，实现与湿动态坐骨神经之间形成快速、导电且稳定的整合。

结果：①脑皮层电极器件能够稳定地记录脑皮层电信号并且能够捕捉外部刺激所引起的脑皮层神经电信号动态变化。

②水凝胶电极材料应用于器件上，可实现对大鼠坐骨神经的慢性调制。

结论：通过微加工对器件结构优化，并结合电极材料设计，能够构建更加稳定且高性能的神经界面

关键字：生物电子，神经界面，柔性器件，电极材料

ID 2650

Beta Synchronization of the Inhibitory Control Cortical Networks Causally Link to Response Inhibition: Evidence from Dual-site Transcranial Alternating Current Stimulation (tACS)

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Objective: Using dual-site tACS to explore the causal relationship between beta synchronized inhibitory control cortical networks and response inhibition.

Methods: A novel dual-site tACS method for exploring causality was used with a sample of 160, multiple control group and replicated experimental design. In Experiment 1, 120 healthy participants were randomly assigned to five dual-site 20Hz-tACS groups, including each phase (in-phase or anti-phase) and each network (right inferior frontal gyrus(rIFG) and primary motor cortex (M1) network(rIFG-M1), rIFG and pre-supplementary motor area(preSMA) network (rIFG-preSMA)), or sham stimulation. To validate the primary findings of Experiment 1, 40 healthy participants took part in Experiment 2 and were randomized into three groups including two in-phase 20Hz-tACS network groups and a sham stimulation group. The stop-signal task (SST) assessing response inhibition was completed for all participants during and after 20 minutes dual-site tACS. The Barratt Impulsiveness Scale was completed before the experiment to evaluate participants' impulsiveness.

Results: In Experiment 1, compared to sham stimulation group, in-phase but not anti-phase 20Hz-tACS over both rIFG-M1 network group (F1,43=6.66, p=0.01, ηp^2=0.13) and rIFG-preSMA network group (F1,43=6.14,p=0.02,ηp2=0.13) significantly improved response inhibition. The Results of Experiment 1 were repeated in Experiment 2, compared to sham stimulation group, in-phase 20Hz-tACS over both rIFG-M1 network group (rIFG-M1:F1,23=4.58,p=0.04,ηp2=0.17) and rIFG-preSMA network group (rIFG-preSMA:F1,23=4.46,p=0.05,ηp2=0.16) significantly improved response inhibition . Combining the data from the above two experiments, further analysis showed individuals with higher attentional impulsiveness greater improvement in response inhibition induced by in-phase 20 Hz-tACS in rIFG-M1 network (r=-0.53,p<0.001) and rIFG-preSMA network (r=-0.33, p=0.04).

Conclusion: Response inhibition in healthy adults can be improved by in-phase dual-site 20Hz-tACS on inhibitory control cortical networks. These Results strongly support a causal link between beta synchronization of the inhibitory control cortical networks and response inhibition, and offer new potential treatment targets of synchronized cortical network activity for patients with clinically deficient response inhibition.

Key words: Response inhibition, Inhibitory control cortical networks, Causal relationship, Beta synchronization, Dual-site transcranial alternating current stimulation

ID 2715

The Effects of HD-tDCS on the Changes of Corticomuscular Coherence after Running-Induced Fatigue

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Objective: The purpose of this study was to investigate the effect of HD-tDCS on corticomuscular coherence between EEG and sEMG signals in beta and gamma bands after running-induced fatigue.

Methods: A total of 24 healthy male college students were enrolled in this study. Subjects were randomly assigned to real and sham HD-tDCS groups and received real and sham stimulation, respectively. After the subjects wore EEG caps and wireless sEMG electrodes and warmed up, the running-induced fatigue test was performed. Immediately after the fatigue test, continuous maximum force is performed in an ankle plantar flexion-dorsiflexion exercise (this process simultaneously acquires EEG and sEMG signals). After the first trial, HD-tDCS intervention was performed. On the first day after the end of the intervention, a second trial was conducted: the procedure and duration of the run were the same as above.

EEG data selection: 8 regions of interests (FC1, FCz, FC2, C1, Cz, C2, CP1, CP2) were selected.

sEMG data selection: The tibial anterior muscle (TA), lateral and medial head of gastrocnemius were selected.

A two-way ANOVA (Stimulus condition x Time) was performed on tested variables.

Results: In the beta band: After the intervention of the real stimulation group, the coherence coefficients between EEG of C1 Cz and TA were increased significantly during the ankle joint dorsiflexion phase as compared to the sham group.

In the gamma band: After the intervention of the real stimulation group, the coherence coefficients between EEG of C1 CP1 Cz FC1 and TA were increased significantly during the ankle joint dorsiflexion phase as compared to the sham group.

Conclusion: HD-tDCS can increase the synchronization of bioelectric activity between peripheral muscles and contralateral motor cortex in beta and gamma bands after running-induced fatigue, and the central nervous system regulated motor cortex and peripheral muscle activity, resulting in increased coupling between contralateral motor cortex and peripheral muscle activity.

Key words: HD-tDCS; Corticomuscular Coherence; Running-Induced Fatigue

ID 3111

基于注意力分频卷积神经网络的脑电神经反馈方法探索

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目的：本实验室之前发展了基于认知引导的神经反馈方法，在吸烟成瘾干预上取得了显著效果，但分类性能仍不够理想。发展有效提取和整合多频段脑电特征的模型是提高分类准确率的关键。因此，我们提出一种可以应用于脑电神经反馈任务的分频神经网络，旨在通过提高神经反馈准确率进一步改善其在脑疾病干预上的效果。

方法：本研究发展了一种基于注意力机制的分频卷积神经网络。该网络使用分组卷积提取多频段脑电特征，使用通道和频段注意力模块融合不同频段信息，从而实现对大脑认知状态的高精度识别。首先在吸烟成瘾数据集验证了本文提出的方法，对成瘾线索和中性线索诱发的脑电活动模式进行分类，并与原工作中 SVM 算法进行比较。进一步，在十名被试的睁闭眼实验中验证模型在实时神经反馈任务中的有效性。

结果：本方法在吸烟成瘾数据集的平均准确率从之前的 66.4%（±9.4%）显著提升到 79.9%（±10.4%）（t=-4.1，p=0.002）。此外，睁闭眼实验的离线准确率平均达到 98%，实时神经反馈调控的准确率最高达 90%。

结论：基于注意力分频卷积神经网络表明了多频段信息对脑状态离线和在线识别的重要性，并为发展基于人工智能算法的神经反馈平台及其在脑疾病的干预提供新方法。

关键字：脑电；神经反馈；神经网络；注意力机制

ID 3312

低强度超声在大鼠感觉皮层通过神经 - 血管通路诱发血流动力学响应

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目的： 在大鼠感觉皮层上探究 LIUS 是否通过 NVC 通路引起血流响应

方法： 大鼠 (n=20) 被随机平均分为实验组和对照组。本研究使用丙戊酸钠 (Sodium valproate,VPA)，增强抑制性神经元表达从而降低皮层整体神经元活性。LIUS 前十分钟对实验组大鼠腹腔注射 200 mg/kg VPA 溶液，对照组注射等量生理盐水。使用针状微电极和激光散斑对比成像技术分别记录麻醉静息状态下、LIUS 前和 LIUS 后局部场电位 (Local field potential,LFP) 和血流（Cerebral blood flow，CBF）信号。

结果： 实验结果表明，两组 LIUS 前后 CBF 变化存在显著交互效应（CBF*Group：F = 29.7, p=2.42 * 10-7）。实验组：LIUS 未能引起 LFP 和 CBF 信号统计上显著变化；对照组：LIUS 引起两种信号统计上显著变化（LFP：p = 0.029；CBF：p=7.17 * 10-6），且对照组在 LIUS 前后信号呈正相关（r=0.552, p=0.049），异于实验组的负相关（r=-0.143, p=0.6928）

结论： 为 LIUS 由 NVC 通路调节血流动力学响应提供了直接的证据。

关键字： 低强度超声、血流动力学、局部场电位、神经血管耦合

ID 3341

基于多元全局同步指数的皮质肌肉耦合分析

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目的： 皮质肌肉耦合分析能够有效探究不同任务状态期间的脑肌同步关系，被视为量化大脑皮层与肢体肌肉间信息交互作用强度的重要标志物。本文提出多元全局同步指数分析方法，从全局层面衡量多通道脑肌电信号间的局部频段同步特征，进而探究任务执行期间大脑运动感觉区及相应肢体肌肉间的信息交互关系。

方法： 采集 12 名健康被试在不同重量物体“伸取 - 抓握 - 提起 - 维持 - 放下”任务过程中的多通道脑肌电数据，基于二元同步分析方法计算不同通道信号间关联强度并构建相关矩阵，并进行矩阵变换得到仅包含脑肌间同步关系矩阵，进一步计算其对应熵值，探究特定任务下多通道脑肌电信号间的同步关系。

结果： 相较于静态维持任务，动态抓握任务下 beta（12-30 Hz）及 gamma（31-45 Hz）频段的皮质肌肉耦合具有更高的同步指数。此外，所有被试在低重量任务期间表现出更高的耦合程度，且 beta 频段下同步指数更高。

结论： 多元全局同步指数方法能够定量描述多通道脑肌电信号在特定频带下的同步耦合特征，有助于理解运动控制机制并为评估患者康复状态提供一定的理论基础。

关键字： 皮质肌肉耦合；多通道脑电；多通道肌电；局部频带

S04
康复工程——“新理念、新方法、新进展”
Rehabilitation Engineering –“New Ideas, New Methods, New Progress”

ID 174

老年人智能洗浴辅具及机器人研究进展

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目的：我国有失能、半失能老年人约 4000 万，而在这其中有 90% 的老年人存在洗浴失能。由此，本文在国家重点研发计划课题的支持下，系统性的梳理了老年人洗浴辅具及机器人的国内外研究现状，并结合课题组前期研究，提出了一种可实现多位姿转换、多角度喷淋及辅助擦洗的智能洗浴机器人系统。

方法：通过国内外文献梳理，厘清了老年人洗浴辅具及机器人的研究现状。进一步，针对现有洗浴辅具姿态转换困难、喷淋范围有限、缺乏辅助擦洗等问题，提出了一种智能洗浴机器人系统，并对其结构设计、控制系统、样机试验等依次进行了仿真分析和样机实验。

结果：本文所研发的智能洗浴机器人集多位姿洗浴椅多角度喷淋臂为一体，采用模块化设计，可以有效的解决半失能老年人洗浴过程中的姿态柔顺转换、多角度喷淋、辅助擦洗等问题，具有安全、高效、智能等特点。仿真分析、假人样机实验、真人实验等结果验证了设计的有效性、可行性及安全性。

结论：积极应对人口老龄化国家战略，研发老年人洗浴机器人是极为必要的。本文研发的智能洗浴机器人可以为未来半失能老年人洗浴提供技术手段和理论基础，对于提高老年人生活质量，降低护理人员的劳动强度具有积极的意义。

关键字：老年人、洗浴、机器人、半失能

ID 570

Pulse Wave Characteristics as New Indexes to Evaluate Musculoskeletal Injury and Response

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Objective: This study was aimed to investigated whether enhanced external counterpulsation (EECP) can promote recovery of exercise induced muscle damage (EIMD). Additionally, we aimed to explore that whether arterial pulse characteristics can be a new non-invasive index to evaluate the responses of EIMD.

Methods: Ten healthy male volunteers (n=10), ranging from 25 to 31 years old were enrolled in this study. The experiment was conducted by Cardiopulmonary exercise test (CPET). The incremental rate was 20-30W/min until individual exhaustion. Arterial pulse waveforms were monitored during the whole process. The blood collection was conducted at baseline, at peak exercise and 2min before the treatment of EECP and 60 min during EECP treatment. Aspartate aminotransferase (AST) and creatine kinase (CK) were detected using an automatic biochemical analyzer and a corresponding kit. The data segment and feature extraction were conducted at each measurement point. The systolic blood pressure (SBP), ratio of notch peak and systolic peak (P0/P1), △ TBVP (time difference between notch and peak), the ratio of diastolic area (S3) and total area (S4) of each waveform were calculated.

Results: CK and AST were significantly decreased (both p<0.01) and recovered to baseline level after 60min-EECP intervention (CK: 49.26±11.93 vs. 45.21±11.08, p=0.431; AST: 17.71±2.28 vs. 21.53±6.33, p=0.102). TBVP (0.38±0.03 vs. 0.30±0.04, p=0.002), while P0/P1 (0.70±0.08 vs. 0.82±0.03, p=0.009) markedly reduced after 60min EECP compared with baseline. S3/S4 (0.39±0.13 vs. 0.11±0.08, p=0.000) were significantly increased, while SBP (120.20±9.33 vs. 167.76±21.86, p=0.000) markedly decreased after 60min-EECP compared with before EECP. In addition, △ TBVP are obviously related with AST (r=0.302, p=0.003) and CK (r=0.317, p=0.002).

Conclusion: This study found that both blood markers and pulse wave characteristics improve the EIMD after 60min EECP intervention. Moreover, The non-invasive pulse wave characteristics such as △ TBVP can be used as a new kind of indexes to assess the response of EIMD after EECP intervention.

Key words: Exercise induced muscle damage; Enhanced external counterpulsation; Blood marker; Pulse wave characteristics; Injury recovery.

ID 597

数字医学与 3D 打印技术在脊柱外科矫形辅具领域的创新与临床转化

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目的：以转化医学的视角，对数字医学在脊柱外科矫形辅具领域的临床转化进行系统阐述。

方法：对上海交通大学数字医学工程中心以及当今发展迅速的 3D 打印技术应用于脊椎外科特发性脊柱侧弯、颈椎病等疾病的矫形治疗进行介绍与展望。

结果：上海交通大学数字医学临床转化教育部工程研究中心作为国内第一家聚焦于“数字医学”创新研究与临床转化的工程研究中心，已建立了医学内植物数字化技术、数字化外科手术和数字化物理治疗装备三大技术研发与服务平台。民政部智能控制与康复技术重点实验室则是以 3D 打印康复辅具、康复机器人技术与装备研究等为重点研究领域的实验室平台。上海交通大学医学院附属第九人民医院、上海交通大学戴尅戎院士团队也获得国内第一个 3D 打印医疗器械注册证，也是注册人制度下科研机构申请到的国内首张医疗器械注册证。同时参与制定 3D 打印矫形器通用技术规范，从临床、注册、转化、应用等方面全方位开展 3D 打印康复辅具技术。

结论：数字骨科与 3D 打印技术在脊柱外科矫形辅具领域的临床转化已经进入关键阶段，需要产学研管用等全产业链整合与推进。

关键字：数字医学；3D 打印；特发性脊柱侧弯；康复辅具；临床转化

ID 671

Sensorimotor Cortical Activities Induced by NMES During INB

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Objective: Ischemic nerve block (INB) can successfully separate muscle spindle afferents from sensory afferents evoked by neuromuscular electrical stimulation (NMES) above motor threshold. The purpose of this study is to explore how the sensorimotor cortex perceives the incoming muscle spindle afferents evoked by NMES above motor threshold during INB.

Methods: An experimental protocol was composed by four tasks conceived according to a 2 × 2 factorial design. In particular, the first factor was the INB state (Before INB and during INB) and the second factor was the NMES intensity (Sup- and sub-motor threshold). During the tasks, 64-channel EEG signals were record and analyzed to detect beta event-related desynchronization (Beta ERD) for quantizing the activation level of sensorimotor cortex. The psychophysical test was used to assess changes in sensation and movement of the right hand when the right wrist was blocked by the blood pressure cuff. At the same time, active and passive index finger flexion and extension tasks were set before and during INB.

Results: During INB, beta ERD on the contralateral sensorimotor cortex induced by NMES with the sup-motor threshold was significantly decreased, and the difference of beta ERD values on the contralateral sensorimotor cortex induced by NMES with sup- and sub motor threshold was significant. In addition, contralateral dominance of beta ERD on the sensorimotor cortex induced by NMES was transferred to ipsilateral during INB. INB significantly reduced sensorimotor cortical activity induced by NMES with the sup-motor threshold and decreased its perception on the stimulus intensity, which may result from the rapid functional reorganization of the sensorimotor cortex induced by INB.

Conclusion: Therefore, the Results of this study may provide some references for the sensorimotor cortex to perceive the current intensity of NMES above motor threshold inducing hand proprioception, which show a potential value in investigating the sensory feedback of hand prosthesis.

Key words: ischemic nerve block, neuromuscular electrical stimulation, sensorimotor cortex, muscle spindle afferents

ID 808

偏瘫后踝足神经肌肉控制障碍肌电溯源分析

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目的：使用动力学网络肌电溯源技术，观察偏瘫患者在静止站立时的小腿表面肌电网络特征，定位定量分析小腿肌肉控制障碍。

方法：以表面肌电时频域指标均方根值（RMS）、中位频率（MF），网络指标平均层间互信息（I）、平均边缘覆盖率（W）、聚类系数（C）、平均最短路径长度（L）及度中心性（DC）为指标，对 14 例脑卒中男性患者和 10 例年龄、

性别匹配的健康男性静止站立位时，双侧小腿 8 组肌肉神经肌肉控制特征进行比较。

结果：非患侧胫骨前肌、腓肠肌内侧和比目鱼肌 RMS 均高于患侧；I、C 及 W 均高于患侧和对照组，L 低于患侧和对照组；腓肠肌外侧，腓肠肌内侧和趾长伸肌 DC 值均高于患侧；胫骨前肌和趾长伸肌 DC 值高于对照组，以上差异均具有统计学意义（P ＜ 0.05）。患侧腓肠肌内侧 RMS 值低于对照组；趾长伸肌的 MF 较非患侧和对照组低；腓肠肌内侧 DC 值低于对照组，差异具有统计学意义（P ＜ 0.05）。

结论：偏瘫患者患侧易出现腓肠肌及趾长屈肌瘫，肌电溯源技术可以通过线性和网络肌电指标，对每个目标肌肉的神经肌肉控制障碍进行精准的靶向分析诊断。

关键字：脑卒中 表面肌电图 运动控制 评估

ID 823

The Effects of Low Frequency Repetitive Transcranial Magnetic Stimulation on Upper Extremity Motor Recovery Following Stroke: Evidence from Motor Executive and P300 Brain Signals

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Objective: Repetitive transcranial magnetic stimulation (rTMS) has shown its potential for facilitating motor recovery in stroke patients. Low-frequency rTMS (<= 1 Hz) to contralesional M1 in hand motor recovery at the post-acute stage has obtained level A evidence. However, it lacks solid brain imaging evidence for motor recovery after low frequency rTMS intervention, and whether cognitive function would be simultaneously affected by rTMS on M1 remains unknown.

Methods: In this study, we recruited 22 post-stroke patients with upper extremity deficits who received two-week low-frequency rTMS sessions (30 minutes a session and one session per day) in a hospital. Throughout the entire experiment, electroencephalograph (EEG) signals were recorded from patients while they performed several tasks: resting state (close and open eye) and motor executive (ME) for measuring motor function, as well as a visual active oddball task for measuring attention and working memory function. Fugl Mayer Assessment and Barthel scales were used to evaluating the rehabilitation effects after rTMS intervention sessions

Results: The Results showed an obvious increase (around 5 to 8 scores) in the Fugl-Meyer Assessment Upper Extremity subscore but not the Barthel. We inspected significant interaction between tasks (ME vs. oddball) and the according sessions (before rTMS vs. after rTMS), in terms of EEG. The somatomotor responses of the ME task after rTMS were stronger than those before the rTMS intervention. However, the P300 amplitudes did not show a significant difference.

Conclusion: In conclusion, both questionnaire and brain imaging Results demonstrate the efficacy of low-frequency rTMS on motor recovery. In addition, the dissociation of EEG signals between ME and oddball tasks suggests the specificity of rTMS on motor function.

Key words: Repetitive transcranial magnetic stimulation, Stroke rehabilitation, Motor executive, P300, EEG/ERP

ID 840

Peripheral Muscle Fatigue Detected by Near-Infrared Spectroscopy and Surface Electromyography

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Objective: The purpose of this study is to explore the development of peripheral muscle fatigue using both near-infrared spectroscopy (NIRS) and surface electromyography (EMG) measurements, as well as exploring the relationship between the fatigue-assessment parameters derived from NIRS and EMG signals.

Methods: Fifteen young and healthy subjects were recruited. During the experiment, the subject was asked to perform three trials of plantarflexion exercise with 70% maximum voluntary contraction (MVC). Each trial is composed of 10-cycle isometric contraction, with the durations of contraction and relaxation both being 10 s. NIRS and EMG signals of gastrocnemius medialis (GM) and lateralis (GL) were simultaneously recorded during all three trials. The MVC force after each exercise session was also measured to reflect the fatigue level. The oxygen consumption rate (RO2) and peak oxygen extraction (PKV) were obtained from the NIRS-derived deoxygenated signals. The root mean square (RMS), integrated EMG (iEMG) and median frequency (MDF) of EMG signals were also calculated for analysis.

Results: showed that both RO2 and PKV values presented an increasing trend as contraction continued in all three exercise trials of GM and GL. The MDF value showed a decreasing trend during each exercise in both GM and GL muscles, while RMS and iEMG only had a raising trend in GL muscle. Correlation analysis indicated that on one hand, the amplitude-related parameters of EMG signal (RMS and iEMG) displayed significantly high positive correlations with the NIRS parameters (RO2 and PKV). On the other hand, the frequency-relevant variable of EMG (MDF) presented significantly high negative correlations with the NIRS-derived PO2 and PKV.

Conclusion: These Results demonstrate that NIRS method can directly detect the transition from the fast-twitch fibers to the slow-twitch fibers during the peripheral fatigue process. The combination of NIRS and EMG measurements can be used to comprehensively evaluate the development of peripheral muscle fatigue.

Key words: peripheral muscle fatigue, near-infrared spectroscopy, surface electromyography

ID 1154

踝 - 距下关节不稳导致骨性关节炎的动物模型研究

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目的：踝关节扭伤是日常生活中最常见的运动损伤之一，我们拟创建的踝 - 距下关节不稳的小鼠动物模型，探究踝关节不稳损伤如何影响影响踝关节、距下关节和周围邻近关节，厘清踝 - 距下关节复合体生物力学的耦合机制和骨关节炎的发生机制。

方法：将 21 只 C57BL/6J 随机分为三组：假手术组、切断颈韧带 + 距腓前韧带（CL+ATFL）组和切断颈韧带 + 三角韧带 +(CL+DL) 组。平衡木和步态测试用来评估小鼠运动情况的改变。Micro-CT 和组织染色用来评估 OA 的进展。

结果：在术后 12 周的测试中 CL+ATFL 组通过平衡木的时间比术前增加了 35.1%，滑落次数是术前的 3.6 倍；CL+DL 组通过平衡木的时间比术前增加了 32.1%，滑落次数是术前的 3 倍。CT 三维重建结果显示 DL+CL 组约有 28.6% 的小鼠

发生了距骨脱位，并且韧带切断组有明显的骨赘生成。组织染色也提示小鼠出现关节软骨的退变。

结论：踝关节韧带损伤会引起小鼠踝 - 距下关节机械性不稳，情况严重时小鼠还会出现距骨脱位导致踝 - 距下关节骨性结构的稳定受到破坏，踝关节不稳如果没有及时进行干预治疗，随着时间的增加，关节软骨会出现退行性改变从而影响运动。

关键字：踝关节、创伤性骨关节炎、小鼠动物模型

ID 1166

步行中躯干姿势和足底支撑状态变化对下肢关节影响的 生物力学研究

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目的：膝关节内收力矩（KAM）是步行过程中膝关节负荷分布的一个有效指标，且与膝关节骨性关节炎的严重程度、病程进展相关。本文通过改变人体躯干姿势和足底支撑状态，降低 KAM，并分析对下肢各关节的影响。

方法：选 10 名年龄为 20-30 岁的健康受试者参与实验，使用三维动作捕捉系统、测力台装置，采集正常行走步态（NW）、躯干前倾 (KW)、穿用摇摇鞋 (NY) 三种步态的运动学、动力学数据，导入 AnyBody 软件中计算下肢关节力矩、冲量矩，采用统计参数映射方法（SPM）对数据进行对比分析。

结果：对比 NW 组，KW 组，KAM 第一、第二峰值分别减少 13.10%、15.55%；KAM 冲量矩减少 7.31%，矢状面内的膝关节冲量矩增加，冠状面、横断面内均减少；髋、膝、踝三个关节的整体冲量矩均为增加。

对比 NW 组，NY 组，KAM 第一、第二峰值分别减少 24.60%、4.20%；KAM 冲量矩减少 11.14%，矢状面内的膝关节冲量矩增加，冠状面、横断面内均减少；膝、踝关节的整体冲量矩均增加，髋关节略有减少。

结论：通过调整，KAM 第一、第二峰值均减小，由矢状面代替冠状面承载；KAM 冲量矩均减小，载荷由髋关节、膝关节矢状面、踝关节共同承担。

关键字：关节力矩；步态分析；逆向动力学；骨性关节炎；生物力学

ID 1609

Brain-Computer Interfaces in Disorders of Consciousness

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Objective: The development of brain-computer interfaces (BCIs) has established a new communication channel between the brain and external devices for information transmission that requires no muscular signals. An emerging feld of such research involves patients with disorders of consciousness (DoCs), in which BCIs can act as diagnostic, communication, and rehabilitation tools.

Methods: We searched using the term "brain-computer", "P300", "SSVEP" and "disorders of consiousness" in Pubmed, Medline, and Cocharane databases. Finally, 13 articles were included and summarized.

Results: Through the comparison, the application of audio-visual multimodal P300 is relatively more promising. Howev-

er, due to the fuctuation of consciousness in patients with DoCs and the short time period during which patients focus their attention, it is difcult to achieve performance consistency in the BCI paradigm. Currently, the complex paradigm takes an extensive amount of time for training.

Conclusion: Although many studies have shown that BCIs have been successfully applied to patients with DoCs, the high false-negative rate of BCIs cannot be ignored. When designing a BCI for the diagnosis of patients with a DoC, the use of more accurate techniques for judging the patient's state of consciousness should be considered.

Key words: disorders of consciousness, coma, brain-computer interfaces

ID 1779

基于多重递归网络的 GCST-A2 力学模型对下肢神经肌肉动态稳定控制影响研究

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目的：本团队研发的下肢姿势控制再学习治疗力学模型——姑苏约束性站立训练（Gusu Constraint Standing Training，GCST），取得了一定的临床疗效。然而，GCST 力学模型对下肢神经肌肉动态稳定控制的影响尚未进行探究。

方法：招募了 14 名健康志愿者进行静止、20° 和 25° GCST-A_2 步骤站立。应用非线性动力学网络算法——多重递归网络，处理站立过程中采集到的臀部、大腿及小腿 16 块肌肉的表面肌电信号，并提取相关网络参数，评估多肌肉间的动力学协同特性。

结果：受试者在 GCST-A2 步骤站立时，下肢肌肉整体协同性会显著提高，这种变化一部分来源于对单下肢控制的增强，尤其是对优势侧下肢的主动控制，另一部分来源于对下肢间控制的增强；臀部、大腿及小腿前部的肌肉协同参与度提高，其中股内侧肌、股外侧肌和胫骨前肌显著提高，臀中肌轻微提高。

结论：在 GCST-A2 力学模型中，受试者在持续的后上方牵拉力干预下，为了维持直立稳定，通过中枢姿势控制调整，靶向地激活了臀部、下肢前部肌肉，提高了下肢多肌肉整体控制的协同性，从而实现了对姿势的动态稳定控制。

关键字：约束性站立训练；多重递归网络；神经肌肉控制

ID 1835

多通道电触觉刺激重建假肢腕屈伸感觉实验研究

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目的：本文拟研究一套多通道电触觉刺激编码方案，将假肢腕关节的屈曲 - 伸展（FE）位置和运动信息回传给人体。

方法：我们开发了一种时空分布的电触觉方案来编码假肢腕的屈伸位置和运动，并设计了一个集成的实验平台，

招募了 5 名健康被试和 2 名残疾被试开展验证实验。对感觉阈值和不适阈值进行了初步实验。然后，进行了位置感觉实验（实验 1）和运动感觉实验（试验 2）。每个实验包括学习环节和测试环节。分析成功率（SR）和辨别反应时间（DRT）以评估识别效果。通过问卷调查评估了电活动方案的接受程度。

结果：我们的结果显示，5 名健康受试者（截肢 1 和截肢 2）的平均位置 SR 分别为 83.78%、97.78% 和 84.44%。5 名健康受试者的平均运动 SR、手腕运动的方向和范围 SR 分别为 76.25% 和 96.67%。截肢者 1 和截肢者 2 的运动 SR 分别为 87.78% 和 90.00%，方向和范围 SR 分别为 64.58% 和 77.08%。5 名健全受试者的平均 DRT 小于 1.5 秒，截肢者的平均 DR 小于 3.5 秒。

结论：结果表明，经过短时间的学习，受试者可以感知手腕 FE 的位置和运动。所提出的替代方案有可能让截肢者感知假肢手腕，从而增强人机交互。

关键字：本体觉，假肢，腕，电触觉

ID 1922

自供能医疗器件和神经电刺激

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目的：电活动是人体生命活动的基础，电刺激可以改变神经兴奋和抑制的状态，从而实现疾病的治疗。

方法：纳米发电机是一种可将低频机械能转换为电能的新型能源转换器件，并且因为器件结构多样、可柔性化、可纺织、可选择的材料多种多样、输出电压高等优点，获得了研究者的关注。我们通过纳米发电机将人体运动的机械能高效的转换为电能并给电刺激器件供电，构建自供能的电子医疗器件，开展了神经电刺激的研究工作。

结果：所构建的神经电刺激装置，具有柔性、便携式、可长期工作、自供电和良好的生物相容性等优点。同时，由于构建的是闭环式的低水平迷走神经电刺激系统，我们的神经电刺激装置没有副作用，达到了实现治疗同时又减少了神经刺激并发症的风险的目的。

结论：我们的研究工作围绕自供能电子医疗器件和神经电刺激治疗，在面向慢性节律性疾病的管理和治疗问题上具有重要的潜力。

关键字：神经电刺激；纳米发电机；自供能

2095

基于扫描几何数据缩放的足部重建方法及有限元建模

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目的：足踝复合体有限元模型可评估足部对各种外部载荷的生物力学响应，并用于足矫形器优化设计，但模型开发过程耗时和昂贵。本研究拟采用足扫描数据，建立并验证基于足表面标志点缩放的足踝有限元模型。

方法：实验采集了 6 名受试者的足表面数据（12 个足），来进行有限元建模。研究选取 Glasgow-Maastricht 足部模型（包括足表面数据和骨几何数据）作为参考模型，扫描足表面数据为目标模型。在足表面参考模型和目标模型分

别选取对应的骨标志点，建立个性化缩放函数。同时，基于参考模型骨几何数据，通过缩放函数得到目标模型的足部骨几何数据。研究分析了缩放的足表面与扫描足表面的几何误差，并比较了有限元模型和实验数据的足底压力最大值。

结果：缩放足与扫描足之间的最大距离为 9.6 ± 2.8 mm。测量和预测值的足底压力峰值呈显著线性相关（R2 = 0.77; p <0.001）。

结论：本研究建立了基于扫描几何缩放的足部有限元模型，并对模型预测的足底压力进行了验证，此方法有潜力应用在矫形鞋垫的个性化优化设计中。

关键字：足踝复合体；数值分析；非线性缩放

ID 2112

Tailoring rTMS Therapy Based on Personalized Neural Reorganization: Towards Individualized Treatment for Stroke Patients

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Objective: Repetitive transcranial magnetic stimulation (rTMS) has been proven a promisingly potential therapeutic intervention for stroke patients' neural rehabilitation. However, in the face of patients' various individual differences, the clinical effects of neural modulation therapy vary greatly among patients, and it is confusing to further improve its efficiency. This study aimed to explore the hypothesis that tailoring individualized neural modulation therapy according to different types of neural reorganization patterns promisingly contributes to stroke patients' motor rehabilitation.

Methods: We randomly applied three kinds of rTMS treatments on nineteen subacute stroke patients and observed their cortical activation changes after the 2-week neural modulation therapy. rTMS treatments consisted of ipsilesional activation, contralesional suppression and ipsilesional suppression. Motor imagery tests with EEG recording and Fugl-Meyer assessment were conducted on the day before and after the 2-week rTMS therapy. Event-related desynchronization (ERD) analysis was used for motor-related cortical activation analysis. In the comparative analysis before and after the intervention, patients were grouped by intervention or lesion side respectively.

Results: Neural reorganization patterns showed the characteristics of individual differences. Patients with motor cortex lesion mostly showed contralesional recruitment and patients without motor cortex lesion mostly presented ipsilesional focusing. Neural modulation treatments also showed individual effects on brain activation pattern changes. rTMS can effectively enhance the motor-related cortical activation but is hard to reverse the neural reorganization tendency.

Conclusion: Stroke patients with different neural reorganization patterns responded differently to rTMS therapy. Tailoring personalized rTMS therapy by recognizing neural reorganization patterns and lesion location is promising for the improvement of rTMS effectiveness in clinical use. This study provides a novel perspective in personalized trajectory to precision rehabilitation medicine.

Key words: Repetitive transcranial magnetic stimulation; Neural reorganization; Personalized treatment; Stroke rehabilitation; Electroencephalography

ID 2997

点击化学法构建工程化细胞外囊泡用于神经修复

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目的：中枢神经系统损伤，包括中风、脑外伤、脊髓损伤，是导致死亡和长期残疾且难以治愈的重要原因，这主要是由于神经修复的两大障碍——神经元再生有限和星胶疤痕的形成。因此，触发内源性神经干细胞并刺激它们产生新的神经元是一种有效的治疗策略。

方法：因此，M2 小胶质细胞分泌的细胞外囊泡（Extracellular vesicles, EVs）被应用于改善损伤部位干细胞分化微环境，并通过无铜点击化学法在其表面同时修饰损伤血管靶向多肽 DA7R 和干细胞募集因子 SDF-1，以此发挥对干细胞的有效募集作用，并通过诱导神经干分化为神经元，在损伤部位充当纳米导弹（Dual-EV）。

结果：结果证明，DA7R 和 SDF-1 被成功修饰在 EV 表面，并且修饰后的 Dual-EV 具有靶向 HUVECs 和募集 NSCs 的能力，并能促进 NSCs 的体外分化。生物信息学分析表明，M2-EV 表达丰富的 miRNA 与 NSC 神经元分化有关。体内实验结果表明，Dual-EV 可有效地靶向脑卒中模型小鼠缺血区，减少了脑萎缩体积，增强了体内 NSCs 的募集，增加了神经发生。

结论：这项工作为神经损伤后的神经元再生治疗提供了启示。

关键字：细胞外囊泡、点击化学、神经修复、卒中

ID 3054

虚拟环境中多感觉刺激的神经响应及行为表征

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目的：虚拟现实技术利用计算机模拟产生一个完全虚拟的数字化环境，可为使用者提供视觉、听觉、触觉等多感官的交互体验。近些年，围绕虚拟现实技术的优势，涌现出众多具有高沉浸感、强交互性的康复任务，并在临床应用中取得了积极的干预效果。脑卒中后的康复治疗主要是基于中枢神经系统的可塑性理论，通过引导患者的运动再学习，促进他们的运动和认知功能重建。然而，虚拟现实提供的多感觉刺激是否会有效的激活大脑运动和感觉皮层的神经响应，进而促进患者功能表现的恢复，仍鲜有研究报道。

方法：本研究开发了肢体匹配、物体定位等虚拟康复任务，通过对视觉呈现（如颜色、深度等）和触感输入（如碰撞、震动等）的量化编辑，实现视觉、触觉和力觉的精确调控。

结果：通过联合分析受试者的脑电、肌电和运动行为的特征，明确多感觉刺激下的神经表征及运动表现。

结论：为虚拟现实技术更加有效的应用于脑卒中的康复治疗提供了理论依据。

关键字：虚拟现实；神经表征；运动表现

ID 3122

A Study on Soft Hand Rehabilitation Robot for the Relief of Hand Spasticity

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Objective: Hand spasticity, as a common complication of stroke patients, is extremely difficult to treat. The stretching training assisted by rehabilitation physicians is the most commonly used physical method to alleviate spasticity. The shortage of rehabilitation physicians in our country offers an opportuntiy to the application of rehabilitation robots (RehaRot) in the clinical practice. However, the sudden appearance of spasticity during stretching can hamper hand RehaRot training. A new type of soft hand RehaRot (SHRehabRot) is a good choice. However, its output force is too small to meet the clinical needs. This Objective of study is to provide a SHRehabRot that may alleviate hand spasticity.

Methods: Based on the clinical characteristics of hand spasticity after stroke, the design requirements and the overall design scheme of the SHRehabRot were determined. After it, a soft actuator with a large output force was designed (a bending force of about 22 N under 0.1 MPa). Based on this, SHRehabRot, which was adapted to the individual characteristics of hand spasticity, was developed. Then, an EEG experiment, in which eight subacute stroke patients with hand flexor spasticity were recruited for hand stretching training, was carried out. Six patients of all patients carried out a two-week rehabilitation training.

Results: The experiment's result showed that hand stretching training led to a significant decrease in the power of contralesional primary sensorimotor cortex (S1-M1, p=0.03) and ipsilesional S1-M1(p=0.048) in the sub-alpha band compared with pre-training. The MAS score of six patients after two weeks of rehabilitation training decreased significantly compared with that before training (p<0.05).

Conclusion: This study can provide a SHRehabRot that may alleviate hand spasticity by activating S1-M1, thus promoting the adaptive plasticity of S1-M1.

Key words: Hand spasticity, stretching training, soft hand rehabilitation robot, the activation of S1-M1

ID 3148

轮椅运动上肢肌肉疲劳检测与预测

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目的：在轮椅运动依赖于上肢肌群的力量，运动过程中产生的运动疲劳可能会导致运动损伤，对轮椅使用者产生二次伤害。本研究的目的是识别早期运动疲劳，并应用机器学习算法对运动疲劳进行预测。

方法：本研究邀请了了 11 位轮椅使用者参与研究。受试者在轮椅跑台上进行递增负荷测试，要求受试者在 8-12 分钟内到达最大摄氧量，每隔一分钟功率增加 5W。同时采集了右侧肩部三角肌前部、中部、后部、肱二头肌、肱三头肌、胸大肌、斜方肌上部、冈下肌等 8 块肌肉的表面肌电信号和摄氧量信号（氧气、二氧化碳含量）。本研究采用的

疲劳阈值为通气域（VT）和肌电阈（EMGT）。采用 Bland Altman 一致性分析与组间相关分析对两种检测方法进行了一致性分析并对不同肌肉的疲劳阈值进行了相似度检验。最后采用支持向量机算法对通气域和肌电阈进行了预测。

结果：肌电阈值和通气阈值之间具有良好的一致性。八块肌肉的肌电阈值相似性很高（ICC = 0.91）。八块肌肉的肌电信号的预测效果最好，准确率为 97%，摄氧量和二氧化碳排出量的预测准确率为 91%。

结论：采用表面肌电信号可以有效的对上肢运动的肌肉疲劳进行检测与预测，为下一步实时监测肌肉疲劳系统的开发奠定了基础。

关键字：表面肌电；运动疲劳；通气阈；肌电阈；支持向量机

ID 3275

多模态运动功能障碍监测与辅助系统

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目的：我国有大量的下肢运动功能障碍者，如何科学地帮助患者进行下肢运动功能康复成为了亟需解决的重大民生问题。患者的康复训练不仅需要对其行走时的多模态运动参数进行监测，也需要提供重力支持与保护。现有类似的系统存在如下几个问题：第一，整个系统功能模块较多，需要监测的信息很多，多数系统仅仅是不同产品的整合，这造成每个模块之间的信息难以交互或同步；第二，硬件设备与系统平台大都依赖进口且价格昂贵。

方法：针对上述两个问题，本研究研发了一款多模态运动功能监测与辅助的集成系统，系统包括了重力辅助、肌电采集传感、惯性传感、足底压力传感、动作捕捉、多通道电刺激发生等 6 个主要模块。

结果：本研究自主开发了各模块的硬件设备与软件集成平台，初步实现了国产化替代。各模块每小时的累计通讯同步误差在 1ms 以内，硬件设备的主要性能指标与现有进口相应产品相当。此外，系统配有常用分析软件，可实现包括多模态信号实时显示、特征提取、运动神经元分解、肌协同分析、运动状态分析、步态周期分析等常用功能。

结论：本研究可为下肢运动功能障碍者的康复训练提供硬件与软件支持，为我国康复医学的发展作出贡献。

关键字：康复系统、下肢运动功能、多模态信号采集、运动分析算法

ID 3384

Effects of Foot Orthosis on Pediatric Flexible Flatfoot

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Objective: Orthotic shoes and insoles for flexible flatfoot are widely used in school-age children to recreate the medial arch and hold the foot in an anatomically correct position during activities. Foot supports directly act on the foot, affecting the motion of the foot and ankle, but may also have consequence on the lower limb. This project is to evaluate the effects of the orthotic shoes and insole on the joint motion of the lower limb in adolescent flexible flatfoot.

Methods: Fourteen children with flexible flatfoot were recruited in participation in gait analysis experiment. They claimed with no history of injuries or pathologies in the lower limbs except for the deformity of flatfoot. Two types of shoes and insoles were prepared including orthotic shoes and insole, deck shoes and flat insole. They formed four foot support conditions and the deck shoes and flat insole were set as control condition. Oxford model was used to define the musculo-

skeletal system of the lower limb. Subjects were asked to walk in their nature speed.

Results: Comparison among four support conditions were conducted to demonstrate the combined function of orthotic shoes and insole and single function of each of them. Parameters analyzed included motion angles of the ankle, the knee and the hip joints and the motion angle between the fore-and hindfoot in three planes. Paired t test was used to analyze the differences.

Conclusion: The orthotic shoes and insole were found to have significant effects on the rotation of joints that the combined function of the orthotic insoles and orthotic shoes decreased the knee joint inversion and ankle abduction. The orthotic insole independently resulted in decrease of the degree of ankle dorsiflexion and ankle inversion and abduction of the forefoot. The orthotic shoes functioned independently had no significant effects on the joint motions.

Key words: Adolescent flexible flatfoot; Foot orthoses; Orthotic shoes and insoles; Biomechnics; Gait analysis.

ID 3530

Prediction of Jaw Opening Functions after Mandible Reconstruction via Subject-Specific Biomechanical

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Objective: To validate the predicted mandibular movements after mandibular reconstruction predicted by a subject-specific musculoskeletal model and to analyze the influencing factors of prediction accuracy.

Methods: Ten patients requiring mandibular reconstruction were enrolled. The patient-specific CBCT images, mandibular movement, and surface electromyography (sEMG) of masticatory muscles were recorded before the surgery. Based on the measured data, a subject-specific mandibular musculoskeletal model was established to predict surgical outcomes. Here, the mandibular bone geometry was replaced by surgical planning results, and the muscle insertion sites were registered based on the non-rigid iterative closet point (NICP) method. The changes in muscular geometric and biomechanical parameters were averaged by each patient. The predicted mandibular trajectories were validated by the corresponding data measured six months after the surgery. Patients' clinical information, including age, pathology, and surgical scope, was investigated to analyze influencing factors of prediction accuracy.

Results: The root-mean-square error (RMSE) of the lower incisor displacement was 31.4%, and the error of the peak magnitude of jaw opening was 4.9mm. The patient's age, postoperative infection, and radiotherapy influenced the prediction accuracy. The amount of masseter detachment shows little correlation with the jaw opening magnitudes.

Conclusion: The proposed mandibular musculoskeletal model successfully predicted jaw opening functions in the short range after mandibular reconstruction. It proved a valuable method for surgical planning and investigating factors for trismus prevention.

Key words: Musculoskeletal model; Subject-specific modeling; Multibody dynamics; Mandibular reconstruction; Surgical planning; Joint Range of Motion

S05
生物医学传感与可穿戴系统
Biomedical Sensors and Wearable Systems

ID 177

Triple Cardiovascular Disease Metabolites Simultaneously Detected based on Electroenzymatic Assembly Transduction Strategy

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Objective: Cardiovascular diseases (CVD) are chronic diseases with high mortality influenced by multiple metabolic factors. Convenient and simultaneous monitoring of metabolites is beneficial for CVD management. We describe an electroenzymatic mediator (EM) sensor based on an electroenzymatic assembly peak separation strategy, which can efficiently realize the simultaneous detection of three typical CVD metabolites in 5 μL plasma under one test. This work has significant implications towards improving the efficiency of chronic CVD assessment.

Methods: Different oxidases and EM were assembled on the electrode surface. Methylene blue has a low redox potential and unique electrochemical properties, while ferrocene exhibits redox properties and stability; these compounds were widely used in biosensors and biomedicine. Coenzyme flavin mononucleotide was a flavoprotein that catalyzes oxidation–reduction reactions. They were both excellent EM and have different potentials. Detected current was generated due to oxidation of metabolites by oxidase and enhanced by horseradish peroxidase. The EM was flexibly designed by the crosslinking of electron mediators and enzymes, and three EM layers with different characteristics were assembled on one electrode. Electrons were transferred under tunable potential; three metabolites were quantitatively detected by three peak currents that correlated with metabolite concentrations.

Results: In this study, the EM sensor showed high sensitivity for the simultaneous detection of three metabolites with a lower limit of 0.01 mM. The linear correlation between the sensor and clinical was greater than 0.980 for 242 patients, and the consistency of risk assessment was 94.6%.

Conclusion: Metabolites could be expanded by the EM, and the sensor could be a promising candidate as a home healthcare tool for CVD risk assessment because of its good consistency and convenience.

Key words: Electroenzymatic mediators; Metabolites simultaneous detection; Cardiovascular diseases; Electron transfer; Potential shift

ID 190

Prediction of Plaque Location and Parameters Based on Hemodynamic Parameters

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Objective: Atherosclerosis is an important pathogenic factor of cardiovascular disease. The formation of atherosclerotic plaque on the blood vessel wall may lead to the risk of blood flow blockage and cause syncope. Therefore, the prediction of plaque location and length based on hemodynamic parameters can help in earlier detection and effective prevention and treatment.

Methods: A two-dimensional stenosis straight tube with a length of 30 mm and a diameter of 4 mm was designed. A width of 0.5 mm was used on both sides of the vessel to represent the thickness of the vessel wall. Plaque-induced stenosis was simulated by shortening the tube diameter at the center of the straight tube. The displacement of the outer wall surface boundary of the vessel wall and the velocity data of the central flow channel of the vessel were monitored. The displacement and velocity data were processed for the first and second order derivatives respectively.

Results: The minimum value point of the displacement corresponded to the narrowest position of the vessel. On either side of this point, the two minimum positions in the second derivative of displacement corresponded to the start and end of the plaque. As for blood velocity, the minimum point of the second order derivative corresponded to the narrowest position of the plaque. On the front side of this point, the maximum point corresponded to the start of the plaque. The minimum value point of the first order derivative corresponded to the end of the plaque.

Conclusion: In this study, based on the first derivative and second derivative of the velocity, the location of the plaque could be roughly determined, and the predicted plaque length deviated from the actual plaque length between 2-15%. This study has implications for the effective clinical prediction of plaque location and length.

Key words: Hemodynamic parameters, vessel wall displacement, blood flow velocity, fluid-structure interaction

ID 203

A Smart Waistband Design with Pressure Alarm and Acupoint Application Function

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Objective: Low back pain is the number one disabling disease worldwide. In conservative therapy, wearing a waistband can provide support and restraint to the lumbar spine, reduce pressure on the lumbar discs and intervertebral joints, and relieve tension on the low back muscles. However, the existing waistband lacks pressure alarm function, so it is easy to squeeze the abdomen or damage the lumbar intervertebral disc when worn too tightly, and cannot enhance the stability of the spine or reduce the bearing load of the lumbar spine when wearing too loose. To design an intelligent Chinese medicine physiotherapy waistband with pressure alarm and acupoint application function.

Methods: Firstly, a multi-channel pressure detection module combined with modern biomechanics is adopted, and the

constant current generated by the constant current source circuit flows through the sensor. ADC collects the voltage generated by the sensor which is positively correlated with the resistance value and transmits the sampled value to the single chip microcomputer. In this way, the pressure value at different positions during the wearing process of the waistband is detected in real time, and the alarm is displayed when the pressure is too high. Secondly, the dressing package is set in the acupuncture point area closely related to the waist, and the heating and temperature are displayed at regular intervals. The temperature inside the waist was collected in real time to avoid high temperature damaging the lumbar intervertebral disc.

Results: The Chinese medicine physiotherapy waistband can realize pressure alarm and acupoint application function, and the detected pressure information and temperature value are uploaded to the big data center through the big data module.

Conclusion: The optimal treatment plan is obtained by collecting a large amount of data on the pressure of the waist circumference and the rehabilitation effect of the wearer.

Key words: low back pain; waistband; pressure detection; acupoint application; big data

ID 421

柔性银三角自组装 SERS 基底的制备及其在体表皮质醇检测中的应用

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目的：基于金属纳米颗粒的表面增强拉曼散射（SERS）方法被广泛应用于生物医学检测。但 SERS 光谱的灵敏度、稳定性及可重复性与所用的 SERS 基底类型密切相关。利用高分子膜材料作为支撑的柔性 SERS 基底适用于生物医学检测与诊断领域快速、可穿戴以及个性化检测的要求。本文以银纳米三角片作为增强粒子，通过三相界面自组装的方法将银纳米三角片聚集成银膜并转移至聚合物薄膜制成柔性 SERS 基底，用来检测汗液中用于评估心理应激的皮质醇。

方法：通过调节银纳米三角片的尺寸、聚合物薄膜中聚氯乙烯与苯乙烯 - 乙烯 - 丁烯 - 苯乙烯嵌段共聚物的比例以及自组装银膜的转移次数使得柔性 SERS 基底的增强效果达到最强。此外，利用皮质醇抗体对柔性 SERS 基底进行功能化修饰，以实现对皮质醇的特异性检测。

结果：在最佳检测条件下，皮质醇在 1268 及 1500 cm-1 处的拉曼峰强度与其浓度的对数在 10-7 到 10-3 M 范围内分别呈现良好的线性关系，检测限分别为 5.47×10-8 M 以及 5.51×10-8 M。

结论：本文构建的柔性 SERS 基底具有特异性好、灵敏度高的特点，在体表皮质醇可穿戴式检测方面具有发展潜力，可为心理应激水平快速检测提供一种可行的方法。

关键字：银纳米三角片，自组装，表面增强拉曼散射，柔性基底，皮质醇

ID 422

Cysteine and GSH Co-modified Gold Nanoclusters with Enhanced Fluorescence Emission for Sweat Glucose Detection

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Objective: Noninvasive sweat glucose detections are less risky and harmful than invasive blood glucose detection. Fluorescence-based detection are convenient but not yet commonly used for sweat glucose detection.

Methods: Hence, we synthesized cysteine and glutathione co-modified gold nanoclusters (CG-Au NCs), and performed the fluorescent detection of artificial sweat glucose based on Fenton reaction.

Results: CG-Au NCs exhibited a larger cluster size and higher fluorescent intensity than GSH-Au NCs, hinting the amplification of detection range. Intriguingly, Fe2+ slightly quenched CG-Au NCs fluorescence, but in the presence of H2O2, Fe2+ was oxidized to Fe3+ which strongly quenched the fluorescence. Based on these facts, we applied CG-Au NCs-Fe2+ system in H2O2 detection. During optimizing the detection condition, we found the fluorescent quenching efficiency of Fe3+ was highest in pH 3. Detection range of H2O2 concentration was from 1 to 2000 μmol/L. Furthermore, by converting glucose into H2O2 with glucose oxidase (GOx), CG-Au NCs-Fe2+-GOx system could detect glucose concentration from 50 to 1000 μmol/L. The detection limits of H2O2 and glucose were 0.252 μmol/L and 9.17 μmol/L respectively. Our system was successfully applied for detecting glucose in artificial sweat samples.

Conclusion: The gold nanoclusters showed a wide detection range and high sensitivity in glucose detection, which has the great potential for development in the field of sweat glucose detection.

Key words: Cysteine; GSH; Gold nanoclusters; Sweat glucose; Fluorescence

ID 486

Propagation of Elastic Waves in Different Elastic Mediums

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Objective: Real-time monitoring of pulse waves can effectively reflect the cardiovascular status. The current commonly used pulse wave detection technology is a photoplethysmographic sensor (PPG). It is convenient and non-invasive but easily affected by ambient light. To make up for the shortcomings of PPG technology, We have studied piezoelectric pressure sensors because of their good dynamic response and simple preparation. It consists of different material layers. To fabricate excellent pulse piezoelectric sensors, we have studied the propagation of elastic waves in different media.

Methods: The device consists of a three-layer structure with a piezoelectric layer, a substrate layer, and an elastic dielectric. To investigate the effect of specific parameters of each layer structure on the sensing performance, we will vary the thickness of the films in the device to 30, 52, and 110 μm, comparing the Results of PET and Kapton as the substrate layer. Besides, the substrate thicknesses are 0.1, 0.15, and 0.2mm respectively. In addition, the effects of the type, thickness and elastic modulus of the elastic medium on the sensing performance were investigated. The Vpp of the simulated elastic wave was used to compare the performance.

Results: The Results show that the thinner the dielectric layer, the better the sensing effect. The elastic modulus of the elastic dielectric layer should not be too soft or too hard. Flexibility will lead to great strain and the device's performance will be declined. However, rigid media do not guarantee conformal contact with the object to be measured.

Conclusion: In this study, we propose a self-powered pulse sensor based on PVDF piezoelectric film. Through the analysis of the research results, we obtained the material parameters of the piezoelectric sensor with excellent performance, which can realize the real-time monitoring of pulse waves. Overall, the device holds promise as a convenient health monitoring device.

Key words: Elastic wave, pulse wave, piezoelectric sensors, elastic mediums

ID 572

Wireless EEG-fNIRS Fusion Signal Acquisition System for Depth of Anesthesia Monitoring

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Objective: Depth of anesthesia monitoring has been adopted in clinic in the recent years. However, misjudgments could occur under certain circumstances, which would harm patients mentally or even physically. We aim to develop a new monitoring system which is accurate, flexible, low-cost and open.

Methods: In this article, we have proposed a novel hybrid EEG-fNIRS signal acquisition system with self-designed EEG and fNIRS acquisition modules. Module hardware and software are designed and prototyped.

Results: show that the EEG module has an indication error between 4% and 14%, the fNIRS module could drive laser sources and acquire signals with a 0.005 volt converted signal resolution, and the system could acquire, visualize and save the data with a stable running time of about 1 hour.

Conclusion: The proposed system is able to acquire human signals in an expected manner, and the system can save and process data on the terminal PC. We expect it to have huge potential for DoA monitoring.

Key words: Depth of Anesthesia Monitoring, EEG, fNIRS, Hybrid-sourced Data

ID 660

摩擦纳米发电机用于临床诊疗的研究进展

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目的：摩擦纳米发电机 (TENGs) 被认为是最有潜力的生物体微能量收集的理想技术之一。特别是近年来，因其具有轻便、轻薄、良好的生物相容性和优异的软组织顺应性，为可穿戴和植入式医疗设备提供了持续供电的创新解决方案。

方法：本文综述了 (1)TENG 的工作原理和典型结构；(2)TENG 的材料选择；(3)TENG 在心血管系统、神经系统、呼吸系统、微生物灭活、抗生物黏附、消毒和组织修复等医疗领域的应用新进展；(4) 基于 TENG 的医疗设备面临的挑战和未来展望。

结果：与传统医疗设备相比，基于 TENG 的自供电医疗设备更加智能、高效、精准。TENGs 在医疗器械中的应用带来了更长的使用寿命、更有效的干预手段、更人性化的数据呈现方式。对于患者而言，基于 TENG 的自供电医疗设备可以降低植入式电池更换的经济成本和身体痛苦。

结论：新兴的 TENG 为可穿戴和植入式医疗设备提供了革命性的解决方案，未来必将改变疾病诊疗的范式。

关键字：摩擦纳米发电机；可穿戴和植入式医疗设备；自驱动系统；临床诊断和治疗

ID 682

Antioxidation of Liquid Metal Nanoparticles by Fabrication of p-aminobenzoic Acids towards a Sensitive Wearable Insulin Biosensor

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Objective: Gallium-based liquid metals (LM) are a class of emerging materials which have attracted lots of attention in biomedical engineering. However, gallium is prone to form a thin oxidised layer on its surface to compromise its electrical properties, altering physicochemical properties of the surface, and thus causing a barrier for biological applications, such as biosensing. Surface modification of Gallium-based LM such as Eutectic Gallium Indium (EGaIn), to avoid the formation of oxidation layers is an active research topic.

Methods: Being different from normal practice by wrapping polymers on LM surface, we developed a simple general method for modification of EGaIn surface with p-aniline derivatives (such as p-aminobenzoic acid) to introduce a monolayer of organic molecules with carboxylic acid groups. Electrochemistry, XPS, contact angle, and SEM were used to characterise the sensing interfcaes.

Results: The formation of these organic molecules on the EGaIn surface anti-oxidates and thus stabilizes the EGaIn nanoparticles while increasing its electrical and thermal conductivity. The resulted EGaIn nanoparticles were very stable in both ethanol and aqueous solution, and are suitable for the further attachment of biomolecules such as antibodies, enzymes or aptamers, for biomedical applications. The EGaIn surface was successfully modified with p-aminobenzoic acid followed by the attachment of insulin aptamer for the electrochemical detection of insulin with the sensitivity of 1 pM.

Conclusion: This study reveals the modification of EGaIn nanoparticles with p-aminobenzoic acid based monolayers can anti-oxidate and stabilize EGaIn in biological environment promising wide applications of Gallium based LM in biomedical sensors. It is potential to develop a wearbale insulin biosensor taking advantadge of the flexibility of liuqid metals and the real-time monitoring capability of the aptasensor.

Key words: Antioxidation of liquid metals, surface modification, stabil-ity, sensitivity, insulin biosensor

ID 698

Preparation of Molecularly Imprinted Polymer-coated Multi-walled Carbon Nanotubes and their Application in Occurrence and Distribution of Thyroid-disrupting Chemicals in Dust Samples

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Objective: Indoor dust contains a multitude of thyroid-disrupting chemicals (TDCs), and ingestion of dust is considered a significant route of human exposure. Extraction of different types of chemicals from complex samples is a great challenge for environmental monitoring. Therefore, we established a method for simultaneous detection of multi-component TDCs in indoor dust.

Methods: In this study, molecularly imprinted polymer-coated multi-walled carbon nanotubes (MIP@MWCNTs) using thyroxine as the template molecule, were synthesized for highly selective capture of TDCs. MIP was grafted to the MWCNT cores by integrating radical polymerization with the self-polymerization of dopamine. Morphological and characterization reveal that blending of the MIP on the MWCNT surface and construction of double-system imprinting cavities could significantly increase the selective surface area and improve the imprinting cavities. This material can be used to recognize TDCs and the coincidence rate reached 89.7%. Therefore, it was applied as the sorbents to extract 7 types of 35 TDCs, followed by their determination by high-performance liquid chromatography-tandem mass spectrometry.

Results: The proposed method shows high precision (RSDs < 7.8%), low limits of detection (0.02-0.23 ng/g), and acceptable recovery (81.8%-103.5%). The occurrence and distribution of TDCs were studied in indoor dust samples collected from four cities in China. Tetrabromobisphenol A was the predominant compound in dust samples, and perfluorinated compounds were the most abundant TDCs. In addition, TDCs levels showed great differences in the regional distribution.

Conclusion: This study provided an efficient technology for exposure assessment of different types of chemicals.

Key words: Thyroid disrupting chemicals; Molecular imprinting polymers; Double-system imprinting technology; Solid phase extraction; Indoor dust

ID 739

Wearable Battery-free Smart Bandage with Integrated Biosensors for Bacterial Wound Infection Detection

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Objective: Wound infection is a life-threatening healthcare issue that can cause severe pain, sepsis, and even amputation. Herein, to address the challenges of point-of-care wound analysis, a battery-free, wireless and wearable smart bandage was developed for bacterial virulence factors detection.

Methods: Typical biomarkers, sortase A and pyocyanin, corresponding to two major types of bacterial infection, Gram-positive Staphylococcus aureus and Gram-negative Pseudomonas aeruginosa, were detected with electrochemical differential pulse voltammetry. Ti3C2Tx MXene was applied to the electrode to enhance the sensitivity. Pyocyanin could transfer electrons with the electrode for sensing due to its redox characteristics, while a peptide labeled with the electro-

active ferrocene was customized for the specific recognition of sortase A.

Results: The integration of near field communication module realized wireless energy harvesting and data transmission with smartphone. The fully integrated system demonstrated good linearity and high sensitivity, with wide detection ranges of 1 pg/mL to 100 ng/mL for sortase A, and 1 μM to 100 μM for pyocyanin. Furthermore, the animal studies indicated the effectiveness of the smart bandage for multi-biomarker profiling of wound.

Conclusion: This wearable system provides a noninvasive, convenient and efficient platform for in situ bacterial virulence factors detection, offering great potentials for the management of infected wound.

Key words: Wearable biosensors, flexible electronics, electrochemical sensors, Ti3C2Tx MXene, wound infection monitoring.

ID 746

Active Sensor for Multidimensional Force Detection

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Objective: The sense of touch is one of the important media for humans and animals to communicate with the environment. It is critical to find a method or device that can detect the multidimensional dynamic micromechanical signals of biological soft tissues such as skin and muscle, quickly and accurately, which is essential for the development of tactile sensing technologies.

Methods: Here, we demonstrate a triboelectric force sensor (TFS) that can convert the mechanical signals of the living creature's soft tissue into detectable electric signals directly. The TFS contains elastic polymer micro-column and micro-cone structures that can be used to detect the normal and tangential dynamic forces quickly, accurately and synchronously.

Results: This work aims to establish an active dynamic micro force sensing model and an overall performance index system of the TFS, which would realize the accurate detection of the mechanical properties of biological soft tissues. The TFS has good linearity (R2 = 0.97) and fast response under an applied force. The sensitivity of the optimal device for normal force detection is 4.8 times higher than that of the pure PDMS cone sensing structure. And a small shear force as low as 255 Pa could be recognized by the TFS.

Conclusion: This work is intended to explore a new type of active mechanical sensing method and mechanism, and establish a universal connection between electrical outputs and relevant mechanical parameters. It may provide reference ideas and a theoretical basis for the research and development of multi-dimensional biomechanics sensors with simple structure, sensitive signals and fast response, and the exploration of bionic tactile systems.

Key words: Active sensor; triboelectric effect; Multidimensional force detection.

ID 751

Quantitative Hematocrit Measurement on a Pressure-actuated Microfluidic Chip

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Objective: In point-of-care diagnostics, hematocrit (HCT), which is the volume percentage of red blood cells in the whole blood sample, is closely related to human health status. Here, we developed a pressure-actuated, polydimethylsiloxane (PDMS) microfluidic chip for quantitative measurement of HCT.

Methods: The narrowest part of its flow channel is 8 μm and acts as a constriction for blood cells, which can lead to retardance of blood flow in the chip. The amount of red blood cells has an influence on the transport time of passing through the constriction for the blood samples, so we can use the transport time to infer the HCT value.

Results: We found a linear calibration curve between blood transport time and HCT value, which showed a correlation coefficient (R2) of 0.9506 for blood samples with HCT ranging from 0.35 to 0.55.

Conclusion: This microfluidic chip can provide the Results of HCT measurement within 1 min, making it well-suited for point-of-care diagnostics.

Key words: Hematocrit measurement, Microfluidic, PDMS, Point-of-care diagnostics, Pressure-actuated

ID 756

Plant Wearable Wireless Ethylene Detection Enabled by MXene Printed Electronics

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Objective: The rise of printed flexible electronics has enabled versatile functional components for wearable intelligent devices that bridge the digital information networks with bio-interfaces. Recent endeavors in plant wearable sensors provide real-time and in situ insights to study plant phenotyping traits, whereas monitoring of ethylene, the fundamental phytohormone, remains challenging due to the lack of flexible and scalable manufacturing of high-performance ethylene sensors.

Methods: Here we present the all-MXene-printed flexible radio frequency (RF) resonators as plant wearable sensors for wireless ethylene detection. The facile formation of additive-free MXene ink enables rapid, scalable manufacturing of printed electronics.

Results: The sensor demonstrates decent printing resolution (2.5% variation), good conductivity (~30000 S m-1) and mechanical robustness. Introduction of MXene-reduced palladium nanoparticles (MXene@PdNPs) facilitates enhanced ethylene response (1.16% at 1 ppm), low limit of detection (0.084 ppm), and decent selectivity. The wireless sensor tags have been attached on plant surfaces for in situ and continuously profiling of plant ethylene emission to inform the key transition of plant biochemistry.

Conclusion: The sensor can potentially extends the application of printed MXene electronics to enable real-time plant hormone monitoring for precision agriculture and food industrial management.

Key words: MXenes, flexible electronics, screen printing, plant wearable sensors, ethylene detection

ID 791

Fast Sample Entropy Atrial Fibrillation Analysis towards Wearable Device

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Objective: AF is a common and often debilitating heart rhythm disorder characterized by an irregular, rapid, and sometimes chaotic heart rate. This paper proposes to use fast entropy estimation algorithm to analyze AF on wearable processors for ECG R wave interval.

Methods: The suggested fast entropy method requires less computation time to detect AF. Information entropy, typical as Sample Entropy (SampEn), is a popularly used complexity measurement metric for AF detection. However, the quadratic time complexity of conventional SampEn restricts its analysis ability.

Results: The fast entropy estimation map original signals by Merge Sort (MS) and use a lightweight (LW) similarity-checking method to avoid unnecessary operations on entropy analysis.

Conclusion: The proposed algorithm is verified on the long-term recordings from MIT-BIH AF database. This fast entropy measurement, MS-LW, has the same complexity measurement result as SampEn but is three times faster than SampEn, especially for long-term ECG, which will bring benefits for wearable applications.

Key words: Sample Entropy, Complexity Analysis, Fast Sample Entropy, Atrial Fibrillation

ID 839

Design of a Soft Exoskeleton with Motion Perception Network for Hand Function Rehabilitation

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Objective: Hand dysfunction seriously affects patients' activities of daily life. Rehabilitation exoskeleton can effectively improve the hand function of patients and reduce the burden of their families. However, most of the existing exoskeletons lack the ability to detect the state of hands during rehabilitation, which is a potential safety risk for rehabilitation.

Methods: In order to improve the safety of hand function rehabilitation training, we proposed a soft wearable exoskeleton equipped with motion perception network. The soft exoskeleton is composed of guided bending bellows actuators, and has good mechanical properties. Besides, the soft bending sensor used to build the perception network has high measurement accuracy.

Results: The Results showed that the soft exoskeleton with motion perception network not only realizes the full range of finger motion, but also measures the angle of each joint during the movement process.

Conclusion: Therefore, this device can improve the rehabilitation effect, avoid secondary injury during rehabilitation training, and meet the rehabilitation needs of patients with hand dysfunction.

Key words: Soft exoskeleton, Motion perception network, Soft actuator, Bending sensor, Hand function rehabilitation

ID 862

Health-care Based on Near Field Inter-body Coupling Communication: Modeling and Analysis of Characteristics

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Objective: The internet of body (IoB) can support future health-care systems for early detection and prevention of diseases through proactive wellness screening technologies. NF-IBCC can achieve much higher data security and lower power consumption than traditional radio frequency communications, which is a potential communication technology applied to IoB. However, its channel model is not totally clear so far. In this paper, we propose a channel model and analyze channel characteristics.

Methods: The circuit models and physical experiments are used to describe the channel characteristics of NF-IBCC.

Results: (1) The proposed circuit model can well capture the channel characteristics of NF-IBCC in the frequency range of 1 MHz-10 MHz, which the maximum absolute value of the errors is only 0.92 dB. (2) The overall channel of NF-IBCC has high-pass filter characteristics in the frequencies range of 1 MHz-10 MHz due to the capacitive path. (3) The channel gain decreases with the increase of d, increases with the increase of Cair caused by the angle q1 and q2, and decreases with the decrease of the relative area SH between bodies caused by heights and postures of the human body.

Conclusion: In this paper, we propose a channel model. Then, the accuracy of the proposed model is verified. Finally, the effect of distances, postures, angles, and heights on the channel characteristics is analyzed and discussed. Our work lays a theoretical foundation for the system design of NF-IBCC and will promote its application to IoB.

Key words: Human body communication (HBC), channel model, circuit model, channel characteristics

ID 920

GCN-ResNet: A Multi-Label Classifier for ECG Arrythmia

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Objective: Automatic ECG classification using artificial intelligence technology is of great significance for the early prevention and diagnosis of cardiovascular diseases. In recent years, many studies have achieved good performance on the task of single label ECG classification. However, in practical clinical application, one ECG record may contain multiple arrhythmia types at the same time, so it is very important to study the multi-label ECG classification.

Methods: This paper proposes a multi-label ECG classification model based on GCN-CNN framework, named GCN-ResNet, which can complete the task of multi-label ECG classification by using GCN to extract label information and CNN to extract ECG information. At the same time, two loss function improvement strategies are proposed to solve the imbalance problem.

Results: Experiments show that our method can achieve F1 score of 0.832 in classifying 55 kinds of arrythmias. The optimized loss function works in improving model performance.

Conclusion: The model proposed in this paper has good performance in multilabel ECG classification task and can help doctors to conduct early rapid ECG diagnosis.

Key words: ECG, multi-label classification, arrythmia, GCN

ID 964

基于本征粘性液态金属导体的电子纹身的研究

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目的：基于硅胶基底的柔性电子难以与皮肤形成可靠的粘附，它们通常通过胶带、绑带或范德华力与皮肤接触，为了实现柔性电子与皮肤的共形与紧密连接，我们将液态金属与压敏胶水（丙烯酸聚合物）结合，开发出本征粘性液态金属导体，并基于此进一步开发柔软、轻薄、可与皮肤共形的电子纹身，用于动作监测、电生理测量等应用。

方法：本征粘性液态金属导体由液态金属和压敏胶水组成，通过在离型纸表面印刷液态金属颗粒、旋涂压敏胶水，最终通过剥离转印工艺，得到本征粘性的液态金属导体，通过对本征粘性的液态金属导体进行图案化，可得到不同功能的电子纹身。

结果：本征粘性液态金属导体呈现出表面富集结构，其中富集在表面的液态金属负责形成电学连接，而压敏胶水基质用于粘附到不同的表面。因此，该导体与皮肤表面接触后瞬间即可形成连接，无需涉及高温和有机溶剂。本征粘性的液态金属导体具有金属级导电性（≈ 417000 S/m）、水凝胶级拉伸性（>900%）和自粘性（1.8 N /cm)。我们基于该材料，研发出可以用于动作监测和电生理信号测量的电子纹身。

结论：本征粘性液态金属导体能与皮肤进行共形，即使在皮肤变形中也能保持稳定的力学连接与电学接触。

关键字：电子纹身，可穿戴设备，可拉伸导体，液态金属

ID 968

可用于生物气溶胶现场量化和感染风险评估的等离激元光学生物传感系统

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目的：等离激元生物传感技术具有灵敏、快速等优势，通过现场检测与量化空气中传播的生物气溶胶，可有效对医院、养老院等场所的病原体传播风险进行高时空分辨率的风险评估。

方法：本研究将介绍集成基于吸湿性生长原理的生物气溶胶收集系统和等离激元光热双功能生物传感（CAPS）系统，用于对病毒等生物气溶胶进行现场定量风险分析。CAPS 系统在医院、养老院等相关环境中可模拟人呼吸速率对生物气溶胶进行收集，并富集到水溶液中用于等离激元光热生物传感，分析样品中的核酸浓度与病毒数量，整个检测过程可在 40 分钟内完成。

结果：在复杂的气溶胶背景中，核酸检测极限达到了 0.25 拷贝 /μL。CAPS 系统能够以高时空分辨率直接测量病毒暴露情况；在医院等实地检测中，CAPS 系统分辨了不同风险程度的病人病房、医生办公室等气溶胶传播环境。

结论：测量结果可通过剂量反应模型，用于计算疾病传播与感染风险概率，并预测在不同环境下达到“可接受风险阈值”的最大暴露时间。检测结果可通过在线平台向医护人员和病人反馈即时检测结果和个人感染风险。该研究相关成果不仅拓展了光学生物传感器件的生物医学应用领域，也为未来生物气溶胶、病原体气溶胶传播机理的探索奠定基础。

关键字：表面等离子体共振，生物传感，病原体防治，风险评估

ID 1129

基于标签解耦的心电多标签异常分类算法的研究

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目的：静态 12 导联心电多标签异常分类一直是人们关注的焦点，加之近年来深度学习的飞速发展，该领域已取得长足的进步。但是，过去大多数多标签心电分类模型都可以归纳为一种深度嵌入方法，即首先将原始信号投影到一个表征空间中再进行多标签分类，这将产生一种标签纠缠的现象，并带来三个缺陷。最致命的缺陷是，随着标签数量的增加，模型倒数第二层的投影空间中的聚类复杂度将呈指数级增长。本文将讨论并提出方法解决此类多标签纠缠问题。

方法：基于标签解耦策略，本文提出一个标签分离层将各种标签的样本投影到不同空间来解决标签纠缠问题，并引入一个可学习的加权层以整合标签解耦和传统标签融合的优势并得到最终结果。此外，本文还引入了度量学习技术进一步发展了此方法的大类间距离版本。

结果：在 CPSC2018 与 PTB-XL 两个数据库的结果表明，本文方法提高了所有被测常用心电模型的表现。与被测该领域流行算法相比，本文方法同样取得了更好的表现。

结论：综上，本文提出的方法优于大多数现有的静态 12 导联心电多标签异常分类技术。并且，本文方法具有通用性，可以配合许多先进算法一起应用从而达到更好的性能，从标签解耦角度为解决心电多标签分类问题提供了全新角度与思路。

关键字：多导联心电分析，多标签学习，度量学习

ID 1411

Noninvasive Assessing Low Back Pain by Near-infrared Spectroscopy with Aid of Cupping Therapy

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Objective: Low back pain (LBP) becomes a general syndrome with high incidence and the leading cause of disability, but how to diagnose remains poorly understood due to numerous related factors and low specificity of traditional techniques. Here we combined Near-infrared spectroscopy (NIRS) and special cupping therapy in China to innovatively explore the noninvasive assessment of LBP.

Methods: A total of 22 patients were recruited in this study, including 12 LBP patients and 12 matched healthy subjects. The experiment contained a 5-min baseline, two 3-min NIRS detection, and 20-min cupping therapy on the "Shenshu" acupoints. The hemodynamic changes were detected through a home-made NIRS with eight optical detectors, located in the two distances (2.5, 3cm) of four directions (0°,90°,180°,270°) around the light source. We focused on the concentration change in oxyhemoglobin (Δ[HbO2]), and deoxy-hemoglobin (Δ[Hb]) to assess LBP with aid of cupping.

Results: After cupping, both groups performed significant increases of Δ[HbO2] in four directions, and absolute variations between control and LBP had no differences. However, the ratio of differences between Δ[HbO2] and Δ[Hb] before and after cupping (ddHb) in the channel (3cm, 270°) was significantly lower in LBP patients than in healthy subjects (Health vs. LBP, 0.679 ± 0.427 (μmol/L) vs. 0.124 ± 0.277 (μmol/L), $p<0.01$). Linear discriminant analysis (LDA) based on ddHb of two channels (3cm, 90° and 270°) correctly distinguished >80% of samples.

Conclusion: Our study found that LBP patients were less sensitive to cupping and confirmed the feasibility of noninvasively assessing LBP based on NIRS and cupping therapy.

Key words: Low Back Pain, Assessment, Noninvasive, NIRS, Cupping Therapy

ID 1427

双层卫星结构用于癌症标志物的超灵敏 SERS 检测

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目的：表面增强拉曼散射（SERS）已成为指导癌症诊断的有前途的工具。然而，现有的检测平台仍然存在 SERS 灵敏度低、检测范围有限的问题。为超高灵敏的检测出癌症标志物，本研究构建了双层卫星等离子体纳米结构。

方法：双层卫星结构中二氧化硅球作为核心，异质金 - 银二聚体作为卫星（其中，Au NPs 在内层，Ag NPs 在外层）。该结构具有均匀且高密度的“热点”，包括异质二聚体内颈部热点和相邻异质二聚体间隙热点，能够显示出极强的 SERS 信号。将柠檬酸稳定的 Au NPs 吸附在氨基化修饰的硅球表面形成内层卫星，然后再在其表面形成一层硅层（即为 silica shell），对内层 Au NPs 实现部分掩蔽，进一步的 Ag+ 在 Au NPs 的暴露表面原位还原，从而形成外层同轴 Ag NPs 卫星。

结果：通过调节 silica shell 厚度实现对双层卫星内部间隙的调控，通过调控卫星的密度、卫星的大小完成对间隙相邻微信间隙热点的调控，使显著增强 SERS 信号，表面增强因子 EF 高达 108。此外，该纳米平台在结直肠癌标志物的检测模型中表现出优异的性能。

结论：这项工作提供了一种有前途的方法，能够便捷高效的实现癌症标志物的超高灵敏度检测。

关键字：表面增强拉曼散射 SERS，双层卫星结构，癌症标志物，结直肠癌

ID 1686

导电水凝胶柔性微创生物传感器研究

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目的：导电水凝胶作为微创植入式生物传感器界面，融合了导电性和柔软性，可以匹配人体组织的机械力学性能，但如何实现导电水凝胶的高精度可控修饰是该领域的技术瓶颈与挑战之一。本研究旨在研发一种导电水凝胶高精度修饰与调控方法，实现基于导电水凝胶的柔性微创植入式生物传感应用。

方法：本研究围绕生物传感器中的导电水凝胶电子界面，探究了金属离子辅助电凝胶化机制，提出了导电水凝胶电化学可控凝胶化的高精度修饰方法，探究了金属离子的迁移半径在不同电流密度、不同反应时间下的调控规律，并进行仿真数据与实验数据的对比研究，建立了一套基于电化学可控凝胶化的导电水凝胶高精度调控策略。

结果：金属离子辅助原位电凝胶化方法实现了微米尺度的高精度导电水凝胶修饰，成功应用于神经递质微电极生物传感器；通过精确调控复合导电水凝胶的力学耦合特性和电化学耦合特性，成功研发了与生物组织杨氏模量匹配的全水凝胶活性氧生物传感器；基于复合导电水凝胶的力学耦合特性和高精度界面修饰特点，研发了高分辨的导电水凝胶微阵列生物传感器。

结论：本研究所提出的电化学可控凝胶化方法，实现了微米尺度的可控界面修饰，为导电水凝胶在柔性微创植入式生物传感领域的应用提供了一条新的技术途径。

关键字：电化学生物传感器、微创植入式生物传感器、导电水凝胶

ID 1690

基于多模态信息融合的瓣膜病患者心震信号自动心拍标注

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目的：心震信号（Cardio-mechanical Signals）是由心脏机械运动产生的经放置在胸腔体表的传感器采集的震动信号，其线性震动（SCG）和旋转震动（GCG）的成分可分别由加速度计和陀螺仪采集。近些年的研究展示了心震信号在心脏瓣膜病的检测中的潜力。在其数据分析的框架中，信号的心拍分割和特征点识别是后续工作开展的重要基础。最新的研究表明，患病人群的心震信号模态与正常人存在差异，典型特征点识别算法因此存在效能降低的表现。而基于机器学习的方法面临标注困难、心电依赖等挑战。因此，本文提出了一种不需要预先标注，且应用部署时不依赖心电的基于多模态数据驱动的心拍分割算法。

方法：首先基于自监督学习解析心震信号的伪周期特性，接着通过同步采集的心电信号建立伪标签，进行模型训练，最后在仅有心震信号的情况下进行标注测试。训练和测试数据集由 100 个心脏瓣膜病患者的样本构成。

结果：实验表明，所提出的算法在测试数据集上得到了 98.94% 的精确率和 97.44% 的召回率。

结论：实验结果初步验证了所提出算法框架的有效性，对于进一步分析心震信号特征点，构成心脏瓣膜病的院外评估方法具有一定意义。

关键字：心震信号；心拍分割；心脏瓣膜病；多模态信号；自监督学习

ID 1764

Recent Advances in Implantable Sensor Technology for Orthopedics

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Objective: As the population ages and traumatic events increase, the number of implants is increasing. Especially in orthopedics, most orthopedic surgeries require implants. However, serious complications such as infection and dislocation of the implant can occur, putting the patient's life at risk. Therefore, it is crucial to be able to monitor these implants accurately and in real time. Sensors have been used in vivo to measure strains in bones as well as forces between joints. They also have important clinical applications in the detection of implants. We review the research progress of implantable sensor technology in orthopedics and look forward to providing a reference for experts and scholars in related fields.

Methods: First we classify the sensors according to their working principle. Then we describe their materials. Finally, we detail advances in implantable sensors for joints, spine and fractures in orthopedics.

Results: Depending on the operating principle, implantable sensors can be divided into electrical sensors, piezoelectric sensors, optical sensors, thermoelectric sensor and electrochemical sensors. Among them, electrical sensors are divided

into resistance sensors, capacitive sensors and inductive sensors, because of its simple principle is the most widely used. We classify the materials of implantable sensors into rigid and flexible materials according to their softness. Flexible materials are widely used in implantable sensors due to their biocompatibility and good fit to tissues. Implantable sensors used in orthopedics for about 50 years. The most common functions are to collect the stresses between the skeletal muscles in the body and to monitor the status of the implant and the healing of the bone.

Conclusion: Implantable sensors for clinical applications have not yet become mainstream, and most are still in the pre-clinical experimental stage. It is hoped that implantable sensors will be used in the clinic soon to realize digitalization and precision treatment.

Key words: implantable sensor; hip; knee; spine; fracture

ID 1898

Tandem Cas13a/crRNA Mediated CRISPR-FET Biosensor: A One-for-all Check Station for Virus without Amplification

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Objective: Path towards field-effect transistor (FET) application from lab to clinic has delivered a compelling push in biomedical domain, yet ultrasensitive and timely pathogen identification without PCR remains a long-lasting challenge. Herein, we create a generic check station termed as "CRISPR-FET", first incorporating CRISPR/Cas13a system within FET modality, for accelerated and unamplified detection of viral RNA. Unlike conventional FETs bearing target-specific receptors, this sensor holds three unique advances: (ⅰ) An ingenious sensing mechanism is used, which converts the signal of large-sized analyte into the on-chip cleavage response of immobilized CRISPR reporter, enabling signal generation events to occur all within the Debye length; (ⅱ) The multipurpose inspection of CoV ORF1ab, CoV N gene, and HCV RNA unveils the potential for a "one-for-all" scalable FET-based molecular diagnostics; (ⅲ) It is shown that Cas13a-crRNAs targeting different sites of viral genome can be deployed in tandem to amplify the FET response, empowering the detection limit down to 1.56 aM, which is a world-record level of sensitivity in FET for direct viral gene sensing. Notably, a brilliant clinical applicability was made in the distinguishment of HCV-infected patients from normal controls. Overall, this study sheds new insight into FET-based nucleic acid sensing technology, and invokes a vision for its possible future roles in various viral disease diagnosis.

Key words: CRISPR/Cas13; Field-effect transistor; Virus; Detection; Amplification-free

ID 1903

基于纳米银花标记的超灵敏蛋白标志物检测电化学传感器

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目的：临床针对蛋白标志物的检测主要采用免疫组化、酶联免疫吸附等技术，存在操作复杂、成本高、特异性和灵敏度低等问题。电化学生物传感器具有便携、易使用和成本低等优点。然而，目前开发的高灵敏度电化学传感器往往采用复杂的结构和工艺，系统稳定性和重复性较差。本研究构建了一种基于纳米银花标记的多通道电化学生物传感器用于蛋白标志物的超灵敏快速检测。

方法：首先制备不同尺寸的纳米银花，再将其通过中间连接体与抗体结合，得到可显著放大信号的纳米银花探针。快速制备具有大比表面积的激光诱导石墨烯（LIG）电极，将筛选出的可特异性识别待测蛋白的亲和肽固定在 LIG 电极表面。电极表面的亲和肽可特异性识别并捕获待测蛋白，并与纳米银花探针构成复合结构，纳米银花探针的氧化电流与待测蛋白在一定浓度范围内呈线性响应。

结果：该传感器的实测检测限低至 1 fg/mL，线性范围达 5 个数量级。使用不同尺寸的纳米银花，可调控传感器的线性检测范围。使用该传感器对临床真实血液样本检测，可同时检测多种标志物，且具有较高的特异性和准确度。

结论：该传感器除不仅有高灵敏度和较强的鲁棒性，还具有操作简便、成本低廉等特点。

关键字：分子标志物；纳米银花；电化学传感器；多通道

ID 1918

自供电生物传感器件及应用

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目的：生物传感器可以对人体的生理和运动状态进行监测，为用户和医护人员提供生理数据和诊断建议。自供电技术可以提升生物传感器的续航时间，为生物传感器的发展提供了新的思路。

方法：纳米发电机是一种自供电的力学传感器，具有材料选择广、输出电压高等优点。我们以纳米发电机为研究基础，设计了一些多功能、高灵敏度的智能生物传感器件与系统。

结果：我们的研究工作大致上分为两个方向，一种是对基本生理信号的监测，结合穿戴式设备，实现对汗液、呼吸、脉搏等信号的精确采集，结合植入式递送装置，实现了对心内压信号的原位测量。另一种则是对运动状态的监测，结合仿生结构、新型材料、人工智能技术，实现了对复杂状态和动作的识别。

结论：这些研究工作围绕自供电技术和生物传感器，具有巨大的临床医疗应用转化潜力和广阔的市场前景。

关键字：自供电；纳米发电机；生物传感器

ID 2020

面向口腔疾病的穿戴式传感与治疗一体化系统研究

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目的：龋齿是全球最普遍的慢性疾病之一，是由口腔内产酸细菌的增加导致的。在此，我们开发了一种可穿戴的聚苯胺 - 钛酸钡纳米复合颗粒嵌入的双交联网络水凝胶器件，对龋齿进行早期筛查和及时治疗。

方法：我们开发了一种可穿戴的聚苯胺 - 钛酸钡纳米复合颗粒嵌入的双交联网络水凝胶器件，可以通过观察其相应位置的颜色变化来判断牙齿病变部位，并可以通过无创的声动力治疗，在空间和时间上高度精确地消除细菌。

结果：在 30 分钟后可以看到明显的蓝 / 绿比例差异。钛酸钡作为高效的压电材料，可以在超声波的催化下产生活性氧，实现杀菌与牙齿美白。此外，该凝胶器件被证明具有优良的机械性能和良好的生物相容性。

结论：由于对产酸细菌的敏感反应和有效治疗，本文提出的穿戴式凝胶器件为预防龋齿提供了一个的解决方案，这对开发口腔疾病的闭环生物医学系统很有希望。

关键字：龋齿；比色传感；声动力治疗；穿戴式；牙齿美白

ID 2107

串联式 Cas13a/crRNA 介导的 CRISPR-FET 生物传感器：一种免扩增的通用式病毒检测站

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场效应晶体管（FET）从实验室到临床的应用和发展，为生物医学领域带来了令人瞩目的推动力。但在不依赖于预扩增的情况下，快速、高灵敏的病原体识别仍然是一个长期的挑战。在此，我们创建了一种 "CRISPR-FET " 通用式检查站，首次将 CRISPR/Cas13a 与 FET 相结合，用于快速、免扩增的病毒 RNA 检测。与传统的以目标特异性受体作为捕获元件的 FET 不同，该传感器有三个独特的进展：(ⅰ) 采用了巧妙的传感机制，将大尺寸分析物的信号转化为固定化 CRISPR 报告子的片上裂解反应，使信号生成事件全部发生在德拜长度内。(ⅱ) 对 CoV ORF1ab、CoV N 基因和 HCV RNA 的多用途检测揭示了基于 FET 的可扩展分子诊断的潜力；(ⅲ) 该研究表明，针对病毒基因组不同位点的 Cas13a-crRNA 可以串联部署以放大 FET 响应，使检测极限低至 1.56 aM，这是目前使用 FET 直接检测病毒核酸的最高灵敏度。值得注意的是，该传感器可成功在区分 HCV 感染者和未感染者。因此，该研究为基于 FET 的核酸传感技术提供了新思路，并为其未来在各种病毒性疾病诊断中可能发挥的作用提出了设想。

关键字：CRISPR/Cas13；场效应晶体管；病毒；检测；免扩增

ID 2138

近零功耗植介入诊疗器件

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目的：植介入医疗电子器件在慢性疾病诊疗过程中需要持续的能源供给。然而，传统植介入医疗电子器件采用电池供能，频繁充电或更换电池将降低患者依从性，更换电池给患者带来二次手术的风险和沉重的医疗负担。因此，构建近零功耗（自供电）植介入诊疗器件一直备受学界和产业界的关注。

方法：针对植介入诊疗器件在长期监测和治疗过程中的能源瓶颈，围绕纳米发电机技术的基本原理，结合人体疾病诊疗应用的具体场景，通过柔性封装和小型化结构设计，构建了多种近零功耗植介入诊疗器件。

结果：研制了柔性经导管微创植入的心内压传感器，压力监测灵敏度和线性度分别达到 1.195 mV/mmHg，R2=0.997；设计了自供电光动力学肿瘤治疗系统，动物模型体内肿瘤抑制率达到 87.46%；构建了自供电光遗传学糖尿病治疗体系，实现对体内葡萄糖稳态的调节。

结论：研究成果将进一步促进植介入医疗电子器件升级变革，为近零功耗诊疗技术发展提供新的思路。

关键字：近零功耗，植介入器件，心内压，光动力学，光遗传学

ID 2149

物联网智能双工电化学传感系统用于嗜铬细胞瘤标志物检测

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目的：本文旨在通过现有的电化学检测理论搭建一种基于物联网的智能双工电化学传感系统并在基于分子印迹的嗜铬细胞瘤标志物检测中开展医学应用。该系统的检测数据可随时上云，实时与医生共享数据，实现无创、便捷的疾病筛查或早期诊断。

方法：双工电化学传感器中使用聚吡咯（PPy）作为分子印迹聚合物（MIP）测定香草扁桃酸（VMA）和基于磷钼酸作为修饰物测定肌酐，用于同时检测人类尿液中的 VMA 和肌酐，并采取以 VMA 浓度与肌酐浓度做比值的方法为用户做出诊断。通过搭建服务器使数据上传至云平台，从而实现数据共享。

结果：电化学研究表明，以 PPy 作为分子印迹聚合物形成的电化学传感器能够识别不同浓度的 VMA；在磷钼酸修饰的传感器上显示出了肌酐对电极修饰物的还原具有抑制活性。传感器对 VMA 在 1.0×10^{-9} M 至 1.0×10^{-5} M 范围内表现出良好的线性响应；对肌酐在 1.0×10^{-8} M 至 1.0×10^{-4} M 范围内表现出良好的线性响应。

结论：成功开发了一种基于分子印迹的嗜铬细胞瘤标志物检测的物联网智能双工电化学传感系统。传感检测系统包括硬件电路检测模块（含双工电化学传感器）和软件检测平台（含物联网通信），实现整个电化学传感检测系统的小型化。

关键字：物联网；分子印迹；嗜铬细胞瘤；香草扁桃酸；肌酐

ID 2181

适配体智能荧光传感检测脑利钠肽

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目的：脑利钠肽可预测急性缺血性脑卒中患者的不良预后，在高危筛查、早期诊断和预后中起着重要作用。适配体具有良好的稳定性和易获得等优点，开发一种基于适体的灵敏度高、稳定性好、精准快速且成本低的脑利钠肽速检方法是非常有必要的。

方法：提出了一种基于适配体的脑利钠肽检测方法并设计了一套智能荧光传感系统用于快速分析。设计了一种序列简单且羧基荧光素标记的适配体用于脑利钠肽传感检测，以羧基化氧化石墨烯作荧光共振能量转移平台猝灭荧光，获得不同荧光信号。智能荧光传感系统包括一个自制的多功能检测控制单元用于信号采集，一个光电转换、滤波放大和模数转换的数字信号单元用于信号处理以及采用智能手机终端结合自编程序实现人机交互，并使用其 OTG 功能做稳定的直插式移动电源。

结果：实验验证了所设计的适配体能够特异性识别脑利钠肽，得到了脑利钠肽浓度与荧光强度在 300pg/mL 以内良好的线性响应关系，检测下限为 0.1pg/mL。智能荧光传感系统能实现灵敏的信号采集、处理与分析，具有高度完整性和稳定性。

结论：该适配体智能荧光传感能灵敏检测脑利钠肽，实现了数字化脑利钠肽速检，填补了便携式荧光生物传感的空白，在脑卒中的急诊速诊领域具有良好的发展前景。

关键字：适配体；荧光；脑利钠肽；生物传感；智能手机

ID 2308

静电纺丝制作具有粘性的透气弹性基底研究

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目的：使用传统材料和工艺制造的柔性传感器是不可渗透的，这大大影响了设备的透气性和穿戴后的舒适性，静电纺丝可以将高分子材料制作成具有透气性的纳米纤维垫，制造具有粘性的透气的柔性基底。本项目在前期液态金属 - 高分子弹性体的研究基础上，将难挥发的液态金属材料和纳米纤维垫结合，设计出具有粘性的透气的柔性基底。

方法：通过静电纺丝设备纺丝高分子材料制作可拉伸和粘性的纳米纤维垫，然后在纳米纤维垫表面印刷液态金属，制作具有柔性和粘性的传感器。探究纳米纤维垫的调控方法，如电场强度、纺丝液浓度等。探究印刷液态金属后的影响，包括传感器的灵敏度，传感器 - 皮肤界面的表面阻抗、电阻随应变的变化关系等。探究传感器的力学性能的调控方法，揭示粘附性基底材料的杨氏模量、尺寸与传感器力学性能之间的关系。

结果：柔性电子系统由 TPU 膜和 LM 电路组成。通过静电纺丝制备的 TPU 膜用作基材，LM 可以通过丝网印刷成 TPU 膜表面的各种图案，

结论：该策略使用电纺 TPU 膜作为柔性基板，并使用模板印刷方法在基板上对 LM 进行图案化，以获得柔性电路制备的柔性电子器件具有超强的可拉伸性、完全柔性、高稳定性、良好的透气性和保护性能。

关键字：静电纺丝，纳米纤维，液态金属

ID 2310

基于大规模声学传感器的心脏振动可视化技术

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目的：心脏在心电传导系统控制下，产生有节律的收缩和舒张运动，实现泵血功能。心腔、瓣膜和血液产生的机械振动，是心脏泵血功能的必然结果。长期以来人们对心脏机械振动保持着强烈好奇心，希望能探索振动源、振动传播、振动感知、振动特征，以及振动模式与心脏功能之间的联系。

方法：本文提出一种感知心脏机械振动的新方法。从硬件上，采用大规模声学传感器阵列，环绕在人体心脏所在的躯干，全面地采集心脏振动信号。感知的振动频率在 6-1000Hz 范围内。把心脏振动的幅值、频率、相位等特征，与传感器的位置对应起来，提出心脏机械振动成像。把人类不可见的心脏振动，转换成人类肉眼可见的图像和视频，从而方便人们对心脏振动理解和分析。在图像基础上，研究心脏收缩、舒张、瓣膜活动等机械振动的成像模式和变化规律，反映心脏各器官和组织的振动特征，研究振动在体表的传播机制。

结果：这种振动可视化技术能反映心脏的机械功能，是一种功能成像，有望成为一种研究心脏振动的新工具。

结论：本文提出的心脏振动可视化技术能够以很高的时间和空间分辨率反映心脏振动特征，具有进一步研究无创心功能检测技术的潜力。

关键字：心脏机械振动，振动传感器，心功能，传感器阵列，功能成像

ID 2347

面向健康监护的内电光调制人体通信方法研究

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目的：针对健康监护数据采集器地电极寄生电容产生的共模噪声干扰等问题。

方法：文本提出了一种基于内电光调制的人体通信信号检测方法。该方法利用人体传输信号对激光器输出的光强度进行直接调制，并通过光电探测器及解调电路完成信号重建。首先，利用传递函数法对内电光调制人体通信系统进行了建模和仿真。其次，通过物理实验验证了模型的准确性，进一步明确了内电光调制人体通信系统的信道特性及优势。

结果：实验结果表明，由于通过隔离接收器对地耦合回路降低了路径衰减，同时抑制了共模噪声，从而提高了信道容量，并潜在地减少检测装置功耗。

结论：相比于体电光调制人体通信检测方法，所提出方法的灵敏度提高了 17.6%，功耗降低了 42.0%，在穿戴式健康监测、远程医疗等领域具有广泛的应用前景。

关键字：人体通信；电光调制；幅频特性；健康监护

ID 2405

可穿戴人体通信系统的动态信道模型及特性分析

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目的：明确人体肢体运动对人体信道特性的影响，是实现可穿戴人体通信系统的前提和基础。然而，已有静态人体信道模型难以模拟连续肢体变化所导致的遮挡效应、反射效应以及返回回路寄生电容的影响。

方法：针对上述问题，本文开展了可穿戴人体通信系统的动态信道模型及特性分析。首先，建立了一种可穿戴人体通信系统的动态信道模型。通过电极模型优化及电容回路参数调整抑制并消除了可穿戴人体通信系统有限元模型中寄生电容的影响。在此基础上，对不同姿态条件的人体通信信道的动态特性进行了仿真分析及物理实验验证。

结果：实验结果表明，基于所建立模型的仿真结果与物理实验结果具有良好的一致性。

结论：人体行走 / 跑步过程中的摆臂运动将对人体信道产生幅度为 3dB 的衰减变化，从而为面向健康监护的可穿戴人体通信系统设计及应用奠定了基础。

关键字：人体通信；有限元；动态特性；健康监护

ID 2420

静电纺丝 PVA/AgNW 电子皮肤制备电场参数优化及其性能研究

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目的：静电纺丝技术可制备高长径比和高孔隙率的纳米纤维网络，可用于制备高可拉伸性和透气性的电子皮肤，是未来电子皮肤大规模工业化制造的首选工艺之一。本研究通过分析制备静电场强度和分布对电纺 PVA 纤维网络和电喷 AgNW 导电墨水的形态和性能影响，探索一种简便有效的制备 PVA/AgNW 导电薄膜的方法。

方法：利用 COMSOL 软件对静电场分布与电压和间距的关系进行仿真；利用 8%-17%PVA 水溶液，在 10-20kV 电压，间距 10-15cm 制备电纺 PVA 纤维网络；利用 0.35wt%AgNW 导电墨水在 25-30kV 电压，5-10cm 间距内在 PVA 纤维表面电喷沉积导电层；SEM 用于表征材料微观形貌，用方阻仪测试导电薄膜导电性。

结果：SEM 图像显示，随着 PVA 浓度和电压的增加，PVA 纤维直径增加，有利于形成大面积的导电区；电喷电压增加和间距缩短使 AgNW 纤维沉积均匀性和分散性提高，有利于提高表面电阻均匀性和稳定性；方阻仪测试显示，PVA/AgNW 导电薄膜的方阻约为 178Ω/ □。

结论：本研究通过探究制备静电场强度和分布对电纺 PVA 纤维网络和电喷 AgNW 导电墨水的形态和性能影响，提出了一种简便有效制备 PVA/AgNW 导电薄膜的方法。

关键字：电子皮肤，静电纺丝，导电薄膜，银纳米线

ID 2443

基于近场耦合的可穿戴非接触呼吸监测装置

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目的：近场耦合（near field coupling，NFC）是检测生物组织电磁特性的新方法，具有无创、穿透性强、可实时连续监测等优势。本文旨在利用 NFC 技术搭建可穿戴非接触呼吸监测装置。

方法：基于近场耦合原理搭建可穿戴非接触呼吸监测装置，其主要由两块电容板、FDC2214 传感器芯片、单片机、ESP8266WIFI 芯片和 PC 端组成。两块电容板在近场范围内施加电场，FDC2214 传感器芯片采集由呼吸改变的电容信号，单片机通过 ESP8266 传输信号给 PC 端进行数据处理以及显示。为验证设备可行性，基于可穿戴非接触呼吸监测装置和多通道生理信号采集仪（RM6240XC）获取 5 名健康志愿者的呼吸数据，并进行 Bland-Altman 对比分析。

结果：通过对可穿戴非接触呼吸监测装置与多通道生理信号采集仪的实验结果对比分析，两套设备测得呼吸频率基本一致，误差为 5% 以内，并且 Bland-Altman 分析结果在 95% 一致性界限以内，符合一致性分析

结论：基于近场耦合搭建的可穿戴非接触呼吸监测装置能够较好地监测呼吸信号，具有无创、便携等优点，有望为呼吸的监测提供一种新的可靠方案。

关键字：呼吸监测、近场耦合、可穿戴非接触式

ID 2538

多功能柔性 MXene 基电子纹身的设计与构筑

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目的：可穿戴电子产品在智能传感器、假肢、人机界面等各种新兴领域引起了越来越多的兴趣。一个重要的挑战是开发多感官设备，即使在动态移动的环境中也能与皮肤共形附着。

方法：我们提出一种基于混合维矩阵网络的电子纹身 (E-tattoo)，它集成了二维 MXene 纳米片和一维纤维素纳米纤维 /Ag 纳米线，用于多感官集成。

结果：多维配置赋予了电子纹身出色的多功能传感能力，包括温度、湿度、平面内应变、接近度和材料识别。此外，得益于混合墨水令人满意的流变性，电子纹身能够通过多种简便的策略进行制作，包括直接书写、冲压、丝网印刷和 3D 打印在各种硬 / 软基材上。

结论：特别是具有优异摩擦电学性能的电子纹身还可以作为激活小型电子设备的电源。我们相信这些皮肤适形电子纹身系统可以为下一代可穿戴和表皮电子产品提供一个有前途的平台。

关键字：MXene，纤维素纳米纤维，多功能，电子皮肤，自驱动传感

ID 2594

基于铅笔 - 纸基的超疏水、可拉伸剪纸结构多功能传感平台

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目的：可穿戴电子产品广泛应用于医疗保健、人机界面、机器人技术等领域。大多数可穿戴电子产品通常成本高昂、制备流程复杂，且基材大多为不可生物降解的聚合物材料，易造成环境污染。

方法：利用生活中最普遍的书写工具（铅笔）在打印纸上快速沉积导电图案，通过浸泡疏水二氧化硅悬浮液和激光切割可拉伸剪纸传感结构，制备了基于铅笔 - 纸基的柔性传感平台，该平台兼具绿色环保、一次性、低成本、超疏水和生物相容特性。

结果：柔性传感平台能够对气体、温度和人体生理电信号进行实时监测。NO_2 气体传感器在室温下表现出 ~1.0% 的大响应量，162/534s 的快速响应 / 恢复时间，以及 6ppb 的超低检测限，并且在应变状态下能保持良好的气体响应。该传感器还可以在 15-120° C 的宽温度范围内保持线性响应和 0.5° C 低温度检测限，可用于水温与人体体温的精确检测。此外，柔性电极能够对人体电生理信号（心电、肌电、脑电信号）进行连续、实时和高保真监测，可用于监测或诊断人体心肺疾病。

结论：通过日常中常见材料制备一次性多功能传感平台，对多种刺激能持续稳定监测。超疏水铅笔 - 纸基多功能传感平台为疾病的早期诊断与治疗，以及人体健康信息管理提供了一种一次性、低成本的解决方案。

关键字：超疏水；铅笔 - 纸基；剪纸可拉伸结构；多功能传感平台

ID 2607

超感生物液电耦合监测精神压力与肌肉疲劳

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目的：本论文研发了超感生物液电耦合监测系统，针对精神压力、肌肉疲劳两个目标检测场景，分别构建丝网传感体系检测相关体液标志物，同时联合皮肤电生理反应检测，实现目标场景的超感生物液电耦合需求。

方法：首先采用唾液皮质醇与皮肤电导联合检测的方式实现精神压力的监测，通过电化学修饰超感纳米衬底，设计完成皮质醇分子印迹检测传感器制作；基于超感生物液电耦合监测系统的电分析多模方式，采用差分脉冲伏安方法进行唾液皮质醇的检测，采用交流电阻抗法进行皮肤电导的实时监测。其次研究了基于生物液电耦合的间质液提取肌肉疲劳检测方法，利用反向离子导入的电刺激提取皮肤间质液，并使用氮掺杂石墨烯修饰特异性传感器识别乳酸、pH、铵离子多模信号。

结果：实现了皮质醇（1-10000 ng/mL）、皮肤电导、pH（3-8）、铵离子（0.1-50 mM）、乳酸（1-50 mM）的检测，为个体精神压力和肌肉疲劳监测提供了较为系统、科学的解决方案

结论：本文提出的超感生物液电耦合监测也为实现更多维度的健康监测目标提供了理想的参考方案。

关键字：生物液电耦合系统；传感器；反向离子导入；生化检测

ID 2879

用于连续无创电生理信号监测的无凝胶海绵电极

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目的：电生理信号的连续、可逆和准确采集在健康监测和疾病诊断中至关重要。对一个合格的无凝胶电生理电极来说，除了在保证高质量获取信号的同时确保低的接触阻抗外，要想保证信号的长期连续稳定监测，电极存储的持久性和二次使用的性能可恢复性变得至关重要。

方法：在这里，我们展示了一种可逆和连续监测的无凝胶海绵电极 (PPEM 电极)，它们是由三聚氰胺海绵 (MS) 和由聚 (3,4- 乙烯二氧噻吩): 聚苯乙烯磺酸盐 (PEDOT: PSS)，聚乙烯醇 (PVA) 和乙二醇 (EG) 组成的混合物，通过真空处理制备而得。

结果：该电极显示出 3.5 kΩ 的低接触阻抗和 10000 次压缩循环的良好机械稳定性。而且，电极表现出长达 6 个月的存储耐久性和阻抗下降后恢复其初始电性能的可逆能力。它们能够持续 8 小时监测表面肌电信号，耐用性可长达 6 个月，并且该无凝胶海绵电极的信噪比优于商用凝胶电极。此外，它们还可以作为干电极或半干电极，用于准确检测包括心电图、脑电图和眼电等生物电位信号。

结论：PPEM 电极优异的存储和性能可恢复能力为连续和长期的高质量电生理信号监测提供了无创和无凝胶电极的途径，向连续长期的健康监测和疾病诊断前进一步。

关键字：PEDOT，无凝胶电极，电生理，可逆性，连续监测

ID 2911

用于监测慢性阻塞性肺疾病（COPD）的柔性传感器研究进展

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目的：慢性阻塞性肺疾病（COPD）作为全球严重的公共卫生问题，是全世界慢性病发病率和死亡率最高的疾病之一。COPD 会降低患者的生活质量并给其家庭带来较重的经济负担，同时诊断不足也是一个巨大的挑战，针对 COPD 疾病研发高精度、低成本、便于穿戴的柔性传感器，实现 COPD 患者生理信号的实时、高精度监测至关重要。

方法：分析了 COPD 患者的重要检测指标，包括呼出气、呼吸频率（RR）、体力活动、动脉二氧化碳分压（$PaCO_2$）等。基于上述检测指标，对现有的可用于 COPD 长期监测的柔性传感器进行研究。

结果：气体传感器可通过检测呼气中疾病标志物诊断 COPD，也可通过检测呼气特征、运动特征、呼吸肌肌电信号的传感器来诊断 COPD。使用传感器可以通过早期检测异常生理测量值来帮助降低 COPD 恶化症状的频率和严重程度，现有的柔性传感器能够初步对 COPD 疾病进行非侵入式的检测。

结论：柔性传感器对 COPD 患者的重要检测指标进行检测，为患者进行早期诊断和实时健康监测提供实用价值。检测 COPD 的可穿戴传感器在智能医疗中会有更深入发展，根据每个患者的预测反应和个人风险量身定制治疗和护理，这是未来智能医疗发展的挑战和趋势。

关键字：慢性阻塞性肺疾病；可穿戴传感器；健康监测

ID 2978

On-chip Electrochemical Detection of MicroRNA Biomarkers from Liquid Biopsies for Early Detection of Prostate Cancer

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Objective: With the overall population aging, cancer will become a bigger problem overtime because cancer disproportionately strikes individuals in the age group 65 years and older. Prostate cancer is the second most commonly diagnosed cancer in male. Statistics from Prostate Cancer UK show that in the UK, 1 in 8 men will be diagnosed with prostate cancer in their lifetime. Every 45 minutes one man dies from prostate cancer. This is more than 12,000 men every year. However, this predicament can be changed if prostate cancer can be diagnosed at early stage. Traditional Methods for prostate cancer screening involves prostate-specific antigen (PSA) test and digital rectal examination (DRE). PSA contributes to most overdiagnosis and overtreatment with prostate cancer, while DRE is not accurate and depend strongly on doctor's clinical experience. An affordable and accurate prostate cancer screening method at early stage is urgently needed.

Methods: MicroRNA (miRNA) is an emerging biomarker for cancer diagnosis. MiRNA141 provides a reliable alternative for early-stage prostate cancer screening compared with PSA and DRE. For miRNA concentration quantification, electrochemical sensor provides both sensitivity and cost-effectiveness compared with RT-qPCR or other fluorescent-based approaches.

Results: Here I present an electrochemical sensor for early prostate cancer diagnosis by using miRNA141 as a biomarker. Two PNA probes was designed and synthesised for the purpose of capturing and sensing of the target sequence respectively. Biotinylated PNA capture probe was immobilized on streptavidin treated screen-printed carbon electrode. The electrochemical detection was carried out using anthraquinone-labelled PNA sensing probe as an electrochemical reporter. The synthesised genosensor provided a linear range from 40 nM to 180 nM, and presented excellent selectivity between complementary and non-complementary sequences.

Conclusion: This study provides a rapid, accurate and cost-effective way of detecting prostate cancer related oligonucleotide biomarker without amplification.

Key words: miRNA; prostate cancer; electrochemical sensor; DNA; early cancer screening

ID 3204

用于触觉传感的自供电多维力传感器

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目的：触觉传感器是人机界面的核心，使机器人或假肢能够灵巧地操纵物体。具体而言，至关重要的是赋予传感器实时检测和区分法向力和剪切力的能力，以便在与物体的交互过程中实现滑动检测和更复杂的控制。

方法：在此，提出了一种基于具有三维结构的摩擦电纳米发电机（TENG）的自供电多向力传感器（SMFS），用于实时感测和分析法向力和剪切力。四个聚二甲基硅氧烷（PDMS）圆柱体充当 SMFS 的力传感结构。由炭黑（CB）/MXene/PDMS 复合材料制成的柔性尖端阵列用于在外力驱动 SMFS 时产生摩擦电信号。

结果：由于 PDMS 圆柱体的适应性，SMFS 可以检测多维力，并且由于柔性尖端的灵敏度，SMFS 能够检测微小力。SMFS 可以识别低至 50mN 的小剪切力。通过分析 SMFS 的位置和输出电压幅度，可以识别外部施加的力的方向。

结论：此外，SMFS 还实现了触觉传感应用，包括试剂称重和力方向感知，这表明了在推动自供电可穿戴传感器、人机交互、电子皮肤和软机器人应用的发展方面的潜力。

关键字：剪切力；触觉传感；多维力传感器；自供电；TENG

ID 3245

Sensitive Detection of Mercury Ion Based on Field Effect Transistor Sensors Using Single-walled Carbon Nanotubes

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Objective: Mercury ions, due to the high toxicity and long-lasting bioaccumulation, can have huge pollution to soil/water and brings threat to human health. Therefore, it is urgent to develop Hg2+ detection Methods in the environment with high sensitivity and selectivity.

Methods: In this study, ssDNA for Hg2+ detection was absorbed on the surface of single-walled carbon nanotubes (SWNTs) by using 1,5-diaminonaphthalene (DAN). The interaction between ssDNA and Hg2+was directly converted into electrical signals based on SWNT sensors.

Results: The limit of detection (LOD) was 42.6 pM. The sensitivity of the biosensor combined with a phase-locked amplifier to detect Hg2+ was further improved. The detection limit was as low as 5.14 pM.

Conclusion: This sensor has an excellent selectivity. It is expected to be used for the detection of other biomolecules due to its simple manufacturing process and excellent sensing performance, which is significant for potential application in the research areas of environmental chemistry, analytical chemistry, and clinical diagnosis.

Key words: Hg2+ detection, Sensors, High sensitivity, Single-Walled carbon nanotubes, ssDNA

ID 3254

Real-time Plasmonic Nanoparticle Monitoring at Single Particles Level via Microsphere Assisted Scattering Image

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Objective: Metallic nanoparticles support collective oscillation of the conduction band electrons induced by incident electromagnetic radiation, known as the phenomenon of localized surface plasmon resonance (LSPR). The acquisition and analysis of LSPR spectral information have been widely used in many research directions. However, the scattering light that carries the LSPR spectral information of single plasmonic nanoparticle is relatively weak. Conventional imaging approaches such as dark-field microscope (DFM) require long acquisition time, high-power illumination sources and special objectives with high numerical aperture. This Results in low time resolution and expensive instrument costs. Here we report that dielectric microspheres can be utilized to excite and collect the scattered light of the plasmonic nanoparticles and achieve the light-scattering imaging of single plasmonic nanoparticles under conventional light microscope. We further use this technique to monitor individual nanoparticle adsorption events on the substrate in real time.

Methods: Conventional barium titanate glass (BTG) dielectric microsphere with size of ~22 μm are coated on the glass substrate with a layer of polydimethylsiloxane (PDMS). The sample is modified with positive surface charges. Citrate gold nanoparticles with diameter of 100 nm are dropped on the dielectric microsphere lens. The sample is characterized under a conventional inverted microscope with 40′ Objective and CCD camera under reflected light path. The gold nanoparticles adhere on the substrate due to the electrostatic force. The back scattering light of the nanoparticles in the photonic hotspot can be recorded and imaged.

Results: Single nanoparticle can be distinguished clearly with a high signal-to-noise ratio in the image. The process of a single nanoparticle adhesion event can be monitored at millisecond scale.

Conclusion: The light-scattering imaging method for plasmonic nanoparticles will assist in realizing of fast LSPR acquisition and high sensitive LSPR based biosensors, as well as providing a platform for investigating plasmonic nanoparticle based fast interaction processes.

Key words: single particle, microsphere assisted scattering image, real time monitoring, surface plasmon resonance

ID 3280

Ultrasensitive Plasmonic Detection of Mirna Based on Lateral Displacement Measurement

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Objective: MicroRNA-21(miRNA-21) plays an important regulatory role in the proliferation, differentiation and apoptosis of cancer cells, which makes it a reliable biomarker for the early diagnosis of cancer. However, traditional analytical strategies for miRNA detection such as RT-qPCR or electrochemical Methods require either additional amplification or labeling procedures and may cause cross hybridization problem. As a result, surface plasmon resonance (SPR) technology has become one of the most potential biosensors due to its advantages of label-free, real-time, dynamic monitoring abilities and good stability. Nevertheless, limited by the detection sensitivity, traditional SPR biosensors based on wavelength or angle are difficult to detect biomarkers

with small molecular weight or low concentration. To overcome this challenge, we have proposed an optical biosensor based on the detection of lateral displacement known as Goos–Hänchen (GH) shift for miRNA detection.

Methods: The GH shift signal change appears to be more drastic than the phase change, which greatly enhancing the signal strength and sensitivity. In this paper, a highly sensitive SPR detection device based on GH shift measurement is designed with prismatic SPR sensor as the core component, combined with signal detection and control system and other peripheral equipment. To realize efficient miRNA detection, we first immobilized capture DNA-probe onto our plasmonic substrate. Then, 1mM MCH solutions were injected into the microfluidic chamber as the blocking agent to prevent non-specific binding. Then,by measuring the real-time GH shift signal, the binding process of miRNA can be monitored.

Results: The experimental Results showed that this SPR biosensor based on the lateral displacement detection mechanism has successfully detected miRNA-21 with concentration down to 1 fM.

Conclusion: We can assert that our SPR biosensing platform provides a promising tool for the effective detection of miRNA-21 and possibly many other tumor biomarkers in clinical diagnosis.

Key words: miRNA detection; Surface plasmon resonance; Phase singularity.

ID 3331

基于无线无源柔性电化学系统的可穿戴生化传感检测研究

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目的：采用无线无源电化学系统，探讨柔性可穿戴传感技术在机体生化传感检测领域中的应用。

方法：基于近场通讯（NFC）和印刷电子技术，构建了一种无线无源的柔性可穿戴电化学传感系统。该系统由全印刷的可拉伸纳米线电极阵列和柔性电路板组成，通过智能手机 NFC 模块即可对系统进行无线供电，并实现待测生化信号的实时无线采集、处理和传输。

结果：通过可穿戴技术与贴皮式、摄入式、植入式等多种检测方法中的生化传感检测设计，实现了汗液等多种体液成分的分析、呼出气成分监测，以及伤口感染的监测和治疗等创新应用。

结论：基于无线无源传感检测，通过可穿戴生化传感器件的柔性化、集成化和小型化，有助于实现分子水平上的健康监测及疾病防治，具有重要的生物传感意义和广阔的应用前景。

关键字：柔性电子，可穿戴技术，无线无源，近场通讯，电化学传感

ID 3374

Dielectrophoretic Trapping Enhanced Plasmonic Biosensing

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Objective: Surface plasmon resonance (SPR) technique has been widely used in biological and chemical applications owing to its label-free and real-time characteristics. However, when detecting target molecules with concentration down to pM or fM level, the detection is highly limited by the diffusion-based mass transport of analytes onto the plasmonic

substrate. To overcome this limitation, we have developed a dielectrophoresis (DEP)-enhanced SPR chip based on an array of interdigital Au electrodes to realize enhanced biosensing with higher sensitivity and shorter response time.

Methods: Here, we have utilized DEP effect to enable the active mass transport of target biomolecules. In this way, molecules are enriched on the surface of the electrode, which largely increases their local concentration in the sensing area. Therefore, the detection sensitivity can be further enhanced with a reduced response time. We have established a theoretical model of the DEP-SPR chip through Comsol software. In this model, the effect of electrical field intensity, fluid velocity, as well as different electrode spacings (EG = 5, 10, 15, 20μm) on DEP trapping performance has been analyzed.

Results: Simulation Results showed that our DEP-SPR chip can realize the efficient trapping of target biomolecules. Compared with traditional SPR sensing limited by diffusion, the Results presented here indicate that DEP-SPR chip can achieve a much higher detection sensitivity and shorter response time. The proposed scheme shows great potential in rapid and sensitive detection of biomolecules.

Conclusion: The Results presented here indicate the great potential of the incorporation of DEP into SPR biosensors for rapid, sensitive, and specific detection of bacteria with broad applications in areas of biomedical diagnostics, environmental monitoring, food safety, and homeland security.

Key words: Dielectrophoresis; Surface plasmon resonance; Enhanced biosensing;

ID 3421

A Miniaturized ECL Microscopic Platform Based on Lens-free CMOS Imaging

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Objective: Developing a simple, sensitive, and miniaturized electrochemiluminescence (ECL) microscopic platform will enable applications in both biosensing and diseases diagnosis at the point-of-care settings. However, this has been challenging because it requires complicated optical instruments to capture the photon signals from the chemiluminescent reaction. With the ever-improved performance and low cost, complementary metal-oxide-semiconductor (CMOS) imagers serve as a good platform for ultra-compact lens-free microscopic imaging systems with the outstanding superiorities of high resolution and wide field of view.

Methods: Here, a lens-free ECL micro imaging platform, which combined lens-free microscopy imaging strategy and ECL reaction system, were innovatively established. We show that a CMOS imager can be turned into an ECL micro imaging chip (CMOS-CL). By integrating a transparent ITO electrode on the imager surface, the photon signals from the ECL reaction can be sensitive captured, and analyzed with an automatic image processing system. To demonstrate the capability of this system, we adapted it to a typical luminal ECL application for glucose detection. The ECL imaging signals were produced by transporting enzymatically produced co-reactant H2O2 to the working electrode surface to initiate electrochemistry catalyzed luminol-H2O2 ECL and ECL resonance energy transfer reactions.

Results: The ECL imaging platform showed excellent detection sensitivity of glucose with a wide dynamic range (15μM -500 μM) and the assay can be performed within 15 min. The device showed high reproducibility while maintaining good linear relationship and high selectivity for glucose detection. Moreover, a satisfactorily detection of glucose in urine samples was also successfully carried out, showing good application prospect in clinical point-of-care diagnosis.

Conclusion: This work will pave an effective way for the establishment of general and robust on-chip ECL platforms. Furthermore, this strategy may be expanded to chemiluminescence (CL), florescence, and other imaging detection systems.

Key words: biosensor chip, miniaturized sensor, lensless imaging, ECL imaging

ID 3504

基于多视角融合的非接触式心率监测系统

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目的：一直以来，成像式光电容积脉搏波技术（IPPG）在非接触式生理参数监测系统中有广泛的应用，近年来，基于视频的非接触式生理参数监测越来越成熟。但是，目前市面上仍然没有非接触式测量产产品，依据 IPPG 的非接触式测量产品主要还是无法全面监测人体健康参数，当用户头部偏移过大时，该系统无法获得有效数据。针对以上问题，本文提出一种融合对视角图像的非接触式生理参数监测方法。

方法：主要是应用多摄像头，结合头部姿态估计合理设计摄像头布置方案，应用多视角融合的方式进行与原始 IPPG 信号采集，实现人体前方 180 度范围内图像的实时采集，避免图像的丢失，形成完善的 IPPG 信号，有效的实现心率的实时监测。

结果：经实验验证，心率误差在 4 次每分钟左右

结论：基于多视角融合的非接触式心率监测系统可以满足日常监测需求。

关键字：IPPG；姿态估计；多视角融合；心率

ID 3517

局部受力自适应调节防褥疮充气床垫控制系统设计

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目的：针对长期卧床患者身体姿态调节的需求，本研究展开了局部受力自适应调节防褥疮充气床垫控制系统设计，结合物联网和云计算，通过实时监测患者的体压分布情况判断压力热点区域，并进行针对性的动态调整，以期有助于预防压疮的发生，减轻护理人员负担。

方法：设计基于端 - 边 - 云结构智能监护系统展开，以防褥疮充气床垫作为感知端之一，结合长期卧床患者从体位及舒适度感受、减少褥疮发生的需求，集成软硬件技术，开发控制算法，实现基于充气床垫调节身体局部受力的自适应控制。设计包括体压检测系统与气动控制系统，根据人床界面压力变化情况调节充气床垫相应气囊充放气，从而改变局部受力分布，达到预防压疮的作用。

结果：系统搭建完成后，基于健康志愿者就卧床压力分布的变化规律展开测试，局部受力自适应调节防褥疮充气床垫控制系统通过调节卧床者人床接触面积，减小人体最大压强与平均压强，有效分散卧床压力，实现人床压力分布均化。

结论：本研究基于气动床垫初步探究了卧床患者人床接触的局部受力调整策略，为长期卧床患者实现远程监护提供了依据。

关键字：压疮；人体压力分布；自适应调节；阀岛；气垫床

ID 3533

自驱动无线可穿戴在体尿液检测系统

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目的：可穿戴、自供能的带有无线反馈系统的电子设备在紧急情况下可以挽救人类生命，尤其是随着老年人、婴儿和残障人口的迅速增长，对特殊可穿戴护理设备的需求显著增加。例如，高全球婴儿死亡率主要由于睡眠中的突发性婴儿死亡综合症，这为新生儿重症监护或日常生活中监护给予提出了新的挑战。

方法：在这里，我们开发了一种无线、可穿戴和自供能的尿监测系统。该系统具有反馈警报功能，可实现监测姿势和尿液中的生化指标。其中，湿气激活的自供电器件（MEG）可以持续为监测系统提供高达 0.6 mW 的瞬时能量。由超低功耗三轴加速度计捕捉姿势变化并反馈用户，通过两通道微流控电化学方法测量尿液生物标志物（pH 和尿酸）。整个检测系统采用柔性基底和防水封装制造。该系统可应用于纸尿裤上，作为实时反馈跟踪姿势和尿液中的生化物质检测平台，以保障及时的指标检测和健康安全的生活。

结果：该系统实现了良好的体外和在体测试，和标准仪器相比，本研究提出的具有无线报警功能的可穿戴自供电排尿监测系统，可监测运动姿势、pH 值和尿酸。

结论：通过监测运动和尿液生化指标，实现纸尿裤生命周期中对纸尿裤使用者的全过程保健。最终通过闭环反馈和排尿提醒实现原位尿液分析和个人健康监护。

关键字：自驱动系统；可穿戴设备；无线系统；纸尿裤；尿液检测；姿态监测

S06
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ID 101

Biomechanical Analysis of an Osteocyte Model by Considering Bone Matrix's Piezoelectricity

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Objective: A finite element (FE) model of lacunar-canalicular system (LCS) considering piezoelectric bone matrix was established by COMSOL Multiphysics software. In this paper, the model consists of an ideal charged ionic fluid within the LCS which surrounding the osteocyte process and osteocyte cell body.

Methods: Differences in mechanical signals sensed by three mechanoreceptors in the LCS which triaxial loads are applied to the bone matrix have being focused on research, and compared with the piezoelectric-free bone matrix model.

Results: The Results show that the bone matrix generates an electric field in the direction of polarization when a triaxial loads are applied, due to the piezoelectric effect, the fluid still flows when the load is applied to the maximum, and is more pronounced in the direction of the electric field. The presence or absence of piezoelectric has no effect on the strain signal felt by the collagen hillock, However, the strain in the piezoelectric model is greater than that in the piezoelectric-free model for the osteocyte process in contact with the collagen hillock, the change in strain felt by the primary cilia is much more pronounced. Compared with strain-amplification factor, primary cilia are optimal mechanoreceptors for any signal, osteocyte process are more pronounced for sensing signals with piezoelectricity, The role of collagen hillock is to effectively amplify mechanical signals.

Conclusion: A lacunar-canalicular model by considering piezoelectric bone matrix was established.The model provides a theoretical reference for piezoelectric signal changes sensed by osteocyte and the established model can be used for studying the mechanism of bone mechanotransduction at the micro-level.

Key words: Osteocyte, lacunar-canalicular system (LCS), Piezoelectric effect, Biomechanics

ID 480

Inside-out Accurate Head Tracking with Head-Mounted Augmented Reality Device

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Objective: External Ventricular Drainage (EVD) is a widely used procedure in neurosurgery that is restricted in accuracy and reproducibility due to free-hand operation. Augmented reality (AR) improves punctuation success rate by superimposing virtual paths on the operation area. However, the effectiveness of surgical guidance is affected by tracking accuracy. This paper aims to achieve accurate and stable head tracking during EVD surgery.

Methods: We propose a dynamic inside-out tracking method combining retro-reflective markers and point clouds. First, built-in infrared depth sensor of HoloLens 2 is used to identify markers pasted on patient's head for coarse registration of preoperative images and intraoperative patient. Real-time 3D point clouds and point-to-plane ICP registration are then used to further improve tracking accuracy and stability. Meanwhile, we calibrate and correct the depth distortion of the HoloLens 2 depth sensor on different materials, improving the accuracy of point cloud-based tracking methods.

Results: The root mean square error (RMSE) of preoperative registration is less than 1.6 mm; average RMSE of intraoperative head tracking is less than 1.28 mm. Meanwhile, average angular tracking jitter is reduced by more than 40% when integrating point clouds. The proposed method can achieve 37.7fps tracking.

Conclusion: The retro-reflective marker and point cloud hybrid tracking method in this paper can achieve high-precision real-time head tracking, providing the potential for accurate visual guidance in EVD surgery.

Key words: Augmented Reality, Head Tracking, Point Cloud, Surface Reconstruction

ID 564

A Model-Guided Method for Ultrasound Probe Calibration

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Objective: Ultrasound (US) probe calibration is critical for the localized ultrasound system. Key points and surfaces are often used for calibration, whose accuracy is restricted by the ultrasound volume effect. The aim of this paper is to accurately calibrate the US probe under volume effect.

Methods: We present a model-guided ultrasound probe calibration method, to provide accurate calibration Results under volume effect. First, we design a rotationally symmetric calibration phantom unit to provide image areas weekly affected by volume effect during continuous scanning. Second, US images from the uncalibrated probe are used to reconstruct the 3D image volume. Finally, we use image registration and point registration for super-resolution unification of US images, the model and the tracking device.

Results: In multiple probe calibration experiments at different probe depths, the average calibration precision was 0.163 mm; in the needle tip tracking experiment, the average detection accuracy was 0.335 mm.

Conclusion: Guided by the specially designed model, our method can realize precise and accurate ultrasound probe calibration under volume effect.

Key words: Ultrasound probe calibration; Volume effect; Model-guided; 3D reconstruction

ID 637

Real-time Medical Tool Runout Monitor Based on Dual Laser Displacement Sensors

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Objective: Robot-assisted drilling or milling is used widely in surgeries concerning bones, which is restricted in precision and safety due to tool bit runout. This paper aims to achieve real-time accurate runout status monitor, to support safer surgeries.

Methods: First, a rigid tool runout model is constructed. An orthogonal dual laser tracking structure and relevant calibration Methods are then proposed. An algorithm is finally proposed to realize tool tip tracking under eccentrical load with the tool model and tracking structure.

Results: The experiment under no load indicated a high accordance between the model and the measurement. Relative errors of 8.11% and 14.96% were presented in accuracy tests on x and y, respectively, while 5.5μm and 6.2μm absolute error were presented for precision. Moreover, the method was able to differentiate different stages during drilling under eccentrical loads. The calculation efficiency reaches 1736fps.

Conclusion: The proposed method can provide real-time accurate surgical drilling tool position status, proving the potential to improve the safety of surgeries.

Key words: Robotic Surgery, Drilling, Runout, Tracking

ID 702

Correction of Premature Closure of Sagittal Suture with Small-incision Traction Bow

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Objective: Premature closure of cranial suture is a disease in which skull suture fuses prematurely, which leads to deformity of skull, and then affects brain development and even endangers life. Traditional surgery can only remove part of the skull after craniotomy, so as to increase the cranial cavity space and avoid restricting the growth and development of the brain. However, the operation is traumatic, and the sagittal sinus is located below the sagittal suture, which has a large amount of blood supply, and the risk of massive hemorrhage is very high.

Methods: Through the simulation analysis of skull reconstruction in children, this study designed a minimally invasive incision, combined with the self-developed memory alloy traction arch, which avoided the destruction of sagitt.Through

the application of binocular vision navigation system during operation, the position of traction arch before operation and the osteotomy line during operation can be accurately navigated to the operation field.

Results: In this group, three cases of early closure of the sagittal suture were corrected, and the skull shape was satisfactory. Upon follow-up for 12–24 months, the average anterior and posterior cranial diameter showed an increase of 16.72 mm (11%) from 151.07 mm before the operation to 167.79 mm after the operation. The average transverse diameter of both temporal parts was 112.29 mm before operation and 131 mm after operation, which is an increase of 18.71 mm (16.7%). .

Conclusion: The use of a small-incision traction bow to correct premature closure of the sagittal suture is worth popularizing and perfecting. Compared with previous surgical methods, this operation is favored by an increasing number of children and their families as it has low risk, low cost, and high efficiency. Problems in surgical methods, design, and other links need to be addressed through further studies.

Key words: Early closure of sagittal suture, memory alloy traction arch, visual navigation

ID 748

YOLOv7-Based Multiple Surgical Tool Localization and Detection in Laparoscopic Videos

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Objective: The aim of this research is to explore the potential of deep learning in laparoscopic videos for the localization and detection of multiple surgical tools. The specific objectives are:

To evaluate the performance of YOLOv7;

To analyze the accuracy of YOLOv7;

Compare the accuracy of YOLOv7.

Methods: Deep learning algorithm based on YOLOv7

Results: The model achieved an average precision of 98.6%.

Conclusion: This paper presents a novel application of the YOLOv7 deep learning algorithm for multiple surgical tool detection in laparoscopic videos. The Proposed approach is based on a combination of object localization and detection techniques, which enables more precise Results than traditional methods. Experiments were conducted using a publicly available dataset to evaluate the performance of the proposed model. The result of the experiment demonstrates that the YOLOv7 model can detect and localize multiple surgical tools in laparoscopic videos with an average precision of 98.6%, switching its potential as an effective tool for medical professionals working with laparoscopic video data. Furthermore, the work provides valuable insights into the application of deep learning for medical image processing and computer vision application including effectively applied to a real-world problem such as surgical tool recognition in endoscopy videos.

Key words: Deep Learning, Laparoscopic Videos, YOLOv7, Surgical Tool Localization and Detection, Multiple Object Detection.

ID 792

Robot-assisted Optical Coherence Tomography for Automatic Wide-field Scanning

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Objective: Optical coherence tomography (OCT) is a three-dimensional, non-invasive, high-speed imaging modality capable of providing micro-scale tissue images in real-time. OCT is widely used in clinical practice and is a promising method for optical biopsy. However, the lateral imaging range at the millimeter level makes it unable to cover larger regions of interest, and the limits of focal depth range make the distance between the probe and the tissue demanding.

Methods: Here, we present a flexible robotic OCT system that enables automatic wide-field imaging on arbitrary tissue surfaces with high resolution. We developed a servo control method based on real-time 3D OCT images to achieve accurate localization of the scan head with six degrees of freedom (DOF). After completing the imaging of multiple preplanned points, we use the robotic pose and the collected image information for coarse-to-fine registration and stitching to achieve an ultra-wide imaging range.

Results: We verified the system's performance by scanning experiments on samples and biological tissues. Qualitative and quantitative Results demonstrated that the system could achieve accurate positioning, scanning, and image stitching, and has better flexibility and higher degree of automation than existing systems.

Conclusion: The proposed robot-assisted OCT imaging system could realize automatic high-resolution and wide-field imaging on complex tissue surfaces. It may be helpful in the fields of lesion boundary identification, precise surgical guidance, and intelligent theranostics.

Key words: Robot-assisted imaging, optical coherence tomography, image stitching, optical biopsy.

ID 820

Adversarial Detection and Defense for Medical Ultrasound Images: From a Frequency Perspective

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Objective: B-mode ultrasound imaging is a popular medical imaging technique, and deep neural networks (DNNs), like other image processing tasks, have become popular for the analysis of B-mode ultrasound images. However, a recent study has demonstrated that medical deep learning systems can be compromised by carefully-engineered adversarial attacks with small imperceptible perturbations.To address the problem that deep medical ultrasound classification systems are vulnerable to attacks, we propose a simple but effective ultrasound adversarial sample detection method to improve the stability of the system.

Methods: First, the ultrasound image is transformed from spatial domain to frequency domain to obtain the spectrum, then the coefficient of variation of the spectrum is calculated, and finally, the value of the coefficient of variation is compared with the set threshold: greater than the threshold is the inverse sample, and less than the threshold is the original sample.

Results: Extensive experiments on two publicly-available ultrasound datasets, i.e., Breast ultrasound and Thyroid ultrasound datasets, have demonstrated that the hereby proposed defense method can detect the adversarial attacks of ultrasound images with a high mean accuracy.

Conclusion: This study first analyzes the adversarial attacks of ultrasound images from a frequency perspective, and proposes an easy-to-use adversarial example defense method that only needs a simple frequency domain conversion to detect the ultrasound adversarial examples, with no need for model retraining. Extensive experiments on two publicly available ultrasound datasets have illustrated that this method can be generalized to different attack Methods and acquire high defense accuracy. In short, the present work emphasizes the importance of considering frequency analysis in the case of designing defenses for ultrasound images.

Key words: Adversarial attacks, Ultrasound images, Defense

ID 865

Feature-oriented Lesion Segmentation Based on CT Images of Acute Cerebral Hemorrhage

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Objective: Stroke is a potentially fatal cerebrovascular disease with a high morbidity and mortality rate. Rapid and accurate diagnosis of cerebral hemorrhage, assessment of hemorrhage volume, and prediction of its progression are essential. Automatic and accurate segmentation of the hemorrhagic lesion and the extent of hemorrhage in CT images of acute cerebral hemorrhage and 3D visualization and localization of the hemorrhage points can provide a database for clinical assessment of the amount of cerebral hemorrhage and prediction of its progression.

Methods: We performed targeted pre-processing of brain hemorrhage images by removing irrelevant parts such as machine tool head-occipital, trained automatic segmentation by fusing attention gating mechanism with recurrent residual convolution structure on the famous U-Net network structure and performed 3D reconstruction using surface drawing after the segmenta-tion was completed.

Results: Our experiments were conducted on two-dimensional slices of CT images collected from 203 patients in the emergency department of Tiantan Hospital. The test set was divided into easy-to-diagnose images test1 and difficult-to-diagnose images test2. We measured using segmentation boundary accuracy, volume accuracy, and position accuracy and obtained better segmentation compared to other U-shaped structure models with frontier models in several metrics test1: Dice=0.921, IoU=0.860, ASD=1.562, RVE=0.109: test2: Dice=0.666, IoU= 0.553, ASD=14.195, RVE=0.931. Also, we achieved 3D visualization and localization of the lesion based on the segmentation Results with the patient's cranial CT images.

Conclusion: Structural improvement of the convolutional neural net-work by the features of the segmentation region can have a facilitating effect on the segmentation results. In addition to this, deep learning Methods have the potential for the applica-tion of segmentation of acute cerebral hemorrhage lesions.

Key words: acute cerebral hemorrhage; image segmentation; convolutional neural network; three-dimensional reconstruction

ID 882

A Novel Model-Independent Approach for Autonomous Retraction of Soft Tissue

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Objective: Surgical robots have played an important role in guiding surgery toward precise interventions and targeted therapy. Aim to provide standard surgical solutions, autonomous surgical robotic systems can potentially improve the reproducibility and consistency of robot-assisted surgery. In robot-assisted minimally invasive surgery, a large portion of the time is spent in repeated retraction and manipulation of the tissue to expose the area of interest. This procedure of tissue retraction requires extensive interaction with soft tissue which has heterogeneous physical and geometric properties, with high inter and intra-subject variability.

Methods: In this study, we propose a novel model-independent training methodology for the retraction and manipulation of deformable tissue in robotic surgery. To automate deformable tissue retraction, we use contrastive optimization to learn the underlying visual latent representations of deformable tissue. Then we use an improved version of DDPG with asymmetric inputs to train an agent in a simulation environment.

Results: To evaluate the effectiveness of our method, we tested our approach based on three different criteria: sample efficiency, accomplishment degree of the task and safety level indicator of the task. Our virtual scene simulates the tissue retraction task during an adrenalectomy procedure. We compared our approach against the state-of-the-art method CURL. Our method can especially accomplish safe tissue retraction task in constrained situations.

Conclusion: We present a novel model-independent vision-based method for retraction and manipulation of deformable tissue in robotic surgery. This method does not need to collect expert demonstrations and can learn visual latent representations of deformable tissue from merely RGB images. Experiments in simulation environment on three different criteria showed that our method demonstrated a higher accomplishment degree of the task and could especially accomplish safe tissue retraction task in constrained situations, avoiding overstretch of the tissue. The proposed method indicates the potential for autonomous control Methods to be used in clinical environments.

Key words: robotic surgery, deformable tissue manipulation, autonomous manipulation, deep reinforcement learning

ID 917

A Soft Robot Using Magnetic-pneumatic Hybrid Actuation that Functions in Unstructured Environments

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Objective: Soft robots show greater medical and industrial application value for their potential miniaturization, inherent compliant softness, and adaptability to unstructured environments than conventional rigid counterparts. However, it remains challenging to simultaneously guarantee carrying load capacity and moving flexibly in unstructured environments and confined spaces. In the present work, we propose a novel magnetic-pneumatic hybrid-actuated soft robot for locomotion in unstructured environments for biomedical and industrial applications.

Methods: We fuse magnetic and pneumatic actuation on a millimeter scale. Design concept and fabrication are inves-

tigated for robots' optimal design and fast fabrication. Motion gait is analyzed for better motion control and fast locomotion. Experiments on various condtions are tested for Validating the feasibility of robots in industrial and medical scenarios.

Results: The hybrid-actuated soft robot is tested in different conditions, including locomotion on varied planes, slopes, and pipes. To explore its potential for clinical application, we tested the robot's motility in scenarios such as a gastric phantom model, a respiratory tract phantom model, a vascular phantom model, a large intestine phantom model, and a porcine colon. Vertical crawling is achieved with using two electromagnetic coils and one air tube. Robots' motion capability of carrying the image acquisition device is also tested. The soft robot can walk on the uneven and wet pig intestine surface and release drugs to the target location by using only one tube.

Conclusion: The present paper presents the design, fabrication and motion analysis of the hybrid-actuated soft millirobots. We fuse the magnetically and pneumatically actuated Methods to meet application requirements for unstructured environments. locomotion experiments demonstrate that the proposed soft millirobot shows potential industrial and medical application values to perform closer inspection and manipulation in unstructured and constrained environments. It is of great significance for reducing patient suffering and improving surgical efficiency in medical application.

Key words: soft robot, magnetic-pneumatic actuation, unstructured envi-ronment

ID 924

A VR Environment for Cervical Tumor Segmentation though Three-Dimensional Spatial Interaction

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Objective: Brachytherapy is an efficient clinical treatment way for cervical cancer, which is one of the most common gynecological malignancies. Traditional manual cervical tumor segmentation is a massive and time-consuming task, and we tend to enhance the segmentation efficiency.

Methods: In this study, we present a novel virtual reality environment that supports cervical tumor 3D segmentation using user hands and spatial pan. We created a cervical imaging visualization platform, included the 2D and 3D medical image display and an interactive plane that connects 2D and 3D medical images. Furthermore, we proposed a 3D spatial interaction method that combines free-hand interaction with an optical localization-based interactive pen, which is both convenient and efficient.

Results: We built a prototype and verified the feasibility of the proposed environment through user research.

Conclusion: Our prototype was well received by the participants, and the average tumor segmentation time was around 5 minutes. We hope to improve our environment in future.

Key words: Virtual reality, human-computer interaction, in-situ interaction, 3D volume rendering, floating autostereoscopic display

ID 941

An Image Fusion Method Combining the Advantages of Dual-mode Optical Imaging in Endoscopy

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Objective: In recent years, endoscopic imaging technology has developed rapidly. Dual-mode optical imaging (DMOI) technology in endoscopy can rapidly image the same position of the mucosa in living tissue with two optical modes. They include white light imaging (WLI) and compound band imaging (CBI), and the images of these two modes are complementary in advantages. It is important to fuse their features to improve the image quality of endoscopy.

Methods: WLI is the most common mode of endoscopy. CBI is a virtual optical staining technique that uses a narrow-band light source to highlight the tiny vascular structures of the gastrointestinal mucosa. The fast imaging of DMOI at the same location makes it possible to integrate WLI and CBI images. In this study, according to the characteristics of the two images, an image fusion network based on proportional maintenance of gradient and intensity is used for image fusion.

Results: A volunteer experiment was conducted in this study. The oral images of volunteers were taken for the training and testing of the fusion network, and the Results of image fusion were obtained. We objectively evaluated the quality of the fused images and compared them with the WLI images. The Results show that the fused images obtained by our method have natural color and rich details, and the visual quality of the image is significantly improved.

Conclusion: This study is the first to propose the image fusion of DMOI in endoscopy. Our method can combine the advantages of WLI and CBI images, which can help doctors make more accurate judgments in clinical examination, and has important significance for improving the detection rate of early lesions.

Key words: Endoscopy, Dual-mode optical imaging, Image fusion, PMGI

ID 1119

Establishment of Digital Diagnosis and Treatment Platform for Zygomatic Complex Fracture Based on Artificial Intelligence

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Objective: Diagnosis of zygomatic complex fracture is difficult and treatment managements are diverse and complex. Inaccurate diagnosis and treatment may lead to a poor prognosis. The study aimed to establish an artificial intelligence diagnosis and treatment platform for classification diagnosis, treatment decision and prognosis prediction of zygomatic complex fracture basing on multi-modal clinical database.

Methods: We selected patients with fresh zygomatic complex fracture that treated in our hospital in recent 10 years as research objects. Maxillofacial Spiral CT and complete medical records that before and after treatment (more than half a

year) were collected. Fracture classification, pre-treatment information, treatment plans and prognoses were recorded in standard format as algorithm training data so that a standardized multi-modal database was established. Region detection algorithm based on U-Net and fracture classification algorithm based on ResNet were trained to establish the diagnosis and classification model of zygomatic fracture. A multi-modal database including image and text information was involved as training samples, and XGBoost algorithm was considered as the basis model to establish the treatment decision and prognosis prediction model of zygomatic fracture.

Results: So far, a total of 600 cases of zygomatic complex fracture were included in the fracture diagnosis model. After training, the accuracy of fracture diagnosis model was 100% and total accuracy of fracture classification model was 85%. A total of 470 patients with zygomatic complex fracture including treatment plans were included in the study, the accuracy of treatment decision model was 88.9% (AUC, 0.814). 350 patients with prognostic information were included, the accuracy of prognostic model was 90.8%. (AUC, 0.801), which showed good model performance.

Conclusion: The classification diagnosis model of zygomatic fracture based on CNN and the treatment decision and prognosis prediction model based on XGBoost algorithm were proved to be certain accuracy and reliability, which can be applied in clinical diagnosis and treatment.

Key words: artificial intelligent, classification diagnosis, treatment decision, prognosis prediction, zygomatic complex fracture

ID 1172

Clinical Accuracy Verification of the Orthognathic Surgical Reconstruction Network (OSR-Net) of Bone Tissue Position after Orthognathic Surgery

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Objective: To establish an orthognathic surgical reconstruction network (OSR-Net) base on CBCT data for predicting bone tissue after orthognathic surgery in patients with skeletal class III maxillofacial deformity, and to evaluate its clinical accuracy.

Methods: Twenty patients with skeletal class III maxillofacial deformity who underwent orthognathic surgery in our hospital and had complete pre- and post-op CBCT data were selected. The data were imported into the OSR-Net established earlier, OSR-Net is a data-driven surgical reconstruction algorithm. Given pre-op CBCT, we estimate dense displacement vector field to account for the surgical deformation. We infer the rigid transformation of underlying movable anatomical pieces of the maxilla and the mandible and introduce piecewise rigidity constraints for explainable surgical reconstruction. The algorithm can directly output the predicted bone tissue CBCT data. The predicted bone tissue and the post-op actual bone tissue were segmented according to the post-op osteotomy line, and then imported into Geomagic Studio 2013 software in STL format. The maxilla and mandible bone blocks were refined into 13 regionsand the prediction accuracy of each region was compared and expressed as root mean square error (RMSE). The bone tissue landmarks A、B、ANS、PNS、Pog and NP，which of the maxilla, mandible and chin were selected to evaluate the actual and predicted displacements after surgery, If the RMSE value and landmarks error were within 2mm, the prediction was considered clinically acceptable.

Results: In terms of the accuracy of bone tissue segmentation, most regions reached the clinically acceptable range（≤2mm）, and the accuracy of teeth（2.55±0.73mm）and chin（2.48±0.67mm）was not acceptable. Except for the chin in the anteroposterior direction（2.35±1.91mm）, the difference between the predicted displacement and the actual

postoperative displacement reached the clinically acceptable range.

Conclusion: OSR-Net was successfully established, and the prediction accuracy of bone tissue basically reached the clinically acceptable except teeth and chin region.

Key words: Deep convolutional neural network; Orthognathic surgery; Bone tissue prediction; Clinical accuracy verification

ID 1218

Automatic Reduction of Unilateral Zygomatic Fractures Based on ICP Algorithm: A Preliminary Study

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Objective: Virtual bone reduction can be challenging and labor-consuming in computer-aided design for maxillofacial fractures. This study aimed to establish an automatic reduction method for unilateral zygomatic fractures based on Iterative Closes Point（ICP）algorithm.

Methods: 30 patients with unilateral zygomatic fractures from November 2018 to August 2021 were included in the study. After acquiring CT images, zygomatic fragments were segmented using self-developed software MICSys. Mid-Sagittal-Plane (MSP) was manually defined using anatomical skull landmarks. Surface of zygoma on the healthy side was then "mirrored" according to MSP. Referring to mirror image, the fragments were reduced by both automatic and manual methods. In manual group, a maxillofacial surgeon translated and rotated fragments until they coincided with mirror images. In automatic group, fragments were registered onto mirror images by ICP algorithm in MICSys. Operating time of each group was recorded. Reduced fragments and mirror image were imported into Geomatic Control X, RMSE between reduced fragment and mirror image was calculated to evaluate accuracy. Operating time and accuracy between the two groups were compared using t-test by SPSS software.

Results: Virtual bone reduction was conducted for all 30 patients by the two methods. Operating time of automatic group and manual group were 3.8±1.2s and 65.4±32.9s, with significant difference($P<0.01$). Accuracy between automatic group and manual group were 1.92±0.62mm and 2.43±0.60mm, with no significant difference($P > 0.05$).

Conclusion: Automatic reduction method based on ICP Algorithm for unilateral zygomatic fractures was initially established and clinically acceptable.

Key words: Zygomatic Fracture, Computer-assisted Surgery, Bone reduction, ICP Algorithm

ID 1543

Automatic Segmentation of Zygomatic Bone Surface from 2D-Ultrasound Images Using Transformer Network

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Objective: 3D-Ultrasound（US）of zygomatic bone offers a new possibility for pre-operative registration and intra-operative guiding in maxillofacial surgery. Detection and segmentation of bone surface from 2D-US images is fundamental to 3D reconstruction. Manual segmentation remains time-consuming and labor-intensive. This study aimed to establish and validate an automatic segmentation algorithm to detect zygomatic bone surface from 2D-US images based on SEgmentation TRansformer (SETR) algorithm.

Methods: Between October 2022 and January 2023, 10 patients with intact zygomatic bone were included in this study. 2D-US images of the zygomatic region were obtained by a portable US device (M9, Mindray) and a linear probe (L12-4S). The musculoskeletal mode was used to get higher resolution. The bone surface of 2D-US images was annotated by a professional doctor serving as the ground truth. Two algorithms, including U-net network-based Methods and SEgmentation TRansformer (SETR), were trained, validated, and tested using 455, 130, and 65 (7:2:1) 2D-US images. The segmentation performance of the two algorithms was respectively compared with the ground truth and evaluated by DICE.

Results: A total of 650 2D-US images of the zygomatic bone surface were segmented. The DICE using U-net network-based Methods and SETR algorithm were 69.7% and 73.4%, respectively.

Conclusion: Compared to U-net network-based methods, SETR network-based Methods showed better segmentation performance to extract 2D-US images of the zygomatic bone surface. The algorithm for automatic bone surface segmentation of 2D-US images will facilitate 3D-US application in computer-assisted maxillofacial surgery.

Key words: Ultrasound, Maxillofacial, Computer-assisted surgery, Deep learning

ID 1640

A Parallel Mechanism and Compliant Rod-driven Lightweight 6-DOF Mini Manipulator for Microsurgery

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Objective: Microsurgery is of great value to clinical and life sciences. The commercially available microsurgical manipulators are often large in volume, while micromanipulators in current research usually cannot produce enough operating force, and both of them are costly. This study expected to construct a 6-degree of freedom (DOF) manipulator with consideration of accuracy, load, volume, and cost for low-cost microelectrode implantation surgery.

Methods: The manipulator is composed of five 2.8 g low-cost stepper motor-driven linear motion modules and replaceable miniature motor rotating modules; A biplane mechanism was used to realize the 4-DOF motion of the surgical tool in XY direction. A compliant rod drive system is innovatively adopted to realize the Z-axis rotation and feed freedom and mechanical structure decoupling; The forward/inverse and RCM kinematics control algorithms of the manipulator are given. Moreover, a microsurgery platform including micro-vision sensing and remote-control functions is also constructed to

test the manipulator.

Results: The proposed manipulator can realize 6 DOF control of micro-needle, micro-drill, and optical fiber with a diameter of less than 0.5 mm. The total weight of the manipulator is only 72 g, with a volume of 75 mm×53 mm×71 mm, and it has a more than 3 N thrust force on the compliant rod drive Z axis. The single DOF of the manipulator has an 8 mm stroke, a 20 μm real motion resolution, a 6.3 mm/s motion speed, a 9 N maximum thrust/pull force output, and a 6 N self-locking force. We have carried out micro-needle puncture and micro-hole drilling experiments on the porcine skin and cartilage, and the system can reliably complete the operation.

Conclusion: Compared with current research, the proposed microsurgery manipulator can achieve sufficient operating force output with considerable accuracy, size, and low cost, providing a potential tool for microsurgery with low cost and portability requirements.

Key words: Microsurgery manipulator, Surgical robot, Compliant mechanism, Parallel mechanism

ID 1783

Evaluation and Analysis of the Effect of Posterior Cruciate Ligament Surgery Based on Computer Simulation Technology

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Objective: In our research, accurate 3-D finite element models of the knee joint were reconstructed with the MRI data from an adult. The biomechanical property of those three techniques was compared using finite element analysis.

Methods: Based on the 3D MRI data of a young healthy volunteer's right knee, we constructed a three-dimensional (3D) finite element model with knee flexion of 90°; The SOLIDWORKS was used to construct the bone tunnels at the model of the knee flexion of 90° and then the ABAQUS was used to load the tibia with 134N posterior force and 5N·m internal and external rotation torque. Biomechanical properties between those different PCL reconstruction techniques were compared.

Results: Under posterior force of 134N, the posterior translation and the graft maximum stress of the intact knee, the PCL-resected knee, the anatomic single bundle PCL reconstruction, 3-tunnel double bundle PCL reconstruction and the anatomic 4-tunnel double bundle PCL reconstruction were 7.4mm(4.41Mpa), 18.3mm(0Mpa), 11.3mm(5.74Mpa), 8.2mm(4.77Mpa) and 6mm(4.59Mpa) respectively. Under internal and external rotation torque of 5N·m, the internal and external rotation angle of the intact knee, the PCL-resected knee, the anatomic single bundle PCL reconstruction, 3-tunnel double bundle PCL reconstruction and the anatomic 4-tunnel double bundle PCL reconstruction were 18.6°, 21.1°, 20.6°, 19.7°, 19.4° (internal rotation angle) and 17.2°, 20.8°, 20.5°, 20.0°, 18.5° (external rotation angle).

Conclusion: Based on the computer simulation finite element analysis, the anatomic 4-tunnel double-bundle PCL reconstruction showed the priority for all the parameters including the posterior stability, the rotational stability and the graft stress of compared to the 3-tunnel double bundle and the single bundle techniques. Besides, the **Results:** of anatomic 4-tunnel double-bundle group were more close to the intact knee, which could be the reference for the operative selection of PCL reconstruction.

Key words: Computer simulation, Knee joint, Posterior cruciate ligament reconstruction, Different surgical procedures

ID 1960

Inverse-Reinforcement-Learning-Based Robotic Ultrasound Control

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Objective: Robotic ultrasound systems (RUS) have gained increasing attention because they can automate repetitive procedures and relieve operator workloads.The purpose of a RUS is to automatically perform scanning to collect ultrasound images of the target, which means that the probe needs to be in brief or constant contact with a soft surface.The complexity and uncertainty of the unstructured environment pose significant challenges for accurate and stable robot-human interaction.

Methods: By analyzing the control pattern during manual scanning in the clinical environment, we propose a force-velocity-based action space and an IRL-based method to perform simultaneous force and posture control for RUS scanning. Our approach uses two parameterized neural networks to establish the relationship between RUS and the contacted skin. First, a simple predefined reward function and RL method establish the relationship between contact force and posture. In the second-round optimization, the policy is re-optimized by a learned reward derived from the generated datasets. Finally, combined with the outer-loop position, the probe continuously scans the human surface.

Results: Several experimental Results indicated that our method could perform stable, smooth, and continuous scanning of different and unknown soft surfaces. Our approach showed significant advantages and better transferability in different and unstructured environments. Quantitative Results show that the difference between the proposed method and the 3-D reconstructed model in terms of posture is (2.3±1.3°, 1.9±1.2°) in continuous scans.

Conclusion: Our method provides a simple solution for scanning robotic ultrasound systems without visual information and has potential applications in combination with other outer-loop trajectory generation methods.

Key words: Robotic Ultrasound System, Reinforcement Learning, Force Control

ID 2061

Non-rigid Registration-Based Virtual Planning on Maxillofacial Surgery with Bone Lesions Across the Midline

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Objective: Objective ： Without "mirror" technique, virtual planning on maxillofacial surgery with bone lesions across the midline remains challenging and ambiguous. This study aimed to establish and validate a non-rigid registration-based algorithm for virtual planning of bone lesions across the midline.

Methods: Methods: From November 2021 to December 2022, patients with maxillofacial bone lesions (including trauma, tumor and osteomyelitis) across the midline who need surgical intervention were included in the study. After acquiring CT images, bone lesions were segmented and erased using ProPlan CMF. The defected skull was then input to self-developed algorithm including (a) Non-rigid registration with statistical shape model (SSM) generated from 3D craniomaxillofacial database of normal Chinese people including 500 skulls; (b) CNN-based landmark detection and comparison network to select the most coordinate model. The model output from the algorithm was considered to be the reference model. Virtu-

al bone reduction, reconstruction or reshaping was then conducted under the guidance of reference model. Intra-operative surgical navigation was applied to realize virtual plan. Post-operative CT data was 3D- reconstructed, mirrored and compared to evaluate symmetry by Root Mean Square Error (RMSE).

Results: Results: 15 patients were included in this study. 67% of bone lesions were fractures, following by tumors (20%) and osteomyelitis (6%). 80% cases were lesions on mid-face and 20% cases were on mandible. The algorithm and virtual planning were conducted successfully. The post-operative asymmetry RMSE was 1.96±0.39mm.

Conclusion: Conclusion: Non-rigid registration-based algorithm for virtual planning of bone lesions across the midline was initially established and clinically acceptable.

Key words: Non-rigid Registration, Computer-assisted Surgery, Landmark detection network, Statistical shape model.

ID 2530

Automatic Registration Algorithm Design and Surgical Planning Software Development for Prosthetic Driven Oral Implantology

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Objective: Dentition defect or even edentulism is a problem that deserves attention. In order to achieve prosthodontic-guided surgery, it is necessary to determine the position of the prosthesis through a pre-made radiographic template, and then the position and angle of the prosthesis are planned in the surgical software. This requires the patient to wear a radiographic template for CBCT. Since the human body will affect the imaging of the radiographic template, a separate CBCT of the radiographic template needs to be taken and registered with the patient's CBCT. However, the registration process is manual. This study proposes an automatic registration method, which is combined with prosthesis planning for software development.

Methods: Firstly, the threshold segmentation and features of the radiopaque markers were used for initial screening to form the patient point set and the standard point set of the radiopaque markers of the radiographic template. Secondly, the respective distance matrices are established. By comparing the distance matrix of each point, for each point in the patient point set, the most probable corresponding point in the standard point set was found and the prediction Results were classified. Thirdly, the optimal solution was obtained and registered. Finally, prosthesis planning was performed in the software.

Results: Three clinical cases were used for verification, and all the Results were automatically registered. The average accuracy error was 0.13mm, which was less than the clinically recommended error of 1.00mm. The average time of the whole process was 13.96s, with an average time of 0.15s for the auto-registration algorithm. Through experiments and simulation of deviations, the method was found to be efficient, accurate, and robust. Furthermore, prosthesis implantation and postoperative follow-up confirmed the feasibility.

Conclusion: The proposed automatic registration method can make the overall process more efficient and accurate. The accuracy and feasibility of this method were verified by clinical cases.

Key words: Dentition defect, Automatic registration, Radiopaque marker, Implant of prostheses

ID 2572

Proximal Femur Fractures Segmentation and Bone Classification

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Objective: Due to the high failure rate and numerous complications associated with surgical treatment of proximal femur fractures in elderly patients with local osteoporosis, there is a need for more advanced interventions to guide doctors in preoperative planning. Artificial intelligence algorithms can provide this guidance. Our work utilizes a deep learning algorithm to analyze preoperative image information and to determine the relationship between the image information and the patient's treatment effect post-operation, thus aiding in surgical planning.

Methods: To prepare the data, we propose a unique labeling strategy involving two steps. In step one, doctors roughly mark the fracture area in the CT image, separating the different fracture blocks with a straight line without the need to judge the fuzzy boundary of the bone fracture and its bone classification. In step two, doctors mark the fracture area for the same dataset, judging the area division of the fracture boundary in detail and including the hard-to-distinguish spongy bone into the area as the final "gold standard". We built a attention-guided neural network using our customized dataset to segment CT image data of fracture patients and determine the specific area of the fracture. The region judges the bone type according to the HU value.

Results: Experimental Results show that our algorithm's Dice score for fragment segmentation reaches 95.6%, which is higher than the existing SOTA model. Additionally, our algorithm can distinguish between cortical bone and spongy bone in the fracture part, which is significant in clinical practice and facilitates implantation planning of fractured intramedullary nails.

Conclusion: In conclusion, the deep intersection of clinical medicine and information science allows us to build artificial intelligence algorithm tasks, which can automatically segment the fracture area and determine bone type, reducing labor costs and work difficulties for clinicians. This approach also provides highly qualified computer-assisted instruction for young doctors.

Key words: proximal femur fractures, deep learning, HU value, fractures segmentation

ID 2602

Design of a Bionic Whisker Force Sensor for GI Endoscopy

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Objective: We aim to design a bionic whisker force sensor that can be easily integrated into commercial endoscopes, which is used to detect interactive forces during endoscopy. The sensor can accurately detect radial forces in six directions and the whiskers have a low stiffness to ensure safety during the inspection.

Methods: We use Fiber Bragg grating (FBG) as the sensing element and super-elastic Nitinol wire as the whiskers, which are connected by a square block. Three fibers in a broken line configuration are distributed on the outside of the endoscopic sleeve for force sensing, and one fiber in a straight configuration is distributed on the inside of the endoscopic

sleeve for temperature decoupling.

Results: To eliminate the influence of manufacturing and assembly errors and to obtain the true sensitivity value of the whisker force sensor, we performed calibration experiments. In the experiment, we conducted loading and unloading experiments on the whisker force sensing unit with steps of 0.1N in the range of 0-1N. The Results show that the sensitivity of the whisker force sensing unit can reach 1.61 mN and the hysteresis error is less than 4.9%.

To further validate the performance of the whisker force sensor, we conducted dynamic tests. Forces of different magnitudes and random frequencies were applied to the whisker force sensing unit, and the Results were recorded. The average relative error is no more than 3.31% compared with the data measured by commercial ATI force sensor. In addition, the crosstalk among different whisker force sensing units is almost zero, which proves the high reliability of the proposed sensor.

Conclusion: The whisker force sensor has a high resolution of 1.61 mN for radial force and can recognize random loading effectively.

Key words: whisker force sensor, Fiber Bragg grating (FBG), endoscopy.

ID 2648

Modeling of Tendon Driven Soft Robot with Stiffness-Tunable Structure

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Objective: In order to realize variable stiffness of soft robots, the existing research adopted the method of adding stiffness-tunable structure to the soft body. The kinematic model of soft robot changes with the addition of stiffness-tunable structure, which brings new challenges to the precise actuation of soft robots. Therefore, updated and appropriate theoretical models are needed.

Methods: The multi-structure fitting mode is mostly concentric circle sleeve assembly, which can be referred to the modeling of concentric tube robot. Based on the hypothesis of Euler Bernoulli beam, the deformation of a stiffness-tunable soft robot with under tendon drive is theoretically calculated. The two basic assumptions are that: the equilibrium constant moment determines the final shape of the robot; the curvature of each segment of the robot is constant under constant torque. In this study, the kinematic equations of multi-stage stiffness-tunable robot are derived. Besides, we verified the model in a finite element simulation environment.

Results: According to the existing research——a stiffness-tunable actuator based on thermoplastic polymer, the theoretical calculation, simulation and verification of its deformation are carried out in this work. The rationality and availability of our theoretical model were verified by experiments.

Conclusion: Our work provides a theoretical basis for the precise driving of soft robots with stiffness-tunable structure, which expands potential of soft robots for medical application.

Key words: stiffness-tunable soft actuator, Euler Bernoulli beam, finite element simulation

ID 2838

Development and Validation of a Treatment Planning Tool for Transforaminal Epidural Steroid Injection

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Objective: Transforaminal epidural steroid injection (tESI) is an effective therapy for relieving the acute or chronic pain caused by lumbar disc herniation. To avoid complications such as nerve damage or bleeding during drug injection, preoperative planning is essential. However, traditional trajectory planning is based on 2D image viewers, which cannot provide intuitive 3D visualization and friendly interaction for planning. Therefore, this work aims to develop a treatment planning tool that can integrate 3D reconstruction of lumbar structures and user-friendly interaction.

Methods: The treatment planning tool was developed based on the 3D slicer and includes three parts: image segmentation, trajectory planning, and parameter calculation. First, a 3D-Unet deep learning method was developed to segment both the lumbar structures and soft tissues (such as nerve roots, intervertebral discs, etc.). Then, the segmentations were loaded into the planning tool and intuitive 3D visualization of the target area was provided. A ray-casting method implemented in the software could assist the surgeon in quickly finding a proper insertion trajectory. Finally, the parameters of the planned trajectory were calculated, particularly the relative position of the insertion point on the skin from the marked planes.

Results: The planning tool was verified in the clinic and used for the trajectory planning of 3 patients with lumbar disc herniation. The Results showed that the surgeons could easily find a proper trajectory with the planning tool. The average planning time, including segmentation, was less than 5 minutes. With the planned trajectory and parameters, all needle insertions were performed successfully with an average operation time of 10 minutes, and no nerve stimulation or bleeding was found.

Conclusion: We developed a treatment planning tool for tESI, which was verified in the clinic and could provide easy and fast trajectory planning. With the planned trajectory, tESI could be performed safely.

Key words: Treatment planning, Transforaminal epidural steroid injection, Segmentation, 3D slicer

ID 2912

A Novel Algorithm for Automatic Implantation of Internal Fixation Screws in Pelvic Fracture Closed Reduction Surgery

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Objective: Internal fixation screw implantation is an essential part of fracture reduction surgery for the pelvis to keep the repositioned fracture tissue stable until it heals. Traditionally, the implantation is an experience-oriented pre-operative task by the surgeon, which is time-consuming and has poorly reproducible results. Therefore, a novel robust algorithm was developed for automatic implantation planning of internal fixation screws with the deep-learning-based pelvic segmentation and fracture reduction algorithm proposed by our team as the pre-work.

Methods: The repositioned fracture bone was used as input. Firstly, automatic extraction and matching of pelvic fracture surfaces were realized via the distance threshold and KDTree. Then, the quantity of implanted screws was obtained by Density-Based Spatial Clustering of Applications with Noise (DBSCAN) algorithm and Principal Component Analysis (PCA) on the point clouds of the fracture surfaces. Afterwards, the Chebyshev Center of each point cloud was computed as the corresponding implantation position. Finally, the optimal direction of each screw was obtained by traversal search in cone space based on Random Sample Consensus (RANSAC).

Results: Experiments on clinical CT scans were conducted and the Results showed the algorithm was able to achieve the ideal orientation and position of the fixation screws in most cases within 30s. Meanwhile, phantom experiments were also conducted demonstrating the reliability and efficiency of the proposed algorithm.

Conclusion: The method proposed in this study successfully realized robust and efficient planning of the internal screw implantation for pelvic fracture closed reduction surgery, which solved the above problems faced traditionally. And with further research to integrate segmentation, reduction, and implantation algorithms into a system, great benefits may be brought to doctors and patients in this domain.

Key words: pelvic fractures, screw implantation, automatic pre-operative planning.

ID 3040

Development of a Novel Robotic System for Fast and Accurate Localization of Lung Nodules with Respiratory Compensation

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Objective: Accurate localization of pulmonary nodules presents a considerable challenge for surgeons during transthoracic needle biopsy and thoracoscopy surgery. Existing localization Methods suffer from several drawbacks, such as low accuracy, difficulty in ensuring respiratory synchrony, high radiation exposure, and laborious procedures. To address these issues, a preoperative computed tomography (CT) image-guided robotic pulmonary nodule localization system was developed in this study.

Methods: To compensate for the patient's intraoperative respiratory movements, we integrate our respiratory compensation algorithm into the patient-image registration procedure. Specifically, an optically tracked probe is used to collect the patient's surface point cloud which is then used for joint optimization of respiratory compensation and registration. Moreover, intraoperative safety strategies are proposed to safeguard punctures. The puncture guide is utilized to constrain the movement of the optically tracked needle while synchronizing the puncture procedure with the patient's respiration, thereby enhancing accuracy and intraoperative safety. Finally, the algorithm is integrated into the robotic percutaneous puncture system for the localization of lung nodules.

Results: We conducted phantom experiments to evaluate the accuracy and feasibility of the proposed system. The average entry point error of the robotic system was 1.85±0.37 mm, the average endpoint error was 2.37±0.51 mm, and the 3D Angle error was 1.26±0.47°. Furthermore, the entire localization procedure can be accomplished in no more than 7 minutes.

Conclusion: Our proposed system eradicates the need for intraoperative CT, which drastically reduces radiation exposure. Our registration method with respiratory compensation facilitates fast and accurate localization of pulmonary nodules. Animal and clinical experiments will be conducted to further evaluate the performance of the system.

Key words: Lung nodule localization; Thoracoscopic surgery; Image-guided surgery; Surgical robot system

ID 3128

Introducing Superelasticity into Cosserat theory for Modeling a Compliant Surgical Manipulator

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Objective: In minimally invasive surgery (MIS), controlling of surgical manipulators requires a high accuracy which demands an accurate kinematic model(KM). However, KM of manipulators made of superelastic material remains a challenge owing to their non-linear behavior. In a previous study,Cosserat theory was applied in KM of a 3 degree–of-freedom(DOF) surgical manipulator made of Ni-Ti[Wang,2022].The manipulator consisted of two pairs of springs, 3 DOFs are benging of spring As(motion α),benging of spring Bs(motion β) and grasping of spring Bs(motion γ). Despite fast calculation time, the accuracy of the KM needed to be improved. Thus, in this study we introduce material properties of Ni-Ti, segmented based on elastic/yielding stage, to the current Cosserat technique.

Methods: Initially, the stress-strain curve of the Ni-Ti was obtained experimentally, segmented in to three stages based on elastic/yielding stage. For each stage a linear approximated function was computed.While modeling the manipulator, its superelastic springs were discretized into short links defined by a set of differential equations.Then the function of each segment was introduced as material properties, based on the stress applied on the material. To solve the resulting differential equations, shooting method was used.The model computed angular positions of 2 DOFs of bending for input displacement.

Results: To evaluate the results, calculation speed, the accuracy ratio (ratio of slopes of displacement-angle curve in simulation and prototype, closer to 100% is better） and error of 2 DOFs of bending were compared with previous method and finite element analysis (FEA).Thus, accuracy ratios were 103.50% and 102.49% (previous-103.72%,103.47%,-FEA-107.94%,86.09%) respectively (data is in order of α and β bending).Error values were 1.086° and 0.929°(previous-1.099°,1.211°,FEA-3.15°,3.21°).Computation time was improved from 23561s to 84s to 63s and 12628 to 289s to 229s respectively.

Conclusion: Towards accurate KM of superelastic material, Cosserat theory and segmented representation of material property yielded better Results in terms of accuracy and simulation time.

Key words: surgical manipulator,kinematic model,superelastic material,shooting method, Cosserat theory

ID 3233

Design of a Mobile Robot for Endotracheal Intubation Operation

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Objective: The current endotracheal intubation procedure, which relies on manual manipulation by healthcare professionals, is associated with a high risk of infection, while the best time for resuscitation is easily missed by wearing the required tertiary protection. The design of an mobile endotracheal intubation robot is aimed at alleviating this pain point by achieving non-contact operation on the basis of ensuring the efficiency of surgery.

Methods: The robot is composed of intubation actuation, environment sensing, motion control and parking system, integrating intelligent robotics technologies such as teleoperated force feedback, simultaneous Localization and Mapping,

and automated motion control.The robot starts from outside the operating theatre and navigates to the selected bed, the 6-DOF manipulator is then tele-operated by the surgeon outside the theatre to complete the surgical task of mask insertion and catheter propulsion, after that the robot disengages from the patients and leaves.

Results: The simulation environment of the operating room is built in Gazebo software based on the physical layout drawings of the ICU in Xinhua Hospital affiliated to Shanghai Jiao Tong University. The mobile robot described in this paper is modelled and the simulation test of the autonomous navigation function is completed. A high-quality reconstruction of the ICU raster map is obtained with the use of laser sensor information. A total of 10 simulation experiments are successfully conducted with different patient bed targets selected.

Conclusion: We developed an endotracheal intubation mobile robot, which solves the problem of loss of surgical accuracy due to manipulator movements in other existing systems, fills the gap in the design of autonomous navigation for endotracheal intubation robots and achieves completely non-contact operation. Simulation experiments show that the autonomous navigation system works well and can meet the needs of surgery.

Key words: Endotracheal intubation surgery, Mobile robot, Autonomous navigation

ID 3265

Design of a Mobile Robot for Endotracheal Intubation Surgery

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Objective: The current endotracheal intubation procedure, which relies on manual manipulation by healthcare professionals, is associated with a high risk of infection, while the best time for resuscitation is easily missed by wearing the required protection suit. The design of an endotracheal intubation mobile robot is aimed at alleviating this pain point by achieving a non-contact endotracheal intubation operation on the basis of ensuring the efficiency of surgery.

Methods: The robot is composed of intubation actuation, environment sensing, motion control and parking system, integrating intelligent robotics technologies such as teleoperated force feedback, simultaneous Localization and Mapping, and automated motion control. The robot starts from outside the operating theatre and navigates to the selected bed, the 6-DOF manipulator is then tele-operated by the surgeon outside the theatre to complete the surgical task of mask insertion and catheter propulsion, after that the robot disengages from the patients and leaves.

Results: The simulation environment of the operating room is built in Gazebo software based on the physical layout drawings of the ICU in Xinhua Hospital affiliated to Shanghai Jiao Tong University. The mobile robot described in this paper is modelled and the simulation test of the autonomous navigation function is completed. A high-quality reconstruction of the ICU raster map is obtained with the use of laser sensor information. A total of 10 simulation experiments are successfully conducted with different patient bed targets selected.

Conclusion: We developed an endotracheal intubation mobile robot, which solves the problem of loss of surgical accuracy due to manipulator movements in other existing systems, fills the gap in the design of autonomous navigation for endotracheal intubation robots and achieves completely non-contact operation. Simulation experiments show that the autonomous navigation system works well and can meet the needs of surgery.

Key words: Endotracheal intubation surgery, Mobile robot, Autonomous navigation

ID 3340

Research on Surgical Robot System for Free Fibula Flap Mandibular Reconstruction

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Objective: The purpose of this study is to present a surgical planning system for robotic aided mandible reconstruction with fibula free flap, which is capable of performing the intricate steps essential for a successful operation, including anatomic and symmetric bone moulding, precise osteotomy trajectory plotting and smooth osteotomy executing.

Methods: The key algorithm for free fibular flap osteotomy plan planning is proposed to establish the coordinate transformation correlation between the mandible and fibula based on the anatomical landmark points at the mandibular defect, and effectively estimate the length and angle of the donor bone segment. A novel algorithm for optical navigation ased control of robotic-assisted osteotomy has been proposed to address the necessity of protecting the vascular tip during fibula flap grafting plasticity, along with the development of a corresponding control strategy and safety guarantee mechanism for the robotic surgery.

Results: The overall architecture of the surgical robot is designed and integrated with the proposed key algorithmic components. In order to verify the accuracy and surgical effect of the surgical robot system in this study, a model experimental scenario was built to simulate the real surgical procedure, 35 patients underwent surgical planning to assess the practicality of our system's virtual surgical planning module, which took an average of 13 minutes. Phantom experiments were conducted to evaluate the system's reliability and stability, with an average distance and angular deviation of the osteotomy planes being 1.04±0.68 mm and 1.56±1.10°, respectively.

Conclusion: Our system is capable of providing not only accurate and efficient preoperative planning, but also secure and dependable osteotomy trajectories. Utilizing model experiments and preclinical studies, we have substantiated its precision, efficacy and dependability, which can advance the progress of mandibular reconstructive surgery to the direction of personalization, safety, accuracy and minimal invasion.

Key words: Mandibular reconstruction, surgical robot, surgical planning, free fibular flap

ID 3399

An End-to-end Spatial-temporal Transformer Model for Surgical Action Triplet Recognition

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Objective: Surgical activity recognition plays an important role in computer assisted surgery. Recently, surgical action triplet has become the representative definition of fine-grained surgical activity, which is a combination of three components in the form of <instrument, verb and target>. The goal of our method is to realize accurate action triplet recognition directly from surgical videos.

Methods: In this work, we propose an end-to-end spatial-temporal transformer model trained with multi-task auxiliary supervisions. Our method fully exploits the strong processing capability of transformer for both visual and sequential

data, seamlessly integrates Swin-B Transformer as the backbone for spatial feature extraction and self-attention layers as temporal modelling module. Auxiliary supervisions of triplet's sub-components and surgical phase are adopted. Our method is evaluated on a publicly available dataset CholecT45 through five-fold cross validation.

Results: Comprehensive ablation studies are conducted to demonstrate the capability of each component that we proposed in our method. We further compare our method with several state-of-the-art methods. Experimental Results show that our method outperforms the best state-of-the-art method by 6.8%, achieving 36.5% mAP for triplet recognition. Moreover, our method won the 2nd place in action triplet recognition racing track of CholecTriplet 2022 Challenge.

Conclusion: Our method demonstrates superior recognition capability for surgical action triplets, and holds the potential to be a powerful baseline for surgical action triplet recognition, which is helpful for future works.

Key words: Action recognition, surgical action triplet, transformer, self-attention, auxiliary supervision

ID 3407

2D/3D Reconstruction of Patient-specific Surface Models and Uncertainty Estimation via Posterior Shape Models

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Objective: In this study, we aim to develop and validate a method for 3D reconstruction of patient-specific surface models from biplanar X-ray images and for estimating the reconstruction uncertainty.

Methods: We propose a novel method for 3D reconstruction of patient-specific surface models from 2D X-ray images and uncertainty quantification via posterior shape models. Taking the silhouette point cloud generated from biplanar X-ray images as the given partial information, a posterior shape model is constructed to compute the posterior distribution of the surface model given the silhouette. By sampling surface models from the posterior distribution, we can not only compute the patient-specific 3D reconstruction but also quantify the reconstruction uncertainty. To evaluate the proposed method, comprehensive experiments were conducted on 25 synthetic cases and 10 cadaveric cases of the proximal femur.

Results: The proposed method achieved a mean ASD of 0.91 mm and a mean HD95 of 2.26 mm on the synthetic cases. The mean ASD and the mean HD95 obtained by the proposed method on cadaveric cases were 1.02 mm and 2.28 mm, respectively. Meanwhile, the reconstruction uncertainty on both synthetic cases and cadaveric cases was quantified based on the proposed method.

Conclusion: Both quantitative and qualitative Results demonstrated the effectiveness of the posterior shape model-based reconstruction method, which shows a potential for real medical application.

Key words: 2D/3D Reconstruction, Posterior Shape Model, Bone Surface Model, Biplanar X-ray imaging, Orthopaedic Surgery

ID 3474

Semantics-Preserved Domain Adaptation with Target Diverse Perturbation and Test Ensembling for Image Segmentation

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Objective: Deep neural networks have achieved significant progress in semantic image segmentation with large amount of labeled training data in a specific domain. However, when applying it to other unseen domains, the model could completely fail due to the excessive domain discrepancy/shift.

Despite the remarkable advance in unsupervised cross-domain image segmentation, existing works suffer from two main limitations. They either ignore the semantics preservation when transferring knowledge from source domain to target domain, or ignore to fully explore the rich information of the large amount of unlabeled data in target domain, leading to a bias segmentation model.

Methods: To address these issues, we propose a novel semantics-preserved cross-domain image segmentation method with a new diverse image perturbation in the target domain, improving the capacity and robustness of the model. We also propose an effective test-time ensembling strategy for a more confident prediction result.

Results: Experiments on the cross-domain spine lumbar segmentation task demonstrates the effectiveness of the proposed method. Our method shows its effectiveness with an average Dice of 78.38%, which were much better than other two SOTA methods. Extensive ablation studies demonstrates the effectiveness of different components in our method.

Conclusion: In this paper, we proposed an end-to-end cross-domain segmentation model based on semantics-preserved image translation and target diverse perturbation for effective learning of the target domain. We additionally introduced a test-time ensembling strategy for further improvement of the model capacity to difficult and out-of-distribution cases. The experimental Results demonstrated the proposed method achieved better Results than the SOTA methods.

Key words: unsupervised, domain adaptation, image segmentation, semantics-preservation, diverse perturbation

ID 3583

Stage-specific and Location-specific Cartilage Calcification in Osteoarthritis Development

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Objective: Osteoarthritis (OA) involves pathological cartilage calcification, its progress is not fully understood. This study investigated the stage- and location-specific deposition and characteristics of minerals in human OA cartilages via multiple nano-analytical technologies.

Methods: Normal and OA cartilages were serially sectioned for micro-computed tomography, scanning electron microscopy with energy dispersive X-ray spectroscopy, micro-Raman spectroscopy, focused ion beam scanning electron microscopy, high-resolution electron energy loss spectrometry with transmission electron microscopy, nanoindentation, and atomic force microscopy to analyze the structural, compositional, and mechanical properties of cartilage in OA progression.

Results: We found that OA progressed by both top-down calcification at the joint surface and bottom-up calcification at

the osteochondral interface (figure 1). The top-down calcification process started with spherical mineral particle formation in the joint surface during early-stage OA (OA-E), followed by fiber formation and densely packed material transformation deep into the cartilage during advanced-stage OA (OA-A). The bottom-up calcification in OA-E started when an excessive layer of calcified tissue formed above the original calcified cartilage, exhibiting a calcified sandwich structure. Over time, the original and upper layers of calcified cartilage fused, which thickened the calcified cartilage region and disrupted the cartilage structure. During OA-E, the calcified cartilage was hypermineralized, containing stiffer carbonated hydroxyapatite (HAp). During OA-A, it was hypomineralized and contained softer HAp. This discrepancy may be attributed to matrix vesicle nucleation during OA-E and carbonate cores during OA-A.

Conclusion: This work refines our current understanding of the mechanism underlying OA progression and provides the foothold for potential therapeutic targeting strategies once the location-specific cartilage calcification features in OA are established.

Key words: cartilage calcification; OA; nucleation mechanism; osteochondral interface

ID 3588

Cartilage Lacuna-inspired Microcarriers Drive Hyaline Neocartilage Regeneration

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Objective: Cartilage equivalents from hydrogels containing chondrocytes exhibit excellent potential in hyaline cartilage regeneration, yet current approaches have limited success at reconstituting the architecture to culture nondifferentiated chondrocytes in vitro. Our aim was to develop functional microcarriers capable of inhibiting chondrocyte dedifferentiation.

Methods: In this study, we report specially designed lacunar hyaluronic acid microcarriers (LHAMC) with mechanotransductive conditions that rapidly form stable hyaluronic acid (HA) N-hydroxy succinimide ester (NHS-ester). Specifically, carboxyl-functionalized HA is linked to collagen type I via amide-crosslinking, and gas foaming produced by ammonium bicarbonate form concave surface of the microcarriers.

Results: The temporal three-dimensional culture of chondrocytes on LHAMC uniquely remodels the extracellular matrix to induce hyaline cartilaginous microtissue regeneration and prevents an anaerobic-to-aerobic metabolism transition in response to the geometric constraints. Furthermore, by inhibiting the canonical Wnt pathway, LHAMC prevent β-catenin translocation to the nucleus, repressing chondrocyte dedifferentiation. Additionally, the subcutaneous implantation model indicates that LHAMC display favorable cytocompatibility and drive robust hyaline chondrocyte-derived neocartilage formation.

Conclusion: Our findings reveal a novel strategy for regulating chondrocyte dedifferentiation. The current study paves the way for a better understanding of geometrical insight clues into mechanotransduction interaction in regulating cell fate, opening new avenues for advancing tissue engineering.

Key words: Microcarriers, cartilage tissue engineering, chondrocyte dedifferentiation, Wnt pathway, geometric constraints

ID 3590

Microcarriers Promote the Through Interface Movement of Mouse Trophoblast Stem Cells by Regulating Stiffness

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Objective: Mechanical force is crucial in the whole process of embryonic development. Unfortunately, it is not clear how mechanics affects trophoblast implantation. Currently, trophectoderm cells, or mixed with other cells (embryonic, induced, adult stem cells) were used to construct in vitro mouse embryo implantation models . However, due to the common problem of self-assembly, these models overlook the role of the mechanical environment, which will cause uncontrollable trophoblast cells stiffness, and no significant phenomenon in the through interface cell movement from these models.

Methods: In this study, we constructed a model to explore the effect of stiffness changes in mouse trophoblast stem cells (mTSCs) on implantation: microcarrier was prepared by sodium alginate using a droplet microfluidics system, and mTSCs were attached to the microcarrier surface with modifications, called T(micro).

Results: Compared with the spheroid, formed by the self-assembly of mTSCs (T(sph)), we could regulate the stiffness of the microcarrier, making the Young's modulus of mTSCs (367.70 ± 79.81 Pa) similar to that of the blastocyst trophoblast ectoderm (432.49 ± 151.90 Pa). Moreover, T(micro) contributes to improve the adhesion rate, expansion area and invasion depth of mTSCs. Further, T(micro) was highly expressed in tissue migration-related genes due to the activation of Rho-associated coiled-coil containing protein kinase (ROCK) pathway at relatively similar modulus of trophectoderm.

Conclusion: We constructed a trophoblast implantation model with variable stiffness used droplet microfluidics. By changing the modulus of the microcarrier, we can modulate the stiffness of the mTSC on its surface. mTSCs on microcarriers had a higher implantation capacity at a similar stiffness to the trophectoderm, activating the RHO/ROCK signaling pathway and promoting through interface movement by regulating cytoskeletal reorganization. Based on this, mTSC implantation capability can be regulated, which broadens our understanding of embryo implantation through a biomechanical perspective, and provide one criterion for evaluating embryo implantation capacity in vivo.

Key words: Biomechanics, microcarriers, embryo implantation, cell migration

ID 3601

EATSNet: Event-type Aware Time-Sensitive Network for medical event prediction

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Objective: Medical Event Prediction(MEP) based on Electronic Medical Records(EMR) is an essential and valuable task in healthcare tasks, which can sufficiently support clinicians in decision-making. One patient's EMR can be viewed as a sequence consisting of many nodes, each representing one visit of this patient, containing information about visit time and various event types. From some basic medical cognition, we know that information about event type and time inter-

val in EMR is quite significant when analyzing patients' situations.

Methods: We proposed Event-type Aware Time-Sensitive Network(EATSNet), in which we elaborately designed the Event-type Aware Block and Time Sensitive Block to make use of the related information in EMR. We designed Event-type Aware Crossed Attention to capture the correlation between medical events using three types of attention mechanism, and we also designed Global-Time Aware Module and Delta-Time Aware Module to apply the impact of time interval in global and local levels respectively.

Results: We conducted experiments on MIMIC-III and eICU to verify the good performance of EATSNet on different prediction targets compared with other state-of-the-art methods. Ablation study are applied to verify the effectiveness of each component in the model and visualization study are applied to show the influence of TAB clearly.

Conclusion: Event-type Aware Time-Sensitive Network(EATSNet) focuses on the information about event type and time interval in order to make full use of the information in EMR to complete MEP task using EMR accurately.

Key words: Medical event prediction, Deep Learning, Attention mechanism, Event-type Aware, Time-Sensitive

ID 3670

Cryogenically Storable Microcarrier Bioink for Bone Repair

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Objective: To develop an all-in-one bioink for remote preparation, cryogenic storage, and long-distance transport

Methods: Sodium hyaluronate microcarriers with concave structure were prepared by using air bubbles under water-in-oil conditions. The antifreeze matrix material was obtained by aldehydelation of sodium alginate and further modification of photosensitive groups, and then Cell-loaded microcarriers were combined with antifreeze matrix materials prepared by photocrosslinking oxidized sodium alginate.

Results: The photo-crosslinked oxidized sodium alginate microcarrier ink achieved low-temperature freezing for 3 days under the condition of 5% (w/v) DMSO, and the cell viability rate was above 86% after melting and recovery. At the same time, the rheological Results showed that the system had shear Thinning, low-temperature gelation and other properties. With high printing accuracy, the printing of microcarrier scaffolds with complex structures is realized. The rat distal femur defect model showed good biocompatibility and could promote bone regeneration and repair.

Conclusion: This integrated bio-ink system is expected to solve the predicament that existing bio-inks cannot be stored at low temperature and can only be prepared and used immediately, and realize the “take-and-use” of bio-inks, which greatly expands the applicability of 3D printing technology.

Key words: microcarriers, cryopreservation, 3-D bioprinting,bone restoration

ID 3677

One-arm and Two-arm Switchable Positioning Robot

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DGIST

Objective: To position and hold surgical instruments, including endoscopes and retractors, various types of holders and commercial collaborative robot arms have been employed. However, as these positioning arms can typically accommodate only one instrument at a time, more than one positioning devices are necessary when multiple instruments or different weight instruments are employed, such as in endoscopic thyroidectomy. This study proposes a one-body dual-arm positioning robot that is capable of holding two instruments or one relatively heavy instrument by switching the mode.

Methods: Depending on the weight and number of instruments, the proposed robot operates in one of three different modes. Single mode using one arm, dual mode using two arms independently, and integrated mode combining the two arms for providing twice the payload capacity, while satisfying the workspace requirements for surgery. Each mode positions instruments without compromising their freedom of movement. Furthermore, the design allows for switching between operational modes quickly and with little effort.

Results: The performance of the proposed system is evaluated through a series of experiments on gripping forces. One arm can position up to 3kg of an instrument, and the two arms can combine to position up to 6kg of an instrument.

Conclusion: This study demonstrated the one-arm and two-arm switchable positioning robot capable of positioning one heavy instrument or up to two light instruments by switching operational modes.

Key words: positioning arm, three different modes, robotic surgery

ID 3681

3D Liver Tissue Model with Branched Vascular Networks by Multimaterial Bioprinting

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Objective: Complicated vessels pervade almost all body tissues and influence the pathophysiology of the human body significantly. However, current fabrication strategies have limited success at multiscale vascular biofabrication.

Methods: This study reports a methodology to fabricate soft vascularized tissue at centimeter scale using multimaterial bioprinting by a customized multistage-temperature-control printer.

Results: The printed constructs can be perfused via the branched endothelialized vasculatures to support the well-formed 3D capillary networks, which ensure cellular activities with sufficient nutrient supply and then mimic a mature and functional liver tissue in terms of synthesis of liver-specific proteins. Moreover, an inner and external pressure-bearing layer is printed to support the direct surgical anastomosis of the carotid artery to the jugular vein.

Conclusion: In summary, this study demonstrates the use of low concen- trations of GelMA with fibrin for the first time as a bioink for extrusion-based printing of vascularized tissues, producing model organ tissues with high-resolution and high cell viability. This 3D-engineering-based methodology has allowed us to fab- ricate vascular networks in centimeter-scale tissues with active tissue functionality. Furthermore, it opens an amenable avenue for pharmaceutical screening, studying human tissue develop- ment and disease, and definitely liver tissue engineering toward transplantation therapies.

Key words: 3D bioprinting, liver tissue, perfusion, transplantation, vascularization

ID 3706

Digital Health and Telemedicine in Thailand

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Objective: To explain how does digital health implementation in Thailand.

Methods: Observation and action research.

Results: In July 2020, The Medical Council of Thailand announced rules and regulations for Telemedicine and online clinics as a legal and timely solution to the fight against the Covid-19 pandemic, especially, Delta variant. Since then this service has been expanded for 42 simple illnesses.

Thailand's digital health strategy officially started at the opening ceremony of 18th ACCAS2022 at Sappaya-Sapasathan, the National Assembly of the Kingdom of Thailand in August 24, 2022. Medical platforms are currently being adapted through Royal Medical Colleges and Medical schools with the support of the Ministry of Public Health and medical personnel from all sections. When a new government is formed after May 2023, the Ministry of Digital Economy and Society is planning to establish a central personal health record. This will be a key Telemedicine achievement and will allow doctors to access parts of their patients' medical records from anywhere.

As digital health platforms move forward, the first hardware, additions will be smart watches with health parameters, which can be connected to the central health platform. After that, many medical robots, for use outside and inside the human body, will gradually join the digital healthcare system alongside human doctors, until there is full transition to a full digital health era.

Conclusion: The Asian Society of Computer Aided Surgery and the ASEAN Society of Computer Aided Surgery and Medicine will work closely together to exchange knowledge and contribute to digital health for our people. Digital Health and Telemedicine implementation and action plans in Thailand will serve as a case study for the health system transition.

Key words: Digital Health, Telemedicine

ID 3707

Design and Development of Position Control System for Laparoscope Manipulating Robot based on Deep Learning of Endoscopic Images

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Objective: Automatic control systems are increasingly playing a role in human daily life. Especially in medicine, the control system technology is helping doctors become more efficient. Laparoscope Manipulating Robot (LMR) is a device that helps keep a camera steady as it moves to desired positions during surgery. High performance Image processing is able to support real-time fast processing during surgery, and send control commands to the Robot holding a surgical camera or Laparoscope Manipulating Robot immediately. Currently available robots in Thailand are all imported, making them ex-

pensive and they lacking image processing functions. Local production would reduce costs and dependence on imported technology.

Methods: This research therefore intends to extend the original invention to develop a more efficient, smooth moving, and more accurate prototype surgical camera-handling robot control system using feedback control and position control with digital (PID control), with a microcontroller.

Results: The robot's movements will be controlled using a deep learning technique as the robot learns and memorizes patterns within the vaginal cavity, and then processes and sends commands to the control system to move to the surgical position the doctor wants.

Conclusion: This prototype camera-holding robot will also recognize the location of the previous movement and save it as information for using in the next surgery as well. The design is consistent with electrical and material standards in order to prepare for the medical devices' standard certification process.

Key words: deep learning, endoscopic images, Laparoscope Manipulating Robot, position control system

ID 3708

Design and Development of Force Feedback Control System on Surgical Instruments for Single-port Laparoscopic Manipulating Robot

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Objective: A Laparoscopic manipulating robot (Robot holding a surgical camera) was developed for gynecological surgery in 2008. This Laparoscopic manipulating robot is able to fix the camera and stabilize and control the visual field during surgical procedures and requires little set-up time before commencing surgery. At least 300 gynecological patients have now received surgical operations by this robot.

Methods: This robot is also designed for single-port surgical which includes 2 surgical devices, Scissors and Forceps, for this Single-Port Surgery Robot. The robot can move both the camera and surgery devices to the specific location for the surgery.

Results: The Laparoscopic manipulating robot has been further developed to have more mobility, and integrated with artificial intelligence (AI). The movement of the robot uses a spherical coordinate system, with a camera that can move along its axis motion of angle scope was from -15 to + 15 degrees (30 degree span). On its Z axis, the camera is able to move from 0 to 15 centimeters.

Conclusion: The robot's control systems for more efficient robotic assisted surgery. Holding camera and surgical instruments together at the same time, requires a system sensor to measure the compression and cutting force of the surgical instruments on the internal organ. The sensor data will be sent to the processing unit, for integration with digital image processing data (digital image processing capacity has been developed already). This integrated data will be used for decision making by the robot itself to provide Gynecology Surgery automatically or semi-automatically.

Key words: Laparoscopic manipulating robot, Force feedback control, Digital image processing

S07
生物力学与人类健康
Biomechanics in Human Health

ID 153

How Muscle Strength and Technical Posture Predicts the Performance in Cross-Country Sit-skiing

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Objective: Cross-country sit-skiers use double poling (DP) technique to generate propulsion. The aim of this study is to analyze how muscle strength and technical posture affect the capacity of power output and biomechanical parameters of during the DP process of cross-country sit-skiing.

Methods: Non-disabled college students were recruited to perform three successive 30-s or 3 min maximal effort tests with different shoulder abduction angle of 0°, 15°, 24° and 30° using a sit-skiing ergometer. The biomechanical parameters, isokinetic strength, output power and muscle activation of the subjects were analyzed.

Results: A medium correlation was found between DP output power and isokinetic upper limb muscle strength (shoulder strength at all speeds, $r = 0.39\text{-}0.74$, $p \leq 0.1$). Multiple regression analyses which were employed to predict power production in the 30-s and 3-min tests showed that shoulder extension strength at 60 °/s accounted for 34% of the variation in the 30-s test, and 40% of the variance in the 3-min test. Technically, the output power increased when poling with shoulder abducted, however the poling efficiency as well as the temporal-spatial parameters such as cycle time (CT) and poling time (PT) decreased. Flexion range of motion (ROM) and joint moment of shoulder and elbow also increased. In addition, shoulder muscles such as Anterior deltoid (Antdelt) and Biceps brachii (Bic) were found to be sensitive to the shoulder abduction.

Conclusion: Upper limb extensor muscle strength and muscle coordination were found to be important factors for the power output generation in sit-skiing DP. And poling with shoulder abducted increased the output power but decreased the efficiency, which means the optimal shoulder abduction may depend on the terrain or the skiing speed. These Results may guide the competition techniques and tactics in the matches, and may further influence the strength-training programs of cross-country sit-skiing athletes.

Key words: cross-country sit-skiing; isokinetic muscle strength; shoulder abduction angles; musculoskeletal modeling; inverse-dynamics simulations

ID 244

侧位放置钢板可提高内侧撑开胫骨高位截骨术后的生物力学性能

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目的：因 T 形钢板的非解剖设计和手术医生的操作习惯差异，胫骨高位截骨术中钢板的放置位置很难标准化，并且不同的放置位置又会产生不同的力学性能差异。本研究基于三维有限元分析方法，找到最佳的钢板放置位置，指导临床医生术中操作和制定更为合理的术后负重方案。

方法：将髌腱内侧缘到半膜肌止点之间的胫骨平台区域四等分，形成三个分界点，钢板 B 孔与这三个点分别重合时定义钢板位置为前、前侧、侧。建立胫骨内侧双平面截骨不同钢板位置有限元模型，观察不同工况下，胫骨平台后内侧高丢度失与合页、内固定、垫块应力分布情况。

结果：钢板侧置时胫骨平台的轴向位移和外侧合页、钢板和螺钉的最大应力最小。随着负重增加，三种钢板放置位置模型的合页最大应力均在升高，前置负重 30kg 和前侧放置负重 50kg 时，合页最大应力接近骨质疏松骨屈服强度。任意钢板位置加垫块情况下力学性能得到明显改善。

结论：钢板的侧方放置能够为胫骨平台提供更有效的力学支撑，并有效降低内固定的应力集中。钢板侧方放置能够保证完全负重下合页的完整性，达到术后即刻下地要求。垫块的使用能够有效弥补钢板放置位置不佳导致的应力增加。

关键字：胫骨高位截骨术；内固定位置；术后负重；三维有限元分析

ID 275

A Method to Measure mechanical Properties of Lamina Cribrosa Based on AFM and Morphological Images

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Objective: Deformations of the lamina cribrosa (LC), which is composed of glial LC meshwork and the retinal ganglion cell (RGC) axons in LC pores, induced by elevated intraocular pressure might squeeze RGC axons and then cause the optic nerve injury, which is associated with mechanical behaviors of LC. This study aimed to propose a method to evaluate the mechanical properties of the glial LC and RGC axons of rat eyes by combining morphological imaging and the indentation experiment.

Methods: Unfixed 10 μm cryosections of LC were obtained from five rats. The nano-indentation experiment was performed on sections at three different sizes of the region of interest (ROI) by atomic force microscope (AFM). The adjacent surface sections of it were stained by glial fibrillary acidic protein and then captured by a confocal microscope at 4096 × 4096 pixels. The fluorescent images were processed and segmented using Matlab and then registered to acquire the segmented images of ROIs. The segmented Results were mapped to Young's modulus images obtained by AFM to get Young's modulus of glial LC and RGC axons respectively.

Results: Combing the morphological features and scanning time of the scanning region, we took the size of ROI as 30

μm×30 μm. After mapping the segmented images to the modulus images, Young's modulus of glial LC and RGC axon could be obtained respectively.

Conclusion: This study indicated that 30 μm×30 μm could be the appropriate size of ROI for measuring the mechanical properties of LC by AFM. The method by combing morphological imaging and mechanical properties experiment could obtain Young's modulus of glial LC and RGC axons respectively.

Key words: Lamina cribrosa, Atomic force microscope, Young's modulus.

ID 294

The Effects of Middle Cerebral Artery Stenosis on Contrast Material Transport

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Objective: Introduction & Aim: Digital subtraction angiography (DSA) is the 'Golden Standard' for evaluating artery anatomy. And the main aim of this study is to evaluate the morphological effects on the hemodynamics and the contrast material concentration at the middle cerebral artery stenosis. We proposed a quantitative parameter, contrast material remaining time (CMRT) to describe the variation of perfusion information within interventional therapy.

Methods: Method: This study is based on the computational fluid dynamics simulations of synthetic models and patient-derived models. These models included the area of the internal carotid artery, middle cerebral artery, and anterior cerebral artery. The perfusion information was extracted from the time density curve by the DSA image series.

Results: Results: In synthetic models, it was found that increasing the degree of stenosis (30%-80%) resulted in a significant increase of CMRT in the anterior cerebral artery outlet (p=0.0238) and a decrease of CMRT in the middle cerebral artery outlet (p=0.012). And in the patient-derived models, which were reconstructed from pre- and post-interventional DSA images of a patient with middle cerebral artery stenosis, the stenosis of the middle cerebral artery decreased from 83% to 20%, the velocity of blood at the middle cerebral artery outlet increased from 0.3 m/s to 0.8 m/s. And the pressure differential of stenosis declined from 15 mmHg to 5 mmHg.

Conclusion: Conclusion: The perfusion analysis demonstrated the improvement of perfusion function after interventional surgery. In conclusion, changes in stenotic degree at the middle cerebral artery can make apparent differences in hemodynamic distribution and contrast material transport. CMRT may be a quantitative indicator to evaluate the changes in blood perfusion after intervention for middle cerebral artery stenosis.

Key words: digital subtraction angiography (DSA) , middle cerebral artery , stenosis , contrast material

ID 315

平滑肌细胞表型转变在动脉粥样硬化斑块发展中的作用

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目的：血管平滑肌细胞（VSMC）在动脉粥样硬化斑块中会呈现多种表型表达，多项实验表明，VSMC 可以调节其表型以响应斑块微环境变化。本研究旨在建立一个多尺度混合离散 - 连续模型，研究 VSMC 表型转变在动脉粥样硬化病变中的复杂作用。

方法：本研究考虑了斑块中常见的三类 VSMC 表型：分泌型、巨噬细胞样（MΦ-like) 型以及成肌纤维母细胞样（MF-like）型。VSMC 和巨噬细胞（MΦ）的增殖、迁移、表型转变以及细胞坏死等过程进行建模，利用元胞自动机方法离散模拟。模型中还考虑多种斑块微环境因素，如脂质、细胞外基质和细胞生长因子等，其动态变化过程由一组反应 - 扩散偏微分方程描述。

结果：模拟结果表明，VSMC 的复杂活动会改变细胞外微环境，从而影响斑块发展。不同的 VSMC 表型转变条件不仅会改变坏死核心大小和纤维帽厚度，还会影响多种微环境因子的累积和分布。调控表型转变会形成不同类型的斑块，其中，阻断 VSMC 转变为 MΦ-like VSMC 可以有效抑制易损斑块的形成。

结论：动脉粥样硬化斑块发展为稳定型或易损型与 VSMC 的表型转变有关，利用靶向治疗手段，定向调控 VSMC 表型转变过程，可以作为稳定斑块发展的治疗新思路。

关键字：斑块微环境，平滑肌细胞，斑块易损性

ID 344

Development and Validation of a Novel Physiological Model for Noninvasive Diagnosis of Myocardial Ischemia

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Objective: This study develops and validation of a novel non-invasively computed tomography (CT) fraction flow reserve (FFR) technique based on a new coronary physiological model (CPM). The CPM simulation, which provides boundary conditions, gave a vital role in CT-FFR. A novel CPM relying on mechanisms of compensation in pre-arterioles from the anatomy of the coronary circulation has been developed. It aims to improve the ability of CT-FFR in the diagnosis of myocardial ischemia. However, its accuracy has not been verified.

Methods: 328 patients (369 vessels) in multicenter prospectively underwent 128 detectors, coronary tomography angiography, and FFR. Quantify the compensatory changes induced by the pre-arterioles at resting to ascertain a new CPM that provides precise resistance boundary conditions for the CT-FFR. The novel CPM is applied to the closed-loop geometric multi-scale model to calculate CT-FFR non-invasively. First, 35 patients (40 vessels) formed the derivation cohort to determine the optimal CT-FFR threshold with which to detect functional stenosis, defined as an FFR of ≤0.80, which was validated in the subsequent 293 patients (329 vessels).

Results: Derivation cohort Results demonstrated optimal threshold for CT-FFR was 0.80 with 85.71% sensitivity and 88.46% specificity. In the validation cohort, the CT-FFR correlated closely with FFR ($r=0.66$, $p<0.001$) with good diagnostic performance (receiver-operating characteristic area under the curve of 92%, 95%CI [0.88-0.94] for FFR≤0.80). On per-vessel and per-patient levels, sensitivity, specificity, positive predictive value, negative predictive value, and accuracy of CT-

FFR were 81.72%, 94.07%,84.44%, 92.89%, and 90.59%, and 81.11 %, 95.07%,87.95%, 91.91%, and 90.79%, respectively. The accuracy of CT-FFR (Focal lesions) was considerably higher than CT-FFR (Serial lesions)(91.27% Vs. 87.72).

Conclusion: Based on a new CPM, the CT-FFR technique significantly improves the accuracy of assessing focal functional stenosis. And it has potential application in identifying functional stenosis of serial stenosis.

Key words: Coronary disease, Computed tomography angiography, Fractional flow reserve, Coronary physiological model.

ID 356

Cx43 在骨细胞响应失重环境影响成肌细胞分化中的作用

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目的：骨和肌肉之间存在着力和生化相互作用。骨细胞是骨组织力学感知最主要的细胞。连接蛋白 43（Cx43）是骨细胞重要的力响应敏感分子，其组成的半通道介导细胞与胞外环境的物质交换。本实验拟研究其在微重力下骨骼肌肉细胞间生化调控中的作用。

方法：使用随机回转仪（RPM）处理 MLO-Y4 骨细胞和 Gja1-K 细胞（高表达 Cx43），收集并检测培养上清中分泌因子的含量，并使用培养上清处理 C2C12 成肌细胞，检测其成肌分化和相关基因表达情况。

结果：骨细胞 RPM 处理后培养上清中分泌因子 PGE2 浓度降低，ATP 水平无明显变化，骨细胞模拟失重 2 天后细胞形态无明显变化，但增殖能力显著降低。骨细胞培养上清促进了 C2C12 细胞的分化，骨细胞高表达 Cx43 使成肌分化的肌管数量显著增加，成肌关键调节基因 Myf5 和线粒体融合 / 裂变相关基因表达升高，胞内 ATP 水平显著升高；模拟失重使成肌分化关键调节基因 MyoD 和线粒体融合 / 裂变相关基因表达降低，胞内 ATP 水平显著降低，但肌管数量和直径未见明显差异。

结论：在（模拟）失重下，骨细胞 Cx43 可能通过影响 PGE2 等因子的分泌，影响成肌细胞线粒体代谢和胞内 ATP 水平，进而影响成肌分化。

关键字：Cx43，模拟失重，骨肌相互作用

ID 432

Growth and Remodelling of Right Ventricle Under Pulmonary Arterial Hypertension

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Objective: Pulmonary arterial hypertension (PAH) is a fatal and rapidly progressive disease, and right ventricular (RV) failure is the main cause of death in patients with PAH. This study aims to develop experiment-informed growth and remodelling (G&R) models to provide new insights into the consequences of mechanobiology (strain/stress driven) in RV failure under PAH.

Methods: We will develop a new mathematical RV G&R model based on the recently developed homogenised con-

strained mixture theory by combining constituent-based constitutive laws embedded into an updated reference G&R framework. The left ventricle (LV) is included to provide the support of RV dynamics. The anatomical change of RV at different stages is further qualitatively computed through a large deformation diffeomorphic mapping algorithm, which is used for developing and validating G&R laws.

Results: Growth tensor is estimated by comparing the Control and PAH heart, in which growth mainly occurs along fibre, sheet and sheet-normal axial directions. LV free wall (FW) has balanced growth along three orthogonal axes with mean volumetric growth amount 1.75, whilst RV grows mainly along sheet direction, i.e., thickening RVFW with 2.7, followed by thinner spetum with the least growth (1.3). Growth tensor has a significant correlation with fibre stretch and stress, such as the correlation between square of stretch at end of diastole and growth amount along the mean fibre direction at the septum, with the correlation coefficient 0.77. The negative correlation indicates larger fibre stretch at the septum suppresses the growth along the mean fibre direction.

Conclusion: The methodology to estimate growth tensor by warping the Control and PAH heart provides an achievable approach to quantify growth amount along each material axial direction. Our Results not only show growth amount is associated with positions but also has different correlations with stress or strains under diseased conditions.

Key words: pulmonary arterial hypertension, growth and remodelling, rat heart

ID 451

关节软骨内不同溶质分子的运转研究

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目的：软骨内细胞正常代谢所需的营养物质和细胞生长因子等主要通过分子自由扩散进入软骨，但目前软骨内这些溶质分子的具体传质规律尚有待研究。

方法：考虑到软骨内分子转运路径的不同，设计了三种分子传质路径，分别为表面传质路径、侧面传质路径和复合传质路径，进行 2h、12h 和 24h 三个时间段的分子传质，同时考虑到软骨细胞在获取营养物质及生长因子时，各种分子的大小有所不同，因此，采用了分子量分别为 479Da、40KDa 和 150KDa 的三种示踪剂分子进行传质规律的研究。

结果：示踪剂分子在通过软骨表面路径进行传质时，传质 2h 即可扩散至软骨全层，在达到 12h 和 24h 时，软骨层内的分子浓度在软骨中层出现明显增加。在侧面路径传质时，随着传质时间的增加，分子转运的距离也在增加，且三种分子均表现出随着距离软骨侧面距离的增加，软骨层内分子的浓度逐渐降低。在三种路径条件下，分子的质量传输速率均随着传质时间的增加而降低，但复合路径条件下的分子传质效果要优于表面路径和侧面路径。

结论：复合路径可以促进中、大溶质分子向软骨深层的运转，即复合路径为最佳的分子传质路径。本研究可为软骨损伤的治疗和修复提供参考。

关键字：关节软骨，分子传质，转运路径

ID 519

T 细胞中 ERK 激酶活性对力学微环境的敏感响应

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目的： T 细胞是人体免疫系统的主要组分之一。在维护健康的免疫反应中，许多 T 细胞会经历显著的力学微环境变化，如从循环系统的流体状态到黏附在血管壁，穿过血管在组织中迁移并到达效应靶区。

方法： 基于 FRET 活细胞观测和 ERK 磷酸化抗体的生化检测，研究不同力学微环境条件下 Jurkat T 细胞中的 ERK 活性，其可作为 T 细胞生长发育的一种指标性分子。

结果： FRET 探针或磷酸化抗体检测显示，当 Jurkat 细胞从悬浮培养转为贴壁状态，胞浆和核中的 ERK 活性快速下降。模拟体内组织中的状态，细胞包埋在基底膜或胶原水凝胶中，ERK 活性也快速下降。通过 ATP 瞬间激活或异丙肌苷处理上调 ERK 活性，或抑制胞内收缩作用或肌丝骨架的动态组装，不能阻止物理黏附对 ERK 活性的下调作用。抑制胞内钙信号或激活整合素，ERK 活性下调趋势得到逆转。转录组测序分析证实多组基因出现了表达水平的上升或下降。

结论： Jurkat T 细胞中 ERK 活性对力学微环境变化有高度的敏感响应，并受钙信号和整合素影响，提示生理状态下从循环系统进入组织中发挥免疫功能时，T 细胞可能出现生化活性转换。

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关键字： T 细胞，细胞力学，ERK 激酶，FRET 技术，力学信号转导

543

Do Tumor Cell Mechanics Matter in Malignancy

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Objective: Cancer cells dysregulate cytoskeleton structures and mechanical properties during tumor progression, implicating a clear correlation between tumor cell mechanics and malignancy. However, whether the decrease in tumor cell stiffness is a by-product of or a driving force for tumor progression remains unclear.

Methods: This study targets actomyosin to modulate cell mechanics and examines the influence on tumor cell function through various in vitro and in vivo assays.

Results: Targeting actomyosin decreases tumor cell stiffness and promotes the self-renewing ability in vitro, including colony formation in soft agar, tumor spheroid growth in soft fibrin, the percentage of cancer stem cell (CSC) subpopulation, and the expressions of self-renewal genes. Increasing cell stiffness suppresses these self-renewing functions. Further, softening/stiffening tumor cells promotes/suppresses tumor formation and growth, suggesting the driving role of tumor cell mechanics in malignancy. This finding is applicable to multiple types of cancer, such as liver, breast, lung, colon, and cervical cancer. Importantly, softening/stiffening cytoskeleton weakens/strengthens the interaction between APC and β-catenin, which facilitates/reduces its nuclear translocation. Cytoplasmic β-catenin undergoes protein degradation, while nuclear β-catenin binds to Oct4 promoter and initiates gene transcription, which is crucial in sustaining self-renewal. Further, softening tumor cells facilitates the de-differentiation of non-CSCs into CSCs, while stiffening them promotes the differentiation of CSCs into non-CSCs. Both of these processes depend on Wnt/β-catenin signaling. Therefore, cell mechanics regulate stemness via the cytoskeleton-mediated activation of Wnt/β-catenin signaling. The genes and proteins of the cytoskeleton-APC-Wnt/β-catenin-Oct4 signaling are correlated in clinical samples and associated with patient survival.

Conclusion: Therefore, all these Results demonstrate that tumor cell mechanics drive self-renewal and malignancy, suggesting that the mechanics of tumor cells may be harnessed not only as a marker for cancer diagnosis but also as a new mechanical target for therapy.

Key words: cell mechanics; self-renewal; malignancy; cancer stem cell; mechanobiology

ID 722

Piezo1 信号在机械拉伸诱导气道平滑肌细胞蛋白质折叠紊乱及其在机械通气诱导肺损伤中的作用研究

罗明志 *、杨崇鑫、郭佳、李晶晶、潘艳、刘磊、邓林红
常州大学

目的：机械通气（MV）为新冠肺炎等呼吸道感染危重症患者提供呼吸支持，但也产生肺损伤，临床称为机械通气诱导肺损伤（VILI）。气道平滑肌细胞（ASMCs）在力学刺激后的炎症和收缩表型增强参与哮喘等病理过程。Piezo 是主要力学感知分子，但其在 VILI 中的作用及机制不清楚。本研究结合生物力学和生物信息学手段研究 MV 调控 ASMC 表型转换、信号响应及 Piezo1 在其中的作用。

方法：用 Flexcell-5000 在体外高拉伸（13%）处理 ASMC，光学磁微粒扭转系统、牵张力显微术分析细胞力学特性；qPCR 和 Elisa 分析炎症因子分泌；RNA 测序筛选力学响应信号；分析 Piezo1 在其中的作用。小鼠模型验证 Piezo1 在 VILI 中的作用。

结果：体外研究发现高拉伸增加 ASMC 刚度、牵张力和炎症因子分泌，导致蛋白质折叠紊乱。动物模型研究显示 MV 增加气道阻力、气道炎症和蛋白质折叠紊乱。抑制 Piezo1 则在体内 / 外模型均抑制 MV 引起的生物力学效应和肺损伤。

结论：Piezo1 介导 MV 诱导 ASMC 表型转换和蛋白质折叠紊乱，靶向抑制 Piezo1 显著改善 VILI。这一新颖的细胞力学机制为 VILI 的防治提供新思路。

关键字：机械拉伸诱导肺损伤，ASMCs，细胞表型，Piezo1，蛋白质折叠紊乱

ID 755

水凝胶网络动态性调控内皮细胞血管新生与再生的力学生物学机制研究

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目的：治疗性血管新生与再生已成为逆转外周血管病、心梗、脑梗等血管功能性障碍的重要手段，也是胚胎发育及肿瘤血管化的重要血管发生机制之一，其发生发展过程与基质的三维微环境的动态重构性紧密相关。尽管基质刚度对血管化的调控作用备受关注，但基质动态性（黏弹性）对血管新生与再生的影响及调控机制尚不明确。

方法：1、通过模拟在体血管组织特性，体外构建具有独立可控动态性的水凝胶体系；2、建立体外血管三维培养模型，阐明基质网络动态性对血管新生与再生的影响规律；3、揭示血管新生与再生过程感知动态网络微环境的力学生

物学转导机制。

结果：三维包埋实验证实，高动态性水凝胶网络可导致内皮细胞与基质之间产生更多的整合素簇并形成稳定的黏着斑，促进了细胞收缩力释放及形态发生，进而加快血管网络形成。然而，细胞球血管再生模型表明，适中动态性水凝胶网络可导致内皮尖端细胞侵入周围基质的距离及分枝率增长增多，其原因可能是高动态性网络中强大的细胞收缩力削弱了细胞间黏附连接，从而阻碍了后续茎细胞跟随尖端细胞发生进一步迁移。

结论：因此，具有适中动态性水凝胶网络中平衡的细胞收缩力及稳定的细胞间粘附连接对促进血管稳定性及血管新生与再生过程具有重要意义。

关键字：动态水凝胶 血管内皮细胞 血管新生 血管再生

ID 776

单一探针定量测量斑马鱼胚胎和肿瘤细胞克隆的硬度及牵引力

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目的：细胞硬度和细胞牵引力是细胞力学性质的两个重要表征。目前已有多种方法可以分别定量测量细胞硬度或细胞牵引力，但是还没有一种方法可以对细胞硬度和牵引力都进行测量。

方法：为解决这一问题，研究人员构建了一种硬度可变的探针。首先构建一种钴 - 铂合金的十字架型核心，再将其包裹在聚乙二醇凝胶中，建立了一种高硬度的探针。这种探针在强磁场下磁化后，在与磁化方向垂直的交变磁场作用下，会发生运动，通过计算探针的位移即可计算出细胞硬度。随后用紫外光对探针进行特定时长的照射，使探针变软，此时在周围细胞的挤压下，探针会发生形变，通过计算探针的形变量可计算出细胞产生的力。

结果：将探针与黑色素瘤 B16 细胞共培养，使探针被细胞克隆包裹住。将细胞培养在不同硬度的基质上以及不同硬度的纤维蛋白胶中，对细胞硬度和牵引力进行测量，发现在恶性肿瘤细胞克隆发展的过程中，细胞硬度会随着细胞外基质的硬度增加而变大，但是细胞间牵引力并没有随着细胞外基质的硬度发生变化。将探针注射到斑马鱼胚胎中，对斑马鱼胚胎的硬度和产生的牵引力进行测量，发现在斑马鱼胚胎发育过程中细胞间的牵引力存在周期性的振荡。

结论：开发的这种探针可在同一位置对细胞硬度和牵引力都进行测量。

关键字：细胞硬度、细胞牵引力、细胞磁力扭曲仪

ID 905

A Novel Force Platform for Assessing Multidimensional Plantar Stresses in the Diabetic Foot - A Deep Learning-based Decoupling Approach

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Objective: The multidimensional force platform has gained popularity in assessing the plantar pressures and shear stresses in the diabetic foot, which is believed to be a promising index for early diagnostics of foot ulcerations and proposing effective protective strategies. The effectiveness of decoupling the 3D force components with minimum cross-talk dictates the capacity of the force detection platform. This work presented a deep-learning-based method for multidimensional force decoupling using an optical-force detection platform.

Methods: An optical flow algorithm was utilized to track the displacement field of the elastomeric sensing layer of the force platform due to known external loads. A decoupling model was established by training the convolutional neural network of U-Net with 15,000 sets of multi-dimensional force-optical flow datasets collected by the customized force calibration system.

Results: After the training, the model can achieve real-time vertical (i.e., normal) and shear force detection with an accuracy of 0.089N and 0.020N, respectively. Visualization of the multi-dimensional forces indicated good generalization capability of the trained neural network model.

Conclusion: The method proposed in this work is expected to be used as an efficient tool for multidimensional force decoupling in assessing plantar stresses, and provided the foundation for further research on the biomechanical etiology of foot ulceration in people with diabetes.

Key words: Biomechanics, diabetic foot ulcers, multidimensional force decoupling, deep learning, shear stresses

ID 983

miR-33 调控移植静脉内膜增生的力学生物学机制

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目的：探究动脉环境的周期性张应变在移植静脉内膜增生中的作用，探讨 microRNA（miR）在其中的力学生物学机制。

方法：构建“套管法”大鼠静脉移植模型。检测移植静脉 miRs 表达情况，使用 miR 抑制剂及模拟物观察其对细胞增殖及靶基因调控作用。Flexcell 细胞张应变加载系统施加 10%-1.25Hz 的周期性张应变，检测静脉 VSMCs 的增殖、miR 和靶基因以及相关信号分子表达情况。局部多点注射 miR 模拟物，探究 miR 和靶基因在体功能。

结果：术后移植静脉显著内膜增生，miR-33 表达明显下降。miR-33 模拟物抑制细胞增殖、BMP3 及下游信号分子表达，抑制剂则反之。术后移植静脉 BMP3 及下游信号分子表达显著上升。10%-1.25Hz 的周期性张应变促进静脉 VSMCs 增殖、降低 miR-33 的含量、显著上调 BMP3 及下游信号分子表达。在体条件下 agomiR-33 有效下调 BMP3 以及

下游信号分子，抑制移植静脉细胞增殖并缓解内膜增生。

结论： miR-33 和 BMP3 可能成为移植静脉内膜增生临床干预治疗的潜在靶点。

关键字： 移植静脉，内膜增生，miR-33，周期性张应变，静脉平滑肌细胞，增殖，BMP-3

ID 1068

Muscle Synergy During Cross-country Sit-skiing Double Poling Propulsion Technique

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Objective: Subacromial pain syndrome with muscle imbalance is a common problem among wheelchair users who use their upper limbs frequently. Most upper limb injuries are closely related to the upper limb muscle contracting strategy. This study aimed to dissect the coordination of the upper extremity muscle groups during the cross-country sit-skiing double poling propulsion technique and provide guidance for training and rehabilitation.

Methods: One healthy college student was recruited. The participant was instructed to perform a one-min maximum effort test, in which kinematic data were collected simultaneously with EMG data from six glenohumeral and scapular muscles. Then muscle synergies were extracted from EMG envelopes of thirteen consecutive double poling cycles.

Results: Two muscle synergies were extracted. The first synergy corresponds to the poling phase. This synergy included the infraspinatus, posterior deltoid, triceps, and middle deltoid, ensuring that skiers can drive arm extension and abduction to generate propulsion. The second synergy primarily involved the anterior deltoid, and biceps during the recovery phase which would allow skiers to flex the shoulder and elbow joints.

Conclusion: The assessment of muscle synergies may be a valuable tool for exploring the exercise strategies employed by disabled athletes, providing useful information for improving athletic performance and possibly preventing injury risk. In the future, we will derive muscle-synergy strategies for cross-country sit-skiing from more subjects, considering more shoulder and trunk muscles.

Key words: cross-country sit-skiing; muscle synergy; non-negative matrix factorization;

ID 1093

Effects of Diurnal Rhythm on Human Balance Performance

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Objective: Human physiological activities exhibit cyclical changes with day and night, and studying the effect of time rhythm on human balance performance is of profound significance to explore the postural control mechanism, fall prevention and rehabilitation intervention.

Methods: This paper, adopting phrases related to diurnal time rhythm and balance performance as key terms, searched Web of Science core database, Medline and CNKI database, strictly set literature inclusion and exclusion criteria, and systematically analyzed the selected literature in terms of their times of day, samples, test Methods and parameters of bal-

ance performance as well as research results. Risk of bias was assessed, and a qualitative synthesis completed.

Results: A total of 20 papers met the inclusion criteria. 5 considered balance performance was the best in the morning; 5 in the afternoon. 4 considered it best in the evening. 1 reported it best before dawn, and 1 in the early morning. 5 reported that time rhythm had no effect on balance performance.

Conclusion: The research Results could not reach a consensus on the effects of daily time rhythm on balance performance, due to some influencing factors such as diversified subjects, varied measurement protocols, and unknown degree of fatigue among participants. (Humanities and Social Science Project of Ministry of Education, NO.19YJC890044; Social Science Project of Liaoning Province, NO.L22BTY003).

Key words: diurnal rhythm; balance performance; effect

ID 1128

力学微环境对肝癌干细胞干性的调控及分子机理

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目的：研究肝脏癌变过程中力学微环境的变化特征及其对肝癌干细胞（LCSCs）干性和自我更新能力的调控作用及相关分子机理。

方法：构建大鼠肝脏原位癌变模型，分析肝脏癌变过程中组织力学特性的变化特征及其与 LCSCs 分布的关系。采用氧化海藻酸钠三维培养体系研究不同刚度基质对 LCSCs 干性的影响。采用平行平板流动腔系统探究剪切应力加载对 LCSCs 力学生物学行为的调控及分子机理。

结果：大鼠肝组织杨氏模量随着肝癌病变进程逐渐增大，肝癌组织呈现明显力学异质性，LCSCs 分布与肝癌组织力学异质性明显相关。与软基质相比，硬基质中培养的 LCSCs 耐药性、克隆形成、增殖和在体致瘤能力显著增强，表明 LCSCs 干性响应基质力学微环境的变化。低剪切应力短时间加载促进 LCSCs 的迁移能力，但较长时间加载明显削弱 LCSCs 的干性，其杨氏模量增加，提示剪切应力加载诱导 LCSCs 发生了分化。进一步研究发现，Wnt/β-catenin 信号在低剪切应力调节 LCSCs 干性过程中起着重要的力信号转导作用。

结论：肝脏癌变过程涉及复杂的力学微环境改变，力学微环境改变对肝癌干细胞干性及自我更新能力有重要调控作用。

关键字：力学微环境；肝癌干细胞；自我更新；干性

ID 1131

经椎间孔腰椎椎间融合术植入单、双枚融合器的远期生物力学评价

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目的：研究目标：本文的研究目标在于基于骨重建仿真方法实现经椎间孔腰椎椎间融合术（TLIF）植入单、双枚融合器的远期生物力学评价。

方法：研究方法：基于采集的健康成人腰椎 CT 扫描数据，建立腰椎 intact 有限元模型，然后通过模拟手术操作，建立 TLIF 手术模型。选用应变能密度作为骨重建的力学刺激信号，骨表观密度作为观察指标，通过 ABAQUS 软件二次开发实现骨重建仿真算法。基于所建立的腰椎融合术骨重建仿真方法，分别对在 L3/L4 椎体间植入双枚（双 cage 模型）和单枚（单 cage 模型）箱形融合器手术模型进行瞬时和远期的生物力学评价。

结果：研究结果：在骨重建前、后，两种手术方式的 L3-L4 节段活动度（ROM），差距很小，且都显著小于 intact 模型。在骨重建前，除了个别工况外，单 cage 模型 L4 上终板最大等效应力、融合器最大等效应力、内固定钉棒最大等效应力均大于双 cage 模型。而在骨重建后，两者之间的差值变小，甚至在一些工况下单 cage 模型的值还较小。

结论：两种手术模型在骨重建完成后的远期生物力学性能较骨重建前变得更为接近，在临床上可以考虑采用单枚融合器替代传统的双枚融合器以节省手术花费。

关键字：经椎间孔腰椎椎间融合术，骨重建仿真，远期生物力学

ID 1221

红细胞力学特性高通量测量及其应用

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目的：高通量单细胞力学特性测量在个体化医疗技术中逐渐体现出价值，红细胞力学特性在许多与血液相关的重点慢性疾病中有着重要作用。然而，由于红细胞的优越变形特性使得红细胞力学特性的高通量精准测量极具挑战。

方法：利用狭窄圆形通道中细胞 - 流体相互作用的流体动力学机理，结合机器学习方法，建立了精确测量红细胞力学特性的单细胞高通量测量方法。我们利用高速相机记录红细胞在恒定压力驱动下在微米直径毛细圆管内的时间序列影像。通过红细胞运动速度和稳定形态，学习反演得到红细胞的体积、面积、细胞膜剪切模量、细胞粘度。

结果：提出的高通量单细胞测量方法对红细胞固有力学特性测量的单通道速率可以达到 1 个每秒，并且膜剪切模量相对误差在 0.01±0.11。

结论：临床样本实验显示，利用本方法可以区分不同糖化血红蛋白受试者不同红细胞结构的力学特性差异。该创新从细胞尺度流固耦合动力学机理出发，为细胞力学疾病相关研究增加了与生化无关的生物物理维度，在与血液相关的疾病健康管理中有着巨大的应用前景。

关键字：细胞力学，红细胞，微流控芯片，疾病诊断

ID 1232

表面黑磷纳米片功能化钛植入体的制备及力学性能研究

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目的：为了进一步提高钛植入体的涂层的力学性能以及骨再生速度，用黑磷纳米片（BP NSs）和羟基磷灰石对钛片表面进行改性。本研究通过多种方法将 BP NSs 沉积到钛片表面，制备了不同的黑磷功能化复合涂层，研究了黑磷功能化涂层的形成机理，并对涂层力学性能以及生物相容性方面进行了研究

方法：通过电沉积的方法将 CS 和 BP NSs 共沉积到 Ti 表面，制备出一层 CS/BP NSs 涂层；为了使 BP NSs 缓慢释放，在涂层中引入羟基磷灰石，为了增强羟基磷灰石的抗菌性能，用 Zn2+ 对羟基磷灰石进行改性，实现了 Zn2+, 羟基磷灰石，BP NSs 三者的共沉积，制备出复合涂层 Zn2+/HA/BP NSs。

结果：复合涂层与基底以及骨组织之间具有较高的力学结合强度；且细胞在涂层表面的粘附力增加，另外还具有诱导成骨分化和诱导血管化能力。

结论：在这项工作中，碱热处理和电沉积的方法用于制备高结合强度 HA/BP NSs 涂层。涂层有利于细胞增殖、粘附、成骨分化和血管化，复合涂层将会在骨科临床中具有广泛应用前景。

关键字：黑磷纳米片；羟基磷灰石；涂层；钛植入体；电沉积

ID 1267

拉胀多孔骨支架微结构设计与生物力学性能研究

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目的：骨多孔支架可为细胞生长、血液系统生成、多种代谢发生提供场所，在体内可有效传导力学刺激促进成骨。拉胀结构的内凹拓扑结构和负泊松比变形方式使其具有不寻常的生物特性和力学性能，在骨修复中应用具有优势。本文研究拉胀多孔支架结构设计参数对其力学性能与生物学性能的调控规律，为拉胀式骨多孔支架临床应用提供理论依据。

方法：设计新型结构拉胀多孔支架，采用选择性激光烧结技术对其进行制造。采用力学试验方法对其力学性能进行分析，并建立相应的有限元分析模型与数学解析模型。应用计算流体数值方法分析拉胀多孔支架在载荷作用下的物质传输性能。

结果：内凹角度可以广泛调节拉胀多孔支架力学性能；力学试验结果与有限元分析结果具有很好的一致性，所建立的理论模型可以很好地表述内凹角度与多孔支架弹性模量、泊松比的关系，可实现拉胀多孔支架力学性能定制化设计；多孔支架的内凹角度有利于内部流体均匀分布；载荷作用下，内凹多孔支架渗透性降低，但壁面剪切力平均值变化明显，这表明其可以更好地实现对细胞的动态刺激。

结论：通过调控结构内凹角度可实现拉胀多孔支架力学性能与生物学性能的可控设计，可为研发性能定制化骨多孔支架的临床应用奠定基础。

关键字：骨多孔支架；拉胀结构；3D 打印；力学性能；生物学性能

ID 1352

间质流剪切力在血管平滑肌细胞表型转化中的作用及机制研究

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目的：在动脉粥样硬化发展过程中，血管内皮层受损，导致平滑肌细胞受到的间质流剪切力（Interstitial flow shear stress, IFSS）显著升高，本文针对升高的 IFSS 在 SMCs 表型转化中的作用其分子机制进行研究。

方法：收集 AS 患者动脉血管组织样本，通过数值模拟，计算出 AS 组和正常组的 IFSS。在此基础上，对 SMCs 分别加载 0.5 dyn/cm2 和 3 dyn/cm2 剪切力，通过 qPCR，WB 实验研究 SMCs 的表型转化。同时，收集不同组别的细胞进行转录本测序，分析力学信号传导通路及下游的转录因子，通过 qPCR，IF 和 WB 检测关键因子的表达及分布变化。最后，使用基因编辑技术对转录因子的功能进行验证。

结果：IFSS 可显著诱导 SMCs 的表型转化；MAPK 信号通路响应 IFSS 的作用，其下游转录因子 KLF5 入核活化调控表型转化相关基因的转录程序。

结论：IFSS 通过 MAPK 信号通路激活 KLF5 诱导 SMCs 发生表型转化。

关键字：间质流剪切力；平滑肌细胞；表型转化；动脉粥样硬化

ID 1399

剪切应力刺激启动肝细胞增殖

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目的：肝部分切除后可迅速再生，再生过程中肝细胞的增殖与剩余肝脏单位质量的血流增加密切相关，但是肝血窦内的血流能否经狄氏间隙而直接作用于肝细胞、间隙流引起的剪切应力能否触发肝细胞的增殖仍不清楚。

方法：在体实验采用不同的流量通过门静脉对小鼠的肝脏进行灌注并检测肝细胞增殖。离体实验从小鼠肝脏提取原代肝细胞，并通过微流控芯片对细胞施加不同大小、不同时长的剪切应力，利用 EdU+%、cyclin D1+% 以及细胞周期相关的基因和蛋白表征肝细胞增殖，并通过力学敏感蛋白的抑制或阻断分析相关力学转导通路。

结果：通过小鼠肝脏灌注实验，可实现血流引起的间隙流的可视化，并启动肝细胞的再生反应。体外细胞实验表明，流动产生的剪切应力以时间和幅值依赖的方式启动肝细胞增殖。分子机制上，剪切应力通过 β1 整合素 -YAP 通路促进肝细胞由休眠期重新进入细胞周期。

结论：在体的间隙流和体外的剪切应力均可启动肝细胞增殖，这可能是肝部分切除后再生的机制之一，也为体外实现肝细胞的大量扩增提供了基础。

关键字：间隙流；剪切应力；肝再生；β1 整合素；YAP

ID 1450

透明质酸修饰的内皮细胞源性工程化胞外囊泡通过靶向调控巨噬细胞极化治疗动脉粥样硬化

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目的：对剪切应力作用下血管内皮细胞分泌的胞外囊泡（EVs）进行工程化改造，探究其靶向调控巨噬细胞极化进而治疗动脉粥样硬化的能力。

方法：层流剪切应力诱导的血管内皮细胞源性 EVs，经透明质酸（HA）表面修饰得到工程化胞外囊泡 HA@LSS-EVs。通过流式细胞术、qRT-PCR、免疫荧光检测巨噬细胞体外极化情况。通过活体成像及免疫荧光手段检测 HA@LSS-EVs 靶向病灶区域巨噬细胞的能力。最后，通过流式细胞术、油红 O 等组织病理染色评价 HA@LSS-EVs 在体内调控巨噬细胞极化，进而抑制动脉粥样硬化进展的能力。

结果：工程化修饰显著提升 EVs 靶向炎性巨噬细胞的能力；HA@LSS-EVs 显著上调 M2 表型相关标志物的表达；HA@LSS-EVs 可靶向小鼠主动脉斑块中的巨噬细胞，并显著降低主动脉脂质沉积。

结论：HA@LSS-EVs 具有调控巨噬细胞由 M1 向 M2 极化的能力，可靶向病灶处的 M1 巨噬细胞发挥作用，减缓动脉粥样硬化的病理进程。

关键字：动脉粥样硬化；层流剪切应力；胞外囊泡；巨噬细胞极化

ID 1472

Adaptation of Macrophages to Biomechanical Microenvironment

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Objective: Immune cells, particularly macrophages, in the human body experience various biophysical and biochemical microenvironments. Previous studies have indicated that the stiffness of the microenvironment affects the inflammatory response of macrophages, with a stiffer environment leading to a greater inflammatory reaction. However, in our study, we found that this relationship varied depending on the type of macrophage, whether it is a cell line or a primary cell. Our study aimed to examine how changes in the biomechanical microenvironment can impact the inflammatory response of macrophages.

Methods: We first "domesticated" MH-S (a cell line of mouse macrophage) on soft substrate for 12 hours and 168 hours respectively, and monitored the changes in macrophage biomechanics and inflammation related pathways. The macrophages were then transferred to a stiff substrate, and we re-examined the changes in macrophage biomechanics and inflammation three days later.

Results: This experiment allowed us to identify the reaction rules of macrophages to biomechanical microenvironments before and after "domestication."

Conclusion: Our findings suggest that macrophages have the ability to adapt to biomechanical microenvironments, and this adaptation affects the interaction between biomechanics and inflammation. The Results also confirm the close

relationship between macrophages and biomechanical microenvironments and highlight the importance of further exploration in this area. Further research in this field could have significant implications for understanding the pathological mechanisms of related diseases.

Key words: Biomechanical microenvironment, Macrophages, Cellular adaptation, Inflammatory response, Microenvironmental memory

ID 1506

增龄对小鼠股骨微观尺度断裂力学行为的影响研究

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目的：增龄导致骨的结构及力学性能发生改变。老龄骨折风险的增加与其断裂力学行为密切相关。本研究旨在微观尺度深入理解增龄对骨结构和力学性能的影响，揭示骨断裂失效模式响应增龄过程的规律。

方法：本研究构建了小鼠增龄模型（3 月幼龄鼠、8 月成年鼠、18 月老龄鼠），通过聚焦离子束（FIB）技术制备直径 5 微米、高 10 微米的股骨微柱样品，利用微柱轴向压缩测试骨力学性能与裂纹扩展。利用扫描电镜、micro-CT、拉曼光谱检测骨结构及组成成分。

结果：随着年龄的增加，骨微柱的极限载荷、强度先增加后不变，弹性模量先增加后减小。成年鼠骨微柱强度、弹性模量分别比幼龄鼠高 24%、47%（$P < 0.01$）；成年鼠骨微柱弹性模量、屈服应力分别比老龄鼠高 21%、43%（$P < 0.001$）。老龄鼠皮质骨截面积、组织骨密度、骨矿物结晶度更高。幼龄鼠骨断裂时主要为剪切滑移和轴向楔形断裂，成年鼠和老龄鼠骨断裂主要为剪切应力和轴向应力共同作用的复合模式。

结论：在微米尺度，成年鼠骨的力学性能比幼龄鼠和老龄鼠更为优异，成年鼠和老龄鼠的骨断裂失效模式与幼龄鼠差异较大，提示增龄导致骨微观结构、力学性能及断裂力学行为的显著改变。

关键字：骨；增龄；微观尺度；力学性能；断裂失效模式

ID 1556

中鼻甲手术对鼻腔嗅觉功能影响的生物力学研究

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目的：运用生物力学方式探究双侧中鼻甲部分切除术、骨折内移术对鼻腔嗅觉功能的影响

方法：获取一例健康成年男性上气道 CT 图像，模拟其静息状态下吸气时，中鼻甲骨折内移术、部分切除术后上气道颗粒沉积特征，并将每侧鼻腔嗅觉区域分为四个区域，进一步分析两种手术后各嗅觉区域颗粒沉降情况

结果：两种中鼻甲手术前后上气道整体颗粒沉积率变化不大；术前嗅觉区域颗粒沉降率为 0.867%，中鼻甲骨折内移术后嗅觉区域颗粒沉降率为 1.208%，左、右侧中鼻甲侧嗅觉区域颗粒分级沉降率分别为 37.069%、37.931%，左、右侧鼻中隔侧嗅觉区域颗粒分级沉降率分别为 22.414%、2.586%；中鼻甲骨折内移手术后嗅觉区域颗粒沉降率为 0.558%，左、右侧中鼻甲侧鼻腔嗅觉区域分级沉降率分别为 10.417%、8.333%，左、右侧鼻中隔侧嗅觉区域分级沉降率分别为 62.500%、18.750%

结论：中鼻甲骨折内移术、部分切除术对鼻腔整体颗粒沉降影响很小，但中鼻甲骨折内移手术后嗅觉区域内颗粒沉降增多，增加了嗅觉区域中鼻甲侧颗粒分级沉降率；中鼻甲部分切除手术对鼻腔嗅觉区域内的颗粒沉降有负面影响，改变了鼻腔嗅觉区域颗粒分级沉降率，其中鼻中隔侧大于中鼻甲侧

关键字：中鼻甲手术 嗅觉 数值模拟

ID 1579

Blast-induced Traumatic Brain Injury: Investigating a Potential Role of Intestinal Microbiota in Regulating Neuroinflammation

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Objective: Blast shockwave-induced traumatic brain injury（bTBI), can result in severe neuroinflammation and gastrointestinal dysfunction, both of which increase the risk of death and long-term disability to patients. Accumulated evidence has shown intestinal microbiota dysbiosis may interrupt brain immune function. However, the relationship between intestinal microbiota and the secondary injury mechanism of bTBI is less known. The purpose of this study is to determine the effect of gut bacterial on the progression of shockwave-induced traumatic brain injury and neuroinflammation.

Methods: The Bio-shock tube was used to generate shock waves. Female C57/BL6J mice were treated with antibiotics for 2 weeks (ABX group) and anesthetized before being exposed to 160 kPa (peak pressure) shockwave, the normal feeding group were treated with sterile water before shockwave exposure. Physiological, pathological and behavioral characteristics were examined at different time point after shockwave exposure, to evaluate the level of neuroinflammation. 16S rRNA sequencing of gut microbiota was employed to establishing the correlation between changes in intestinal flora and dynamic processes of neuroinflammation.

Results: Compared with the Normal feeding group, the ABX mice showed significantly increase of the body weight after bTBI. The inflammatory level was lower than the normal feeding group 12 hours after the shock(TNFα: $P<0.05$; IL-1b: $P<0.05$). The proportion of pro-inflammatory microglia in ABX group was decreased. LEfSe analysis combined with differential species information showed that Shigella was the biomarker for intestinal flora disorder in the 12h groups after blast, and Bacteroides S24-7 was the biomarker for intestinal flora disorder in the 7 days groups after blast.

Conclusion: Intestinal microbiota is involved in the regulatory process of neuroinflammation development induced by shock injury.

Key words: Shockwave-induced injury; Traumatic brain injury; Neuroinflammation; Gut dysfunction

ID 1583

跨越里程碑——以 Nike Vaporfly 4% 为例

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目的： NF4% 被誉为创新投资和未来创新的里程碑。但并未改变运动损伤发病率的现状。基于数字化、标准化和程序化数学思维探明跑步落地模式，跨越 NF4%。

方法： 招募 30 名运动员，进行为期 12 周的跑步技能训练，标准化步速、步频和落地模式；数字化关节轨迹、支撑面反作用力 (VGRF)；计算矢状面上身体的运动轨迹；建立鞋的有限元模型，设定边界条件；计算矢状面上人体环节和整体的拉格朗日量。

结果： 1) 步态参数：均无统计学差异；2) NV4% 与飞电 (Spoon) 的 VGRF 存在显著性差异，与飞电 (Elite) 无统计学差异；3) NV4% 的范式等效应力 (VMS) 在碳板外侧，Spoon 的 VMS 在基础弓；4) 拉格朗日量：均无统计学差异。

结论： 在相同的边界条件下，Spoon 优于 Elite 与 NF4%；跑步时，赤足的压力分布更符合足弓结构的承载特征。从演化的角度看，Spoon 也优于 NV4% 与 Elite。这意味着，穿着 Spoon 鞋训练不仅与赤足训练的效果基本一致，提高运动表现，同时能减小足部承载载荷。

关键字： 马拉松；跑鞋；Vaporfly 4%

ID 1587

LASIK 和 SMILE 术后角膜生物力学性能的参数化数值模拟对比研究

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目的： 通过参数化数值模拟研究评估不同手术条件下 LASIK 和 SMILE 术后角膜生物力学响应的差异。

方法： 建立 LASIK 和 SMILE 手术的有限元模型，并研究不同角膜条件和手术参数设置下两种术式对角膜生物力学性能的影响差异。参数包括术前角膜厚度、角膜瓣或帽厚度和直径、屈光矫正度数和光学区直径。统计学比较不同参数下两种术式导致的应力改变、继发性位移和瓣帽接触面压强的差异，并分析差异与各参数的相关性。

结果： 在相同的手术参数下，SMILE 术后角膜基质层的应力改变和继发性位移均小于 LASIK（$p < 0.001$），而角膜帽的应力总体上大于角膜瓣（$p < 0.001$），SMILE 术后切削界面的接触压强大于 LASIK（$p < 0.001$）。随着术前中央角膜厚度、屈光矫正度数和光学区直径增加，以及角膜瓣 / 帽厚度减小，两种术式引起的角膜生物力学响应差异呈减小趋势。

结论： SMILE 较 LASIK 在保存角膜刚度方面有优势，但该优势受多因素影响，其中屈光矫正度数、中央角膜厚度、角膜瓣帽厚度的影响尤为突出。这一结果对个性化术式选择和切削方案优化具有重要意义。

关键字： 角膜屈光手术；生物力学；有限元模拟；参数化学习

ID 1681

Biomechanical Research on Laterality Effect between the Dominant and Non-dominant side of High-level Taekwondo Athletes in the Single-leg Vertical Jump

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Objective: It is explored of the differences of the biomechanical characteristics between the dominant and non-dominant side of the lower limbs of the Taekwondo athletes in the single-leg vertical jump.

Methods: 14 high-level taekwondo athletes were recruited to perform the single-leg vertical jump test. The kinematics and dynamics data of the hip, knee and ankle joints were collected synchronously by the VICON acquisition system and the Kistler dynamometer. The Results were analyzed using the paired sample T-test.

Results: There was no significant difference in the ground reaction force between the dominant and non-dominant side (P>0.05); there was no significant difference between the maximum values of the hip joint flexion and extension angle, flexion and extension angular velocity (P>0.05) , there was a significant difference between the range of the hip joint flexion and extension (P<0.05); the maximum values of the knee joint flexion and extension angle showed a significant difference (P<0.05), and the flexion and extension span range showed a significant difference (P<0.01), there was no significant difference between the maximum flexion and extension angular velocity (P>0.05); there was no significant difference between the maximum value of ankle flexion and extension angle, flexion and extension angular velocity, and flexion and extension spanning range (P>0.05).

Conclusion: High-level taekwondo athletes' single-leg vertical jump presents asymmetrical. Compared with the non-dominant side, there are significant differences in the range of hip flexion and extension, the maximum angle of knee flexion and extension, and the range of knee flexion and extension in vertical jumps on the dominant side. During the training, the weaker limbs can be strengthened through targeted training, and the symmetry can be improved to promote sports performance.(This study was supported by the East Lake Scholars Sponsorship Program of Wuhan Sports University in China, Science and Technology Team Foundation of Wuhan Sports University under Grant (21KT02)）.

Key words: taekwondo; kinematics; dynamics; laterality; single-leg vertical jump

ID 1714

水凝胶的生物界面粘附力学设计及其在组织修复中的应用

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目的：本文聚焦水凝胶的界面粘附问题，从界面粘附力学角度进行理论建模指导优化粘附水凝胶的设计，解决目前水凝胶组织粘合剂的瓶颈问题并拓展其在生物医学工程领域的应用。

方法：依据分子动力学模拟及数字图像相关等数值仿真方法和理论分析，解构水凝胶组织粘合剂的粘附机理，提出生物分子扩散驱动的界面拓扑粘接理论模型。

结果：聚焦液下、低温及油脂界面等复杂环境生物界面粘附的瓶颈，开发了适用于低温环境的明胶基可注射水凝胶、水下生物特异性高强粘附水凝胶以及全层伤口皮下脂肪组织闭合水凝胶，系统探究了这些生物相容性水凝胶对于生物组织的粘合失效机理，识别了小分子扩散与拓扑粘接协同作用在其中的关键调控作用。

结论：基于上述理论模型指导设计的粘附水凝胶克服了低温环境对明胶基水凝胶力学性能的抑制，突破了油脂界面势阱，降低了脂肪液化风险，实现了局部靶向给药和促慢性伤口愈合，从物理力学角度探索和开发生物界面粘附体系提供了新的思路。

关键字：界面粘附，水凝胶，多尺度力学，脂肪组织闭合

ID 1719

空间位阻对淀粉样蛋白成核的抑制机制

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目的：尽管最近的实验和模拟表明，小分子抑制剂和一些翻译后修饰（如乙酰化、糖基化和泛素化）可以抑制蛋白质因空间位阻而产生的致病性聚集，但空间位阻效应对淀粉样蛋白形成的影响还没有被系统地研究。

方法：基于全原子和粗粒化的分子动力学模拟以及蒙特卡洛模拟，我们系统研究了空间位阻效应对淀粉样蛋白成核的抑制机制，详细研究了空间位阻效应对寡聚体成核和构象转化的影响。

结果：研究结果发现，乙酰化和糖基化翻译后修饰均通过抑制 alpha- 突触核蛋白间的氢键网络来阻碍寡聚体形成。更一般的，随着空间位阻尺寸的不断增大，蛋白寡聚化被抑制，而蛋白由可溶态向 β 片态的构象变化，是先被抑制、后被促进；有趣的是，只有部分蛋白被空间位阻修饰的情况下，可以令蛋白的构象转变被明显抑制。

结论：研究结果表明空间位阻可以有效地抑制成核，进而抑制淀粉样蛋白的形成。通过改变空间位阻的大小和修饰蛋白的摩尔分数，空间位阻对淀粉样蛋白成核表现出多样化的抑制作用，并可能改变中间或最终产品的毒性。自然界可能利用这种不同的空间位阻效应来多样地调节蛋白质的聚集过程以及相关的功能 / 毒性。

关键字：淀粉样蛋白，寡聚化，分子模拟

ID 1864

Exploring the Aging-associated Decline in Vascular Smooth Muscle Cell Mechanosensation using an Ultrasound Tweezers based Micromechanical System

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Objective: Aging leads to changes in cytoskeleton architecture and mechanical properties of vascular smooth muscle cells (VSMC), altering their ability to sense mechanical stimuli and modulate their force response. However, current understandings of the physiological mechanisms underlying the aging-related mechanosensation are limited. Thus, we applied an ultrasound tweezers based micromechanical system to explore the aging-associated decline in VSMC mechanosensation behaviors.

Methods: Ultrasound tweezers was used to apply a 10-second, 1 Hz, ~100 pN of transient force to single VSMC through

an RGD-integrin bonded lipid-encapsulated microbubble on the cell membrane under ultrasound excitation, simulating an external mechanical stress. Elastic PDMS micropillar array force sensor was used to measure the time-variant force response of VSMCs after the stimulation over a 55-minute period.

Results: We applied the ultrasound tweezers system to study the mechanosensation behaviors of single VSMC isolated from young (12 weeks) or old (58-78 weeks) mice. Single VSMC subjected to the transient mechanical stress remodeled themselves through a biphasic mechanical allostatic process: a rapid increase in traction force in the first 15-30 min then gradually restored to the initial level. We proved an overexpression gamma smooth muscle actin in old cells that increase the cell stiffness but reduce the mechanical sensitivity of VSMC. Old VSMC exerted a higher traction force than the young cells at static state. However, VSMC from old mice showed defective mechanosensation functions with weaker and delayed response to the transient mechanical stimulus. Furthermore, qRT-PCR and immunostaining Results revealed that the aging-associated decline in mechanosensation behaviors is mediated by hyperactivity of Piezo1-dependent calcium signaling. Knockdown of Piezo1 with siRNA transfection alleviated vascular aging and partially restored the loss in dynamic contractile properties in aged cells.

Conclusion: Our study reveals the novel signaling pathway underlying aging-associated aberrant mechanosensation in VSMC and identifies Piezo1 as a potential therapeutic mechanobiological target to alleviate vascular aging.

Key words: Cell mechanobiology, aging, mechanosensation, vascular smooth muscle cell, Ultrasound Tweezers

ID 1892

基于老年人步态稳定性分析的临界坡度角研究

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目的：倾斜路面改变了老年人的步态稳定代偿方式，但坡度角对其影响规律并不明确，致使社区坡道适老化设计缺乏统一的标准与规范。本研究的目的为通过计算老年人在不同坡度步行的运动学参数，定量分析老年人步态稳定性下降的临界坡度角。

方法：56 位 60 岁及以上老年人受试者参与了本次测试。在摩擦系数为 0.9 的实验环境下，记录受试者不同坡度角（0°~15°，步进角：5°）的 TUG 运动学数据。使用三维动作捕捉系统采集全身 15 体段 42 个标记点坐标，应用《成年人人体惯性参数》计算全身质心（COM）位置，使用足底压力传感器采集的稳定边界（BOS）及 COM 位置相对关系分析步态稳定性。采用网格法、粒子群算法、基因算法优化支持向量回归机模型，拟合得到动态稳定性参数随坡度角变化的曲线特征。

结果：随着坡度角的增加，COM-BOS 最大值及最大差值均显著减少（$p<0.005$），老年人受试者的动态稳定性呈现出下降趋势。且动态稳定性参数随坡道角变化的拟合曲线显示，曲线唯一鞍点为 4.9°，此时步态稳定性差异显著分化，即临界坡道角度为 4.9°。

结论：为降低老年人跌倒风险，倾斜路面的坡道角应控制在 0°~4.9° 范围之间。

关键字：老年人；坡道；动态稳定性

ID 1927

Greater Pelvic Retroversion or Larger Pelvic Incidence Angle Leads to more Fatty Infiltration of Paraspinal Muscles in Patients with Degenerative Lumbar Spondylolisthesis

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Objective: To evaluate paraspinal muscle fat infiltration and spinopelvic parameters in patients with lumbar spondylolisthesis or lumbar spinal stenosis, and to identify the effect of pelvic morphology on paraspinal muscle fatty infiltration in patients with degenerative lumbar spondylolisthesis.

Methods: 70 patients diagnosed with lumbar spondylolisthesis (DLS group), and 70 patients with lumbar stenosis (LSS group) were included. The ratio of the cross-sectional area of fat to the cross-sectional area of total muscle was used to calculate the fat infiltration of paraspinal muscle (PSM) and Psoas major muscle (PMM). Spinopelvic parameters include Pelvic incidence (PI), sacral slope (SS), pelvic tilt (PT), lumbar lordosis (LL), and Barrey ratio. PI, SS, PT, LL, and Barrey ratio were measured on the full-length standing X-ray image. Spearman correlation analysis was performed to illustrate the correlations between the FI and the age, gender, body mass index, and sagittal spinopelvic parameters.

Results: The PSM FI in the DLS group showed significant correlations with PT, PI, SS , LL and barrey ratio . In the LSS group, only the barrey ratio showed a correlation with PSM FI , $P<0.05$. In the DLS group, the PSM FI of the pelvic retroversion group was significantly higher than that of normal pelvic group (0.43±0.14) and pelvic anteversion group. However, PSM FI in the LSS group was respectively 0.41±0.16, 0.41±0.15, and 0.38±0.15 in the anteversion group, normal pelvic group, and pelvic retroversion group, with no difference . In addition, The PSM FI of the large PI group in the DLS patients was 0.50±0.14, significantly higher than that of the small PI group and normal PI group.

Conclusion: In patients with degenerative lumbar spondylolisthesis, fatty infiltration of the paraspinal muscles increased with greater pelvic retroversion or larger pelvic incidence angle, whereas no such trend was found in patients with lumbar spinal stenosis.

Key words: Fat infiltration; Spinopelvic parameters; Paraspinal muscle; Pelvic retroversion; Degenerative lumbar spondylolisthesis

ID 1959

基于患者特异性血液粘度和二尖瓣边界条件对左心耳血流动力学和血栓形成风险的预测研究

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目的：房颤引起的血栓栓塞性并发症是患者致死、致残的主要原因。预测房颤患者左心房血栓形成风险对疾病防治起着重要作用，血流动力学是近年来评估左心耳内血栓形成风险的重要方法。然而，目前左心房和左心耳的血流动力学研究患者特异性信息往往不足，研究者忽略患者血液流变学和患者特异性边界条件对血流动力学的影响。本研究基于四位患者的特异性数据，探究血液粘度 (作为红细胞压积和剪切速率的函数) 以及患者特异性二尖瓣边界条件 (超

声测量的二尖瓣面积和二尖瓣入口流速曲线) 对血流动力学和血栓形成风险的影响。

方法：根据临床数据将四位患者分为有血栓和无血栓两组，设置了四种场景来考虑不同程度的患者特异性，将血流动力学结果与患者临床血栓情况相比较。

结果：结果表明，左心耳内患者特异性血液粘度的平均值远高于 0.0035Pa · S。患者间剪切速率差异不大，红细胞压积可能是导致不同患者间血液粘度和血栓形成风险差异的主要原因。患者特异性二尖瓣边界条件的影响也是显著的。随着患者特异性数据的增加，血流动力学结果与临床观察的一致性也增加。

结论：本研究的发现为患者特异性血流动力学模拟提供了有用的见解，有助于更准确地评估左心耳中血栓形成的风险。

关键字：血流动力学；左心耳；血栓；红细胞压积；患者特异性

ID 1966

基于三次极小曲面 (TPMS) 的骨支架多物理场优化设计

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目的：近年来，基于三周期极小曲面 (TPMS) 的支架被广泛用作骨替代物。然而，当前的 TPMS 骨支架存在弹性模量过高、各向异性与人骨不匹配、渗透性有待提高等问题，且弹性模量与渗透性之间相互矛盾，无法同时提高两种性能。本研究率先提出一种结构优化的方法，通过对结构进行挖孔设计，提高了骨支架的性能。

方法：本文首先以降低结构（Schwarz P）弹性模量使其匹配人骨为目标，通过本构关系推导建立优化框架；其次，对优化后的结构进行弹性模量的计算，得到与人骨弹性模量匹配的结构；最后，对这些结构的渗透性和各向异性进行评估，得到最优结构。

结果：优化后 Schwarz P 结构的弹性模量从 20GPa 下降到 6GPa，与人体松质骨的弹性模量相匹配。对这些弹性模量满足需求的结构进行进一步评估，结果表明其渗透性至少提高了 1 个数量级，这是目前 TPMS 结构中所达到的最高渗透性。此外，结构的各向异性均在人骨范围 0.2-4.0 之内。

结论：在基于本构关系建立的优化框架下，通过结构挖孔进行的优化设计所得到的 Schwarz P 结构同时达到了弹性模量、渗透性、各向异性的优化，使其具有很好的生物性能，也为骨植入物的结构设计提供了新思路。

关键字：TPMS 骨支架；结构优化；增材制造；仿真计算；实验验证

ID 2004

动脉周期性张应变阻滞平滑肌细胞自噬流在移植静脉血管重建中的力学生物学机制

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目的：动脉力学环境诱导静脉平滑肌细胞（VSMCs）异常增殖是临床冠状动脉搭桥术后桥血管再狭窄和堵塞的重要病理原因。自噬是真核生物进化上高度保守，对于维持细胞稳态至关重要的生物过程。动脉力学环境对于移植静脉 VSMCs 自噬的影响目前仍不清楚。

方法：应用“套管”法构建大鼠颈静脉移植模型，FX5000 系统对体外培养 VSMCs 施加 10%-1.25 Hz 周期性张应变以模拟移植术后 VSMCs 受到的动脉张应变力学刺激。

结果：相对于大鼠对照静脉，移植后 VSMCs 胞内自噬小体与溶酶体融合受阻。动脉周期性张应变通过解聚微管，阻碍 VSMCs 自噬小体逆向运输，诱导 VSMCs 自噬流阻滞。自噬受阻引发自噬底物衔接蛋白 p62 累积，上调的 p62 通过激活 nrf2/slc7a11 抗氧化通路促进 VSMCs 增殖。在体外支架介入稳定微管或沉默、突变（T349A）p62 能显著延缓移植后内膜增生进程。

结论：静脉移植术后，动脉张应变力学刺激显著阻滞 VSMCs 自噬流诱导 p62 堆积，p62 通过激活 nrf2/slc7a11 信号通路辅助 VSMCs 抵抗氧化应激。恢复桥血管 VSMCs 自噬流、下调 p62 是延缓内膜增生的潜在治疗策略。

关键字：静脉移植、自噬、周期性张应变、微管、p62

ID 2012

MACF1 通过调节 ERK/TAZ/YAP 信号转导参与模拟失重抑制成骨细胞分化

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目的：研究力学敏感分子 MACF1 参与模拟失重抑制成骨细胞分化的力学生物学机制。

方法：采用 RPM 模拟失重条件，以 MACF1 正常 / 低表达成骨细胞为研究对象，结合细胞松弛素 B 与 ERK 磷酸化抑制剂 PD98059，分别采用碱性磷酸酶染色、细胞免疫荧光染色、纳米压痕、Real time PCR 和 Western Blot 检测成骨细胞分化、细胞微丝骨架排列、细胞弹性模量、以及 ERK 信号转导等。

结果：（1）模拟失重条件下，对照成骨细胞中 MACF1 表达下调，成骨分化能力下降，而 MACF1 低表达成骨细胞的成骨分化能力变化不明显；（2）模拟失重条件或 MACF1 低表达均引起细胞微丝骨架重排，细胞弹性模量下降，而 MACF1 低表达成骨细胞对模拟失重条件不敏感；（3）模拟失重条件或 MACF1 低表达抑制 ERK 磷酸化及其下游 TAZ/YAP 表达，并抑制 Runx2 表达而增加 Runx2 磷酸化。

结论：力学敏感分子 MACF1 在成骨细胞感知与响应模拟失重条件中起重要作用，其通过调节细胞内力感知单元（微丝骨架）重排，改变 ERK/TAZ/YAP 信号转导，下调成骨分化关键转录因子 Runx2 表达，最终抑制成骨细胞分化。

关键字：模拟失重，MACF1，成骨细胞分化，细胞骨架，ERK 信号转导

ID 2063

生物力学对骨组织再生中血管生成与成骨耦合调控的研究

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目的：骨组织再生中血管生成与成骨具有在时空耦合的独特现象。骨缺损修复的过程中，血管网络和成骨也是高度力学敏感的生物现象。动态力学刺激可以提高血管体积，从而促进骨缺损的修复。骨骼中独有的 H 型血管在新生骨组织中高度的表达，并与成骨细胞在空间和功能上耦合。但是，动态的力学刺激是如何调控 H 型血管，达到加速骨再

生的机制尚不清楚。本研究猜想力学敏感 G 蛋白偶联受体 S1Pr1 在骨组织再生中有重要作用。

方法：我们利用小鼠胫骨单面皮质骨缺损模型，探索了 S1Pr1 在骨缺损受力学刺激后的作用。结果显示动态加载显著提升了 S1Pr1 在 H 型血管中的表达量，并且激活了血管内皮细胞中的 YAP 信号。通过药物抑制或提高 S1Pr1 的活性也达到了相应的降低和促进骨修复的效果。

结果：骨愈伤组织中，超过 80% 的 S1Pr1 表达在血管内皮细胞中。力学加载显著提高愈伤组织中 S1Pr1 的表达水平。并且，力学刺激缓解了 S1Pr1 拮抗剂对骨量和弹性模量的负面影响。

结论：骨骼血管内皮细胞表达的 S1Pr1 可能作为关键的力学响应蛋白成为促进骨组织再生的生物力学和药物的靶点。

关键字：力学生物学，骨组织再生，骨骼血管，力学敏感蛋白

ID 2103

压缩加载下脑组织力学行为的研究

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目的：精准的计算力学模型作为有效的工具来研究脑组织的力学性能，对于人类大脑在生理和病理条件下的损伤和防护有重要意义。

方法：对新鲜猪脑以 0.002/s 和 0.2/s 两种应变速率进行准静态无侧限压缩试验，统计分析了区域性，应变速率和方向性对脑组织的力学性能的影响。通过建立的本构模型拟合实验数据确定材料参数能够直观得到灰白质各向同性基质以及神经纤维的力学性能。

结果：30% 应变下脑干，小脑和大脑的刚度逐次递减，大脑中白质硬度强于灰质，辐射冠高于其他三个区域，10% 应变下区域效应不明显；白质（延髓，辐射冠，胼胝体）的平均应力满足 D2>D1, 但是辐射冠差异性不显著；应变率从 0.002/s 到 0.2/s 各区域的强度显著增加；压缩加载下，非均质的白质满足 G1>>G2；各区域的表观弹性模量均表现出逐渐增大。

结论：灰质是各向同性的，但是不同区域之间存在异质性，白质方向依赖性随着当压缩应变与加载速率增大时逐渐明显且其力学性能高度依赖于纤维的方向，胼胝体纤维高度定向，辐射冠的偏轴纤维导致分数各项异性减弱。通过对材料参数的分析，轴突在抵抗变形过程中扮演重要的作用，压缩加载下包裹在轴突外的各向同性的白质基质沿轴突剪切的抵抗力要远大于跨轴突。

关键字：脑组织，生物力学，压缩试验，本构模型

ID 2104

Effect of Mechanical Stretch-Induced Gene ATF3 in Extracellular Matrix Metabolism of Keratoconus

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Objective: Keratoconus (KC) is an ectatic corneal disorder characterized by progressive thinning and protrusion of the central cornea. It is a multifactorial disease and the definite mechanisms remain unclear. Eye rubbing, as a risk factor for keratoconus can cause obvious changes in corneal biomechanics. Thus, we aimed to screen the mechanical responsive genes in cornea and analyze the roles in KC pathogenesis.

Methods: To identify the differential expression genes (DEGs) responded to mechanical stretch, the microarray based transcriptional profiles of corneal fibroblasts after cyclic stretch (15 % strain) were analyzed and then subjected to GO and KEGG enrichment analysis. The protein-protein interaction network of DEGs were constructed by STRING. The hub genes responded to mechanical stretch were obtained by Cytohubba. siRNA technology was used to verify the role of the selected hub gene in KC fibroblasts. Cell proliferation and apoptosis were analyzed using CCK8 and TUNEL staining respectively. RT-PCR and western blotting were performed to determine the expression levels of genes and proteins of interest.

Results: In total, we identified 236 DEGs in stretch-affected corneal fibroblasts, which were mainly enriched in the biological processes of cell proliferation, apoptosis, and adhesion. Activating transcription factor 3 (ATF3) was identified as the mechanical-responsive hub gene and was induced by cyclic stretch. We detected elevated levels of ATF3 in KC fibroblasts. Cell proliferation was increased in ATF3-silenced KC fibroblasts, while the apoptosis rate was decreased. In addition, the expression of genes involved in extracellular matrix (ECM) synthesis including COLs and LOXs were up-regulated. Whereas MMP1, which participated in ECM degradation, was down-regulated after reducing ATF3 expression.

Conclusion: Mechanical stretch-induced gene ATF3 could promote cell apoptosis, inhibit proliferation and ECM accumulation in KC fibroblasts. The study would facilitate the understanding of molecular mechanisms underlying KC pathogenesis.

Key words: Keratoconus, Mechanical Stretch, ATF3, Extracellular Matrix

ID 2147

新型维甲酸诱导肿瘤干细胞凋亡的力学生物学机制研究

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目的：肿瘤的力学特征在肿瘤发生发展中至关重要。肿瘤干细胞（CSCs）是一种具有自我更新能力的肿瘤细胞亚群，并对传统抗癌药耐药。为了根治肿瘤，我们研发了新型维甲酸 -WYC-209，可高效诱导 CSCs 凋亡，效率远高于传统化疗药，但其机制并不清楚，这阻碍了抗癌维甲酸的优化和研发。

方法：通过三维细胞牵引力定量技术，实现 WYC-209 处理下，CSCs 牵引力变化实时监测；采用抑制剂等手段确定 WYC-209 抑制细胞张力的分子机制和信号调控网络；基于分子动力学模拟及荧光素酶报告实验探究药物靶点与 Cdc42 相互作用机理；利用电子显微镜及 ChIP 技术揭示牵引力与染色质构象之间的关系，以及对凋亡基因的调控规律，以此阐明 WYC-209 诱导 CSCs 凋亡的机理。

结果：WYC-209 抑制 TRCs 的效率是传统维甲酸的 20 倍。WYC-209 抑制细胞牵引力先于诱导细胞凋亡。WYC-209 通

过结合靶点 RARγ 并诱导其出核下调 Cdc42 的表达，以此下调牵引力。牵引力的降低诱导染色质疏松，促使 Pol II 与凋亡基因启动子的结合，激活凋亡基因表达，诱导 CSCs 凋亡。

结论： WYC-209 通过抑制细胞牵引力诱导染色质疏松激活凋亡基因诱导 CSCs 凋亡。

关键字： 细胞牵引力，肿瘤干细胞，细胞凋亡，染色质构象，力学生物学

ID 2155

高强度明胶基水凝胶的制备与性能研究

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目的： 骨关节炎是一种以关节软骨退化和关节囊发炎为特征的慢性关节病。从改善骨软骨修复材料力学性能和提供修复关节软骨的营养物质两个方面入手能够有效治疗骨关节炎。盐酸氨基葡萄糖 (GH) 可以特异性地作用于关节软骨，恢复软骨细胞正常的代谢功能。

方法： 本研究以明胶和 GH 为主要原料，通过浸泡 $(NH_4)2SO4$ 溶液的方法制备了高强度 A25/G-GH 水凝胶，在满足组织工程学中对于骨修复的同时实现营养物质的供应。通过对 AX/G-G-GH 水凝胶测试其机械性能筛选出最适宜的 (NH4)2SO4 溶液浓度 (X: 浸泡不同浓度的 (NH4)2SO4 溶液)。

结果： 结果表明 A25/G-GH 水凝胶的抗压强度和压缩模量达到了 11.43±0.51 MPa 和 0.18±0.01 MPa，断裂应力和断裂伸长率达到了 1.28 MPa 和 550%，在满足骨软骨修复材料机械性能要求的同时，通过降解作用持续地为细胞提供营养物质 (GH)。体外细胞实验表明 A25/G-GH 水凝胶对 MC3T3-E1 细胞的增殖没有抑制作用，显示了良好的细胞相容性。

结论： A25/G-GH 水凝胶的开发为骨软骨修复领域提供了一种新的策略。

关键字： 骨关节炎；盐酸氨基葡萄糖；高强度明胶基水凝胶

ID 2251

高度近视眼由眼动引起的视乳头变形更大

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目的： 视乳头变形与青光眼密切相关，眼动可导致视乳头变形且在正常眼压性青光眼中更为明显。高度近视是青光眼的危险因素之一，高度近视中视神经弯曲度增大可能会减缓视乳头的变形，但由于其他眼部结构也发生了变化，目前其眼动导致的视乳头变形是否存在异常仍不确定，本研究旨在探究这一问题。

方法： 本研究首先建立了正常人眼和高度近视眼的全眼及视神经有限元模型。随后对 9 名正常人和 8 名高度近视患者的双眼视乳头在内外转各 20 度的情况下进行 OCT 成像。之后运用数字体图像相关技术，测量了不同情况下视乳头筛板的有效应变。

结果： 有限元分析结果表明，高度近视眼睛模型内转 20°、外转 20° 导致的筛板平均有效应变分别为 0.051 和 0.037，显著高于正常眼睛模型。在体三维应变测量结果表明，高度近视眼动导致的筛板平均有效应变显著大于对照组，内转 20° 时筛板应变分别为 0.060±0.040 和 0.039±0.021（p=0.039），外转 20° 时筛板应变分别为 0.039±0.023

和 0.025±0.011（p=0.025）。

结论：与对照组相比，眼动会导致高度近视眼更大的视乳头变形，且内转时导致的变形更大。这可能是高度近视易患青光眼的贡献因素之一。

关键字：近视；青光眼；视乳头；眼生物力学；应变测量

ID 2391

疲劳因素对跑步下肢肌肉协同模式的影响

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目的：本研究旨在通过非负矩阵分解算法研究跑步疲劳对下肢肌肉协同模式的影响。

方法：招募男性受试者 12 人，接受负荷递增式疲劳干预。利用 Bertec 三维测力跑台、Noraxon 无线表面肌电系统采集受试者疲劳前后跑步（12km/h）时优势侧下肢主要肌肉肌电数据，利用非负矩阵分解算法提取肌肉协同模式，以及对应的平均肌肉权重和激活曲线。采用配对样本 t 检验分析疲劳对人均肌肉协同数量的影响；采用 Welch t 检验分析疲劳对肌肉权重，激活时长，开始、结束时刻等参数的影响。

结果：本研究共提取 6 种肌肉协同模式（SYN1-6）。疲劳前后人均协同数量及主导肌肉权重未显著变化，次要肌肉权重小范围改变。此外，疲劳后 SYN3 激活时长显著缩短（p=0.022），激活开始时刻显著延后（p<0.001）；SYN4 激活时长显著延长（p=0.013）；SYN5 激活峰值时刻显著延后（p=0.041）。

结论：肌肉协同模式能整体阐述疲劳对跑步神经肌肉控制的影响。跑步时肌肉协同模式结构稳定，受疲劳影响小，支持神经起源假说。肌肉权重和激活曲线的小范围变化是中枢神经系统维持疲劳后运动强度的适应性改变。

关键字：跑步疲劳；肌肉协同；非负矩阵分解

ID 2472

经导管肺动脉瓣膜移位的生物力学研究

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目的：瓣膜移位是经导管肺动脉瓣置换术的主要并发症之一。本研究从生物力学的角度研究肺动脉介入瓣膜移位的问题，提出一种具有抗位移性能的拉胀结构瓣膜支架，以减少瓣膜移位发生率。

方法：通过体外摩擦学实验，探究了镍钛合金与肺动脉界面在不同法向载荷和滑动速度下的摩擦行。提出具有拉胀结构的肺动脉瓣膜支架，通过数值模拟方法分析了该支架负泊松比效应、压握性能及支架植入和移位过程。

结果：镍钛合金与肺动脉界面摩擦系数与法向载荷、滑动速度有关，发现摩擦系数随法向载荷的增大而减小。拉胀结构瓣膜支架具有抗移位性能。

结论：研究结果为镍钛合金支架与血管的摩擦问题研究提供相关参数。所提出的拉胀结构瓣膜支架具有抗位移性能，为扩大经导管肺动脉瓣膜置换术的适应人群范围提供借鉴和参考。（国家重点研发计划项目 2020YFC1107901；国

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关键字： 生物力学，肺动脉介入瓣膜，支架移位，有限元方法

ID 2520

Kinematic and Biomechanical Responses of the Spine to Distraction Surgery in Children with Early Onset Scoliosis: A 3-D Finite Element Analysis

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Objective: Periodical and consecutive distraction is an effective treatment for severe early onset scoliosis (EOS), which enables the spinal coronal and sagittal plane deformity correction. However, the rate of rod fractures and postoperative complications was still high mainly related to the distraction process. Previous studies have primarily investigated the maximum safe distraction force without a rod broken, neglecting the spinal re-imbalance and distraction energy consumption, which is equally vital to evaluate the operative value. This study aimed to reveal the kinematic and biomechanical responses occurring after spinal distraction surgery, which were affected by traditional bilateral fixation.

Methods: The spinal models (C6-S1) before four distractions were reconstructed based on CT images and the growing rods were applied with the upward displacement load of 0-25 mm at an interval of 5 mm. Relationships between the distraction distance, the distraction force and the thoracic and lumbar Cobb angle were revealed, and the spinal displacement and rotation in three-dimensional directions were measured.

Results: The spinal overall imbalance would also happen during the distraction process even under the safe force, which was characterized by unexpected cervical lordosis and lateral displacement. Additionally, the law of diminishing return has been confirmed by comparing the distraction energy consumption in different distraction distances, which suggests that more attention paid to the spinal kinematic and biomechanical changes is better than to the distraction force. Notably, the selection of fixed segments significantly impacts the distraction force at the same distraction distance.

Conclusion: Accordingly, some Results could provide a better understanding of spinal distraction surgery.

Key words: bilateral fixation; kinematic and biomechanical response; law of diminishing return; spinal distraction surgery; traditional growth rod.

ID 2531

Topological Cues-induced Oriented Growth of Intraneural Vessel Guides Remyelination and Neurite Extension in Peripheral Nerve Regeneration through MMRN1/Integrin Axis

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Objective: Objective: The slow regeneration and misdirected neurite extension following peripheral nerve injury (PNI) threaten a satisfactory outcome, in which uncontrolled vascular reconstruction may restrict efficient peripheral nerve regeneration. However, the intraneural vessel preference and paracrine effects on neuronal growth have not yet been elucidated. In this study, we develop a novel nerve guidance conduit (NGC) to guide efficient vascular reconstruction and then facilitate the processes of remyelination and neurite extension by vessel-nerve crosstalk.

Methods: Methods: By additive manufacturing and oriented crystallization techniques, we fabricated a two-layer NGC characterized by an anti-adhesion outer surface and a well-oriented inner interface. We implanted the NGC into a rat 15-mm sciatic nerve defect model for 12 weeks, and thereafter the walking track assessment, electrophysiological detection, and histological evaluation of the regenerative nerve were performed. The proliferation, migration, and tube formation capacities of vascular endothelial cells on the topological surface were elucidated in vitro. Proteomics was employed to screen the critical paracrine modulator from vessels, by which the crosstalk actions supporting neurite repair were confirmed.

Results: Results: The biomimetic NGC displayed oriented microstructure, appropriate biomechanical properties, and satisfactory biocompatibility. The NGC with oriented architectures exhibited similar regeneration of axons and myelin sheath and recovery of the electrophysiological function compared to autograft, superior to counterparts with random orientation. The vascular functions were enhanced along with refined neurite extension during culture on an oriented topological interface. The MMRN1 secreted by vascular endothelial cells contributed to the improved outcomes by MMRN1/integrin coupling.

Conclusion: Conclusion: These findings demonstrated that the NGC with optimized topological cues could efficiently induce intraneural vessel growth, and the newly formed vascular network as guidance drove rapid neurite extension through MMRN1/integrin axis. This NGC product is promising for tissue engineering applications.

Key words: Peripheral nerve regeneration, Topological cues, Vascularization, Vascular endothelial cell, Myelin sheath

ID 2547

可编程钙黏素和整合素介导的细胞黏附对细胞力学感知的调控机制

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目的：在间充质发育过程中，细胞周围的力学信号会从由细胞 - 细胞相互作用主导转变为由细胞 - 基质相互作用主导。而这两种力学信号的转导对发育至关重要，但这些信号如何共同调节细胞的力学感知还不完全清楚，而很大一部分原因在于难以在体外实现这些力学信号的动态调控。

方法：本论文建立了一个 DNA 驱动的细胞培养平台，该平台可以通过 DNA 杂交和链置换反应实现力学信号的动态调控。平台利用来自纤连蛋白的 RGD 多肽模拟细胞 - 基质的相互作用，以及来自 N- 钙粘蛋白的 HAVDI 多肽用于模拟胞 - 细胞相互作用。该平台可以程序化地模拟间充质发育中细胞 - 基质和细胞 - 细胞相互作用的演变过程。

结果：本论文应用该平台揭示了整合素介导的黏附促进 cofilin 磷酸化，而钙黏素介导的黏附抑制了 cofilin 磷酸化。Cofilin 磷酸化上调核周顶端肌动蛋白纤维，使细胞核变形，从而诱导人源间充质干细胞中 YAP 核定位，导致随后的成骨分化。

结论：该可编程培养平台广泛适用于研究生长发育、伤口愈合和组织工程中的动态力学生物学信号，为揭示生理病理过程的动态变化机制提供了有力的技术支撑。

关键字：DNA、钙黏素、整合素、细胞力学感知

ID 2556

新型分形骨支架与天然骨的生物力学适配性研究

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目的：骨组织工程的金标准之一要求骨支架具有与天然骨匹配的形态学结构、力学特性以及渗透率，那么，设计与天然骨生物力学特性匹配的骨支架具有重要意义，至此，本文旨在寻找天然松质骨的分形特征，并设计新的分形骨支架。

方法：以 Menger 海绵的分形构造方式为参考，通过控制结构的自相似指数构造一种新型的多孔分形各向异性骨支架，并对其力学性能及渗透率两个生物力学特性进行系统性研究，结合数值分析和实验研究手段详细阐述一级及二级支架结构 - 力学特性和结构 - 渗透特性，并与天然骨的对应特性进行比较分析。

结果：和二级结构相比，一级结构具有较大的力学特性，但渗透率较小；且结构自相似指数对结构的各向异性特性及渗透率影响较弱；通过和不同解剖部位松质骨的对应生物力学参数相比，能够确定适配不同部位松质骨缺损的支架结构，这说明通过调控结构的设计变量，能够设计出适配天然骨生物力学特性的骨支架。

结论：本研究融合了天然骨结构的分形特征，设计了具有分形支架形态学特征的骨支架，为潜在的骨支架设计提供了新思路。

关键字：骨组织工程；分形支架；力学特性；渗透率；各向异性度

ID 2586

基于大涡模拟定量分析人全肺气道模型中的气流特性

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目的：量化人体呼吸系统中的气流特征对于理解气溶胶输运沉积特性非常重要。

方法：在本研究中，应用大涡模拟方法研究了从口腔延伸至第 13 代支气管的人全肺气道模型中的气流特性。在 15 L/min 和 30 L/min 的吸气流速下，研究了全肺气道模型中平均气流场的特性以及气流的流动不稳定性。

结果：结果表明，咽喉部特殊的几何结构将导致非常复杂的气流结构，其强度与吸气流速密切相关。二次流强度在整个呼吸道中并不单调，即使在非常薄的支气管气道中也允许强烈的二次流。平面内二次流切变和纵向流切变是上气道产生湍流动能（TKE）的主要原因。在支气管树中，TKE 主要由纵向流动剪切产生，直到末代具有一定程度的湍流强度（TI），TKE 更受吸气流速的影响，TI 更受局部几何特征的影响。

结论：吸气流速和局部几何财产对气流特性有很大影响，在较深的气道中可能存在流动不稳定性。因此，在研究人体呼吸系统气流特性时，应特别注意细支气管气道的几何特性和气流不稳定性。

关键字：全肺气道模型；大涡模拟；平均气流场；流动不稳定性

ID 2649

功能化纳米材料与周围神经再生

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目的：神经微环境失衡与周围神经损伤后病理生理改变不可逆以及肢体功能恢复不理想密切相关。传统的神经再生支架由于缺乏仿生纳米技术以及生化或理化性能修饰而导致疗效较差。其关键在于，它们无法对失衡的再生微环境进行合理而简单的重构，更不能恢复神经的结构与功能。

方法：近年来，随着对神经损伤相关微环境认识的不断加深，一系列新策略被应用于提高神经组织工程中仿生纳米支架的生物化学和物理化学性能。这些纳米支架可以通过表面修饰触发生长因子的聚集与分泌，调节 ATP 的合成与水解以及氧化与还原态转换，更可在特定物理条件下激活离子通道从而调控生物电信号。

结果：因此，此类功能化纳米材料可以通过调节再生过程中神经元细胞活力、发育以及细胞周期来决定神经元命运。本研究将围绕功能化纳米材料的仿生支架设计以及拓扑结构、生化和物理特征改性等方面展开，并首次提出基于纳米技术的神经微环境重塑过程中的四大关键要素（免疫应答、神经内血管化、能量代谢和生物电传导）。

结论：功能化生物材料的发展为组织工程再生医学在周围神经损伤治疗中的转化研究与应用提供新思路。

关键字：周围神经损伤；修复与再生；微环境；生物材料

ID 2658

头部碰撞时大脑变形的测量和计算

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目的：头部碰撞导致的创伤性脑损伤是目前人类社会最为普遍的神经性损伤，每年全球约有 2708 万人由于创伤性脑损伤而导致残疾，其中我国约占 440 万人。碰撞导致的大脑变形是一系列神经损伤的起点，故对碰撞时大脑变形的测量与计算对研究创伤性脑损伤的生物力学基础和发展相应的诊断、防护设备有重要意义。

方法：为了得到真实头部碰撞产生的大脑变形，我们提出并发展了一套测量方案：首先通过牙套式传感器测量装置测量撞击时头部的加速度，再通过深度学习头部模型实时计算相应的大脑应变。

结果：牙套式传感器通过上齿与头骨刚性连接，从而达到对头部加速度高精度的测量（角加速度峰值相对误差 5%）。接下来，测得的头部加速度可以作为输入，通过深度学习头部模型计算大脑各处最大主应变。深度学习头部模型的误差约为 0.013，远远小于脑损伤阈值（0.2）。

结论：该测量方案已经应用于测量美式橄榄球和自由搏击运动中的大脑应变，相关数据用于研究碰撞时血脑屏障失效的力学阈值，比较不同种类头盔和保护措施的防护效果等。随着对相关病理的力学损伤模型的不断深入研究，该测量方案有望应用于临床诊断创伤性脑损伤。

关键字：创伤性脑损伤；脑震荡；牙套；大脑应变；深度学习

ID 2688

骨质疏松股骨头结构主向和力学主向的相关性研究

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目的：骨形态结构随着在体力学环境的改变而发生变化，Wolff 骨迹线理论认为骨小梁迹线与在体组织的拉压主应力迹线一致，然而有文献认为该迹线理论不适用于股骨近端或股骨头。至此，本文试图寻找松质骨小梁迹线（结构主向，PMSD）和刚度主向（力学主向，PMD）的相关性，重新认识骨小梁迹线与力学特性的关系。

方法：基于 5 位骨质疏松患者 5 个股骨头样本的显微 CT 影像，通过张量旋转寻找小梁骨的结构主向；同时，将股骨头样本分成 529 个小梁骨块体，结合有限元和力学理论获取所有小梁骨块体的刚度矩阵，并将获得的刚度矩阵进行欧拉旋转，找到小梁骨块体的力学主向。将得到的两个主向分别在三个正交面上进行投影，分析小梁骨结构主向和力学主向的匹配度。

结果：在小梁块体尺度下，结构主向和力学主向的相关性系数达到了 97.4%；而在股骨头尺度上，结构主向和力学主向的匹配度较差（差别为 18.7o），原因是该尺度下整个股骨头影像向三个面投影时，小梁块体以外的部分皮质及

松质骨区域也参与了分析，进而降低了两个主向的匹配度。

结论：本研究确定了小梁结构主向和刚度主向块体尺度下具有较好的一致性，为研究和认识骨小梁迹线分布提供了新视角，并为组织工程骨支架的设计提供新思路。

关键字：骨质疏松骨；结构主向；刚度主向；相关性分析

ID 2724

惯性负载对虚拟现实交互的影响

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目的：当操纵物体时，惯性感觉有助于人类自然的行为表现，但其对虚拟现实 (VR) 交互运动的影响很少被研究。本研究探索了惯性感觉的缺失对虚拟现实环境中进行目标导向运动的影响。

方法：本研究设计了一个虚拟目标导向任务，受试者需要将不同质量的虚拟物体从初始孔洞移动到目标孔洞中。基于同步采集的上肢运动学数据和眼球追踪数据，我们分析了惯性对受试者手、眼运动的影响。

结果：结果发现，当去除惯性载荷时，手在运动前期表现出更大的空间变异性，在运动后期出现更多的不连续并且花费了更多的时间。这表明了受试者运动控制和反馈调节能力的下降，因为惯性负载的缺乏使得感知肢体运动的本体感觉传入减弱。同时眼动证据表明，当手上缺乏惯性感觉时，视觉注意将更多的分配到虚拟物体和目标孔洞上，有助于补偿本体感觉线索的减弱。

结论：这些发现揭示了惯性效应对虚拟现实环境中人类行为的重要性和机制。

关键字：虚拟现实；目标导向运动；惯性；运动控制；眼动追踪；手眼协调

ID 2751

拉伸状态下非均匀泊松比结构气管支架的数值仿真研究

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目的：针对气管运动时支架易出现移位现象，利用支架负泊松比结构的拉胀效应，使直径不会随着拉伸而减小，可以更贴合气管，从而为改善移位问题提供理论依据。

方法：以真实气管数据为基础，设计两端（L1）与中部（L2）均为正泊松比结构支架 S1，与两端为正泊松比结构（L1'），中部为负泊松比结构（L2'）的非均匀泊松比结构支架 S2。人健康气管的伸长量为气管的 20%，伸长时直径减少约 13%，故将两种支架拉伸至原长度的 120%。利用有限元方法计算对比被拉伸后的两种支架 L1 与 L1'、L2 与 L2' 的直径变化以及 L1' 与 L2' 的直径变化，并与气管的直径减少量作对比，分析两种支架的生物力学特征。

结果：S1 在拉伸后整体直径减小，L1 段直径减小了 8%，L2 段减少了 18.2%。S2 在 L1' 处直径减少了 7%，L2' 处直径增加了 4%。两种支架在 L1 段直径均减小，但 S1 的 L2 段减小量超过气管直径的减小量，S2 的 L2' 部分发生拉胀效应，且直径增加量不超过气管支架最佳直径的最大值。

结论：气管支架在拉伸时负泊松比结构可发生拉胀效应，调整支架的结构可使支架更贴合气管。本研究有望解决

气管运动导致的支架植入后移位的问题。

关键字： 气管支架；负泊松比结构；结构设计；数值模拟

ID 2828

股骨粗隆间骨折复位固定拄拐下地行走和坐便受力特点与控制方法探讨

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目的： 设计适当的股骨粗隆间骨折复位固定术后功能活动与生活自理设施。

方法： 穿戴测力鞋（专利号 ZL200520142238.4）训练足底负重控制；采用坐骨承载的坐便圈（专利号 ZL202123027436.4），分别在足底、大腿下和坐骨下设置测力传感器，与普通椭圆坐便圈受力状态比较。

结果： 8 名健康志愿者穿戴测力鞋，通过报警阈值声音提示，受试者在拄双拐行走中控制单侧足底负重在 30(Kg)-40(kg) 范围，设置一定行走距离，自动记录的达标步数占 (71 ± 12.6) % ，小于 30Kg 步数占 (19 ± 11.6) % 和超过 40Kg 步数占 (10 ± 9.1) % ；采用所述专利坐骨坐便圈模拟坐便，6 名志愿者测得单侧坐骨承载占体重 (28 ±6.1) % ，单侧大腿负重 (12 ± 4.9) % ，单侧足底负重 (10 ±1.9) %。而使用普通椭圆圈坐便器时，坐骨落空，单侧大腿后侧负重占体重百分比增加到 (43 ±2.4) % ，单侧足底负重 (7 ± 2.8) % 。

结论： 本方法利于粗隆间骨折治疗中实现动静结合，医患合作，减少卧床并发症。

关键字： 粗隆间骨折，下地活动，坐便，坐骨

ID 2849

膝前痛步态的无接触测量和运动生物力学研究

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目的： 膝前痛的发病机制和康复治疗常与生物力学因素密切相关。目前临床医师常以查体和影像学检测为依据对该疾病进行诊治，缺乏定量的生物力学评价方法；而传统的运动捕捉技术由于测量过程复杂且可能影响患者自然步态，较难广泛应用于临床。本研究基于深度摄像技术对膝前痛患者进行无接触的步态分析，定量评价该疾病不同亚类患者的运动生物力学特征。

方法： 首先对 9 名健康受试者进行无接触运动捕捉，并基于逆向动力学计算地面反力和下肢肌肉力，同步采用 Vicon、三维测力台和表面肌电的数据对上述运动学和动力学结果进行验证。进而对 115 名膝前痛患者进行步态分析。

结果： 研究发现，患者的支撑相占比、髋、膝关节角度、臀肌、股四头肌肌力与健康对照组存在显著差异；髋关节外展角度、髋肌、臀肌肌肉力等指标在骨关节炎、半月板损伤、髌骨疼痛综合征等亚类患者中存在显著差异。

结论：通过无接触的运动捕捉和步态分析可为膝前痛疾病的准确诊断、分类和治疗评价提供生物力学依据。

关键字：运动生物力学 , 膝前痛 , 步态分析

ID 2958

Effect of Exercise-induced Fatigue on Biomechanical Characteristics of Lower Extremitys in Male Runners

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Objective: Compare the effects of exercise-induced fatigue on the neuromuscular control strategies in lower extremity of male runners.

Methods: 12 recreational runners were recruited, and required to run at 12 km/h for at least 30s in pre-test. The Vicon motion capture system, Bertec instrumented treadmill, K4b2 gas metabolism analyser and portable blood lactate analyser were used to synchronously collect the kinematics and kinetic data in lower extremity in the stance phase, as well as the gas metabolism data and blood lactate concentration for 15s. The incremental fatigue intervention started immediately after the pre-test. The intervention was terminated when both the following criteria were met: 1) subjects were unable to continue running, and 2) the maximum heart rate reached (220-age-10) bpm. The post-test started immediately after the fatigue intervention, with the same protocol as the pre_x0002_test. The paired sample t-test was used to compare the effect of fatigue on each dependent variabl.

Results: (1) All the subjects met the fatigue assessment criteria (fatigue intervention duration: 14.6±2.6mins, maximum heart rate: 196.8±9.6bpm, blood lactate concentration: 12.5±3.5mmol/L, RPE: 17.6±1.3). (2) In the stance phase, the hip maximum flexion angle ($p<0.001$), maximum flexion angular velocity ($p=0.031$), and joint range of motion ($p<0.001$)increased significantly after fatigue; (3) the knee maximum flexion angle ($p=0.016$) and the angle at initial contact($p=0.025$) increased significantly after fatigue; (4) The ankle maximum dorsiflexion angle increased significantly after fatigue ($p=0.008$); (5) The vertical stiffness ($p=0.016$) and vertical work ($p<0.001$) in a sagittal plane decreasedsignificantly after fatigue.

Conclusion: After exercise-induced fatigue, the lower extremity developed a "soft landing"strategy to cushion impact, increasing the flexion angle and range of motion. In addition, a decrease in vertical stiffness and vertical work was observed after fatigue, indicating that the functional strength of the musculoskeletal system was impaired.

Key words: exercise-induced fatigue; running; neuromuscular control; soft landing

ID 2960

聚合物血管支架考虑尺寸效应的力学性能与结构拓扑优化设计

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目的：聚合物血管支架存在尺寸效应。建立聚合物血管支架考虑尺寸效应的力学性能有限元计算模型，研究其力学性能，并针对聚合物血管支架径向支撑性能不足的问题，依据应变梯度增强机理拓扑优化出高径向支撑性能的聚合物血管支架结构。

方法：基于 Cosserat 理论建立聚合物血管支架考虑尺寸效应的力学性能有限元计算模型，并通过实验确定聚合物材料的 Cosserat 特征参数，以模拟分析聚合物血管支架的力学性能；发展基于 Cosserat 理论的三维拓扑优化设计方法，提出高阶 Cosserat 理论的普单元法，确保计算和优化结果能够在聚合物支架仅使用一层元素的情况下实现高精度。

结果：在小变形下，聚合物血管支架考虑尺寸效应的力学性能计算结果与经典理论下的计算结果存在较大差异，前者能更准确获得聚合物血管支架的力学性能；与商用聚合物血管支架结构相比，优化支架具有更高的径向单位比刚度。

结论：尺寸效应显著影响聚合物血管支架力学性能以及结构拓扑优化的结果，研究成果为进一步提高聚合物血管支架力学性能提供了有效途径。

关键字：聚合物血管支架，尺寸效应、力学性能、有限元、拓扑优化

ID 3082

软组织损伤多尺度有限元分析

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目的：软组织受力学损伤在多种骨科疾病中均有发生，例如糖尿病足中脂肪垫损伤等。研究力从人体组织表面如何传递到细胞上并且该力学作用对细胞的力学生物学影响对于理解软组织损伤机理并且为设计预防损伤的疗法鉴定基础。

方法：利用多模态影响组学的方法，结合超声弹性成像、自由臂三维超声成像系统、磁共振弥散张量分析等技术，可以对组织进行三维形态学和材料力学属性分析，并且形成有限元模型。利用影像获得宏观组织模型，以及介观的细胞与胞外基质模型以及微观的细胞模型，进行多尺度有限元分析，对静态应力应变从组织传递到细胞量化分析。并且分析利用细胞加载力测试系统对细胞在压缩以及拉伸力学环境下细胞膜与肌动蛋白细胞骨架发生的力学与生化变化。静力学与周期性力刺激对于组织与细胞粘弹性的响应有限元分析同样可以揭示生理病理状态下软组织针对力刺激的力学反应。

结果：以糖尿病足为例，各尺度各部分的糖尿病足部模型平均应力均高于健康者，这指向了糖尿病足部比健康人足部更趋于诱发压疮的临床现状，且随着尺度间的传递，两类模型的几何形态差异越来越小。细胞在静力学下损伤遵循反 S 型曲线，周期性力刺激可以增强细胞。

结论：多尺度生物力学分析可以对软组织损伤与修复进行分析与预测。

关键字：生物力学，多尺度力学，有限元分析；细胞力学

ID 3096

Impact of Cross-Limb Stent Graft Configuration on Hemodynamics in Abdominal Aortic Aneurysm Interventional Therapy

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Objective: The cross-limb technique (CLT) is a frequently used endovascular treatment to address unfavorable anatomical features, such as abnormal aortic neck angulation and large aneurysmal sac, in patients with abdominal aortic aneurysm (AAA). Configuration of vessels or stent grafts can significantly impact hemodynamic properties and physiological behaviors. In this research, we aim to investigate the relationship between hemodynamics and CL configuration.

Methods: In this study, we evaluated the hemodynamic performance of the crossed-limb stent graft with different geometric features using models with varying main body lengths and cross angles obtained from real clinical CTA data. We analyzed the flow pattern, wall shear stress (WSS)-related eigenvalue distribution, localized normalized helicity (LNH), and pressure drop and the displacement force of all models through numerical simulation.

Results: Our Results indicate that for patient-specific cases, increasing the main body length of the CL stent can enhance the intensity of helical flow. However, secondary flow appears at the limb outlets, leading to an increase in flow resistance and pressure drop between the inlet and outlet of the model. The intensity of the helical flow decreases as the cross-angle decreases, and the pressure drop at the inlet and outlet does not increase significantly. The WSS-related parameters of all models exhibit the same variation characteristics as the flow pattern. It is noteworthy that increasing the length of the main stent body or decreasing the cross angle can decrease the displacement force exerted on the stent graft.

Conclusion: These findings are useful in guiding stent selection and treatment plan design for patients with abdominal aortic aneurysm who undergo cross-limb techniques.

Key words: Endovascular, Cross limb configuration, Hemodynamic, Wall shear stress

ID 3130

微重力环境对人体背部骨肌系统生物力学响应的影响

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目的：定量分析微重力环境对人体骨肌系统生物力学响应的影响

方法：基于人体骨肌系统基础理论建立了一个包含腰椎间盘膨胀特性的新型腰椎骨肌人体模型，通过对比不同重力环境中各种姿势下人体腰椎各个组织载荷的变化来探求微重力环境对人体背部骨肌系统生物力学响应的影响。

结果：与重力条件下的放松站立姿势相比，微重力环境中放松漂浮姿势下腰椎间盘的轴向力下降 62%~70%，剪切力下降 47%~92.1%，肌肉力下降 55.7%~92.9%，而椎间盘含水量增加 7.0%~10.2%，椎间盘高度增加 2.1%~3.0%，椎间盘体积增加 6.4%~9.3%，韧带力增加 59.5%~271.3%，同时发现微重力条件下婴儿蜷缩姿势下腰椎各组织力学响应趋向 1G 重力条件下自然站立姿势。

结论：本研究的结果有助于从生物力学角度解释为什么航天员微重力环境中背部骨肌系统发生严重损伤，以及婴儿蜷缩姿势有助于缓解微重力环境中腰部疼痛的生物力学原因。

关键字：微重力，腰椎骨肌系统，骨肌建模，生物力学

ID 3220

Biomechanic Effects of Custom Insoles with Arch-support on Lower Limb during Sudden-stop and High-jumping Motion

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Objective: This study analyzes the influence of custom or personalized arch-support insoles on the kinematics and kinetics of lower limbs during the sudden-stop and high-jumping motions of basketball players.

Methods: Eleven healthy male graduate students majoring in basketball were recruited, aged 20.5±0.5 years old, height 181.7±1.4cm , and weight 75.3±3.4kg. Each subject wore short, tight clothes and the same basketball shoes with custom or normal control insoles, and completed two sections of sudden-stop and high-jumping motion trials. The custom insoles were designed in Delcam OrthoMODEL and OrthoMILL systems based on the foot shape data from 3D foot scanner, then made by Beijing Jindao CNC machining with EVA panels. 22 markers were pasted on the subject's lower limbs. After warming up for 5 minutes, they began the sudden stop and high-jumping motion. From the position 0.5m directly opposite the long side of the two force places, the subject leaped onto the plates with each foot on each and stopped, then jumped as high as possible, and landed buffer down, with 5 such motion trials repeatedly. Vicon 3D motion capture system with eight cameras integrating two AMTI force plates was used.

Results: At the moment of each landing, the personalized insoles reduced the hip flexion angle and abduction angular velocity, knee joint abduction angle and flexion angular velocity, and ankle joint internal rotation angular velocity. The significant cushioning of the vertical ground reaction force reduced the knee joint extension moment and the ankle joint abduction moment. The personalized insole reduced the ankle joint flexion and external force during high jumping, as well as vertical ground reaction force significantly, and the torque in the knee joint extension torque reduced.

Conclusion: Personalized insoles could play an important role in preventing injury to the lower limb and improving performance during basketball sports.

Key words: Personalized insoles; sudden-stop and high-jumping motiono; lower limbs; sports biomechanics

ID 3330

主动脉夹层三维扩展的力学机理研究

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目的：阐明夹层的三维扩展力学机理，为疾病的诊疗提供理论支撑。

方法：建立理想化主动脉的三维扩展有限元模型，（1）使用内聚力模型（CZM）描述主动脉中膜弹性层之间的弹性连接和损伤失效，即界面损伤；（2）基于连续损伤力学理论描述中膜弹性层的拉伸断裂失效模型，即主体损伤。进而，利用上述模型研究初始假腔的几何特点、加载条件等因素对夹层包括面内扩展和透壁扩展等三维扩展的影响，分析其力学机理。

结果：面内扩展：（1）临界压力随深度增大而减小，裂纹尖端的钝化作用对环向角度和轴向长度较大的夹层有保护作用；（2）扩展方向与初始假腔环向角度和轴向长度有关，轴向长度大、环向角度小的假腔出现滑动型损伤主

导的环向扩展，其余出现张开型损伤主导的轴向扩展。透壁扩展：（1）预测了假腔易于破裂的 4 个位置，假腔越浅越易向真腔形成再入破口，越深越易向外破裂，轴向长度较小时均为再入破口，较深且轴向长度较大时均为向外破裂。（2）若破裂位置不变，随轴向长度增大，主动脉纤维束的破裂临界等效应变先减小后不变，夹层破裂临界压力先减小后趋于稳定。

结论：真腔压力固定情况下，初始假腔的深度、环向角度、轴向长度是夹层界面损伤和主体损伤临界压力和破裂位置的影响因素。

关键字：主动脉夹层，数值模拟，夹层扩展，界面损伤，主体损伤

ID 3376

基于力致结构色传感的神经肌肉接头芯片的研究

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目的：神经肌肉接头体外模型缺乏肌源性和神经源性刚度的机械微环境，肌肉收缩的微观力学无法实现量化和直观的评估。本研究构建具有肌源性和神经源性刚度的反蛋白石结构色水凝胶弹性薄膜，共培养运动神经元和骨骼肌细胞，通过轴突延伸形成功能性的神经肌肉接头体外模型。

方法：采用两步光聚合法制备具备神经源性刚度的干细胞笼微结构和具备肌源性刚度的取向性槽微结构的反蛋白石结构色水凝胶弹性薄膜，并共培养光遗传学修饰的人源 hiPSC 分别诱导分化的运动神经元和骨骼肌细胞，通过轴突延伸形成功能性的神经肌肉接头。采用不同的光电频率刺激神经元并触发神经肌肉接头介导的肌肉收缩，引起结构色片层的物理结构色和光谱变化，从而构建光遗传学刺激的神经支配和肌肉致动的“活体”结构色可视化的生物杂化致动器，并通过软光刻技术加工制备器官芯片。

结果：构建光遗传学刺激的神经支配和肌肉致动的可视化的生物杂化致动器，实现从微观力学向宏观光学的变化来进行神经和肌肉耦合的力学评估，并构建用于细胞监测和药物检测的组合式微生理可视化的器官芯片。

结论：此新型的神经肌肉接头的器官芯片将进一步应用于研究神经肌肉疾病的发病机制，治疗靶点和药物筛选具有重大的科学意义。

关键字：生物力学；微流控芯片；器官芯片；光子晶体；干细胞

ID 3403

Fluid Dynamics and Myocardial Function Assessment of Static Mixer's Effect in Cardiac Continuous Chaotic Bioprinting

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Objective: Three-dimensional (3D) bioprinting technology has been widely used to construct in vitro cardiac tissues and organs with complex microarchitecture and physiological function for myocardial Repair repair and drug screening. Nevertheless, constructing myocardial tissue with micron-scale heterogeneous and ordered structural fibers remains a challenge. Continuous chaotic bioprinting, specific extrusion bioprinting where the printing head is coupled with static mixer, can construct micro-scale multicompartmental hydrogel fibers. The aim of this study was to construct myocardial tissues using chaotic bioprinting with a focus on the effects of static mixer elements on the biomechanics during the printing process and myocardial function.

Methods: First, we designed and 3D printed a series of static mixers with different rotation angles (30 degrees, 60 degrees, 90 degrees,120 degrees and 150 degrees) and different numbers (2, 4, 6, 8, 10) of mixing elements. Secondly, using computational fluid dynamics calculated printing pressure and shear stress. Then, human induced pluripotent stem call-derived cardiomyocyte with functional biomaterials were used as the bioink to construct cardiac tissue. And, myocardial tissue microstructure and function are characterized by cell viability analysis, specific protein expression, mechanical function and electrophysiological performance detection.

Results: The helical angle and number of static mixing elements produced different fiber microstructures. The bioprinted cardiac tissue exhibited regular beating, and the cell viability reached 85%, regular electrophysiological activity can be detected through electrical stimulation conduction.

Conclusion: The cardiac tissue constructed by the continuous chaotic bioprinting strategy was myocardial tissue with micron-scale heterogeneous and ordered structural fibers. And the effect of static mixer elements on myocardial function can be inferred from the detected biomechanics with computational fluid dynamics. The bioprinted cardiac tissue functions well and has potential applications in drug screening and tissue repair.

Key words: bioprinting; biomechanic; cardiac tissue; chaotic

ID 3446

核周肌动蛋白环的形成机理和生物学意义

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目的：体内的上皮组织经常面临剧烈的渗透压变化以及复杂的机械力刺激。然而，在渗透压冲击和机械力刺激下上皮细胞如何进行自我保护还有待研究。

方法：通过渗透压冲击和直接机械力加载对细胞施加刺激，探索了胞外渗透压冲击和机械载荷作用下的上皮细胞保护机制，并进一步通过理论模型和数值模拟研究了核周肌动蛋白环的形成机理。

结果：我们发现上皮单细胞在低渗冲击或快速大变形载荷时会激活钙离子信号并在细胞核周形成可逆的肌动蛋白环，阐明了核周肌动蛋白重组是一种依赖于肌动蛋白单体的流动和聚合因子 Arp2/3 参与的细胞骨架的被动响应，进而证明了肌动蛋白骨架的快速响应可以降低核膜张力的过度增加，减少 DNA 损伤以及降低细胞凋亡。

结论：我们的结果揭示了在渗透压冲击或机械力作用下，肌动蛋白网络重组形成核周肌动蛋白环的力学生物学机制，并阐明了其重要的生物学意义。

关键字：核周肌动蛋白环，渗透压冲击，机械力刺激，钙离子，核膜张力

ID 3458

基于数值仿真力学模拟分析高位复杂性肛瘘不同切口的引流效果研究

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目的：通过数值仿真分析比较高位复杂性肛瘘手术弧形加扩展槽、弧形和梭形切口的创面大小及术后引流的生物力学特性，为临床对手术的微创切口选择提供理论依据。

方法：利用 FLUENT 有限元软件，建立典型切口有限元模型，得到不同切口面积，采用 VOF 两相流模型，基于 N-S 方程理论，对伤口引流效果进行数值仿真。设定质量流量入口流速为真实流速 100 倍情况下，计算物理时间 200s 内，各直线模型设置参数保持相同，出口流出的总质量，以此评估各切口引流效果。

结果：（1）以相同长、宽、纵径建模后，由此得出弧形加扩展槽切口对肛周皮肤肌肉的损伤最小。（2）质量流量入口流速为真实流速 100 倍情况下，物理时间 200s，各切口模型设置参数相同，出口流出总质量结果为：弧形加扩展槽模型 > 梭形模型 > 弧形模型，曲线模型＞直线模型，由此得出弧形加扩展槽模型的引流效果最好，曲线切口引流效果优于直线切口。

结论：弧形加扩展槽手术切口创面面积最小，最大限度的减少了肛周皮肤肌肉组织的损伤，符合外科手术微创化理念，且能保证渗出物的充分引流，保持创面肉芽组织正常生长，保护了肛门功能，从而提高患者生活质量，易于临床推广，也为高位复杂性肛瘘的手术治疗提供新思路。

关键字：肛瘘；数值模拟；不同切口形状；引流；流体力学

ID 3478

一种新型治疗 PHT 的 TIPS 支架

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目的：经颈静脉肝内门静脉分流术 (TIPS) 用于治疗门脉高压症 (PHT) 及其并发症已有 30 多年的历史。然而，TIPS 的最佳支架仍然存在争议。本研究评估了在门静脉梯度 (PCG) 上使用不同直径 TIPS 支架的情况，并利用结果为特定患者提供恰当的 TIPS 支架。

方法：从 2017 年 12 月至 2021 年 2 月，一所医院的 27 名 PHT 患者接受了带有 8 毫米等直径支架的 TIPS。立即评估临床结果，包括静脉曲张再出血和肝性脑病 (HE)。然后对每位患者分别使用 6mm、8mm 和 10mm 等直径或锥形支架进行数值模拟。在所有模型中测定 tips 后 PCG 的模拟结果和支架流量百分比。

结 果：对于支架直径为 6、8 和 10 mm 的患者，TIPS 后平均 PCG 降低幅度分别为 7.71 mmHg±4.39 、13.41 mmHg±4.31 和 16.64 mmHg±4.64 。接受 8mm 支架植入后的 PCG 与临床有创测量值密切相关。与等直径支架相比，本研究提出的锥形支架也具有逐渐降低 PCG 的优点。

结论：研究结果为临床医生根据特定患者实际需要的降压幅度在 TIPS 前选择合适的支架提供了理论支持。此外，使用锥形支架似乎比使用等直径支架更可取。

关键字：计算流体动力学，门腔静脉压力梯度，经颈静脉肝内门静脉分流术

ID 3490

基于影像构建的病人特异性脑动静脉畸形血液动力学模型

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目的：脑动静脉畸形是一种大脑动脉与静脉直接相连，而没有通过正常的毛细血管，继而会产生一系列异常的血液动力学紊乱。目前的脑动静脉畸形的集中参数模型包含了整体脑血管的基本结构，但是对于畸形团血管做了理想化处理。本研究旨在通过利用脑动静脉畸形的医学影像信息，建立病人特异性的脑动静脉畸形的特异性集中参数模型。

方法：首先使用 line-shaped profiles 阈值分割方法精细划分脑动静脉畸形的血管结构；然后根据主要的血管结构获取畸形团内主要的动静脉的轮廓图，提取血管连接关系，并建立基础的血管树模型；根据病人影像信息，获得畸形团的空间分布，并根据灰度值构建不同密度的采集点集合；在已有的基础血管树上，根据小血管生成方法，在采集点集合中取点建立小血管树。

结果：采用上述方法构建了病人特异性的脑动静脉畸形的集中参数模型，模型形态与影像重建的几何模型的大小、形态相似，能够体现畸形血管团中的瘘血管结构和小型分叉血管结构。

结论：病人特异性的脑动静脉畸形的集中参数模型可以构建更为精细的血液动力学模型，通过分析血流和压力等生理信息，可以给出畸形团出血风险的判据，为临床诊疗提供理论参考。

关键字：脑动静脉畸形，特异性模型，集中参数模型，医学影像处理，小血管生长模型

ID 3541

基于单细胞 RNA 测序探讨血管结扎损伤模型中平滑肌细胞异质性的研究

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目的：探究血管平滑肌细胞在单细胞水平上对血管损伤的反应，理解血管重塑机制的重要性，为开发一种针对平滑肌特定亚群进行血管疾病治疗的新方法提供思路。

方法：单细胞 RNA 测序探究结扎后颈动脉与正常颈动脉的差异，使用流式细胞术与免疫荧光染色验证 Vcam1+ 平滑肌细胞在损伤后比例不断增加，transwell 共培养验证 Vcam1+ 平滑肌细胞具有更强的巨噬细胞招募能力。

结果：单细胞测序表明平滑肌细胞只有不到 30% 对损伤做出了反应，对损伤反应的平滑肌细胞分为两个亚群，一个高表达与调节应激反应调节相关的基因，起适应压力环境和维持蛋白质稳定作用。另一种高表达炎症基因如 Vcam1 与 Cxcl12，表现出促炎作用。拟时序分析表现了损伤后平滑肌亚群下调收缩型平滑肌基因，上调应激反应及炎症基因的转变过程。流式细胞术与免疫荧光染色指出 Vcam1+ 平滑肌细胞在损伤后比例不断增加，transwell 共培养表明 Vcam1+ 平滑肌细胞具有更强的巨噬细胞招募能力。

结论：血管损伤后平滑肌细胞表现出异质性，适应压力环境，维持蛋白质稳定性的亚群和促炎症亚群，促炎症亚群在损伤后比例不断增加且对巨噬细胞有更强的招募能力。

关键字：单细胞 RNA 测序，平滑肌细胞，亚型，内膜增生

ID 3690

下肢力线内外翻对不同形合度的假体在步态载荷下的力学影响

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目的：下肢力线的内外翻是影响全膝关节置换术术后效果和假体生存的重要因素之一，假体的形合度也因产品的设计存在差异。本研究旨在评估不同角度的下肢力线内外翻对不同形合度假体在步态载荷下应力的影响，为手术计划提供参考。

方法：本研究采用逆向工程，建立了韧带保留型的膝关节假体，根据文献中的实验结果和仿真数据验证模型的准确性，根据临床使用的膝关节产品信息建立不同形合度（低：0.26，中：0.50，高：0.80）的膝关节假体。通过改变假体的初始位置模拟不同角度（0°，内、外翻 3°，5°，7° 和 10°）的下肢力线，根据 ISO 14243-3 施加步态载荷，采用有限元分析计算了步态过程中衬垫的应力变化趋势和应力分布状况。

结果：①步态载荷下，衬垫的最大应力发生在 15% 步态，对于低形合度衬垫，适度的外翻（<5°）会降低衬垫的应力，内翻和过度外翻（>5°）会增大衬垫的应力；对于中、高形合度假体，下肢力线的内外翻都会增大衬垫的应力；②相同力线角度对不同形合度衬垫的应力影响不同，对低形合度衬垫应力影响最小，对高形合度衬垫应力影响最大。

结论：下肢力线显著影响膝关节假体在步态载荷下的力学表现，假体的形合度越高，对于下肢力线的准确度要求越高。

关键字：全膝关节置换术，下肢力线，应力、有限元分析

ID 3694

基于 XRM 成像的前交叉韧带 - 骨界面微观结构三维分布的探究

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目的：移植韧带 - 骨界面愈合不良及并发骨隧道扩大是前交叉韧带 (ACL) 重建术后常见问题。本研究旨在探究原生 ACL- 骨界面微观结构的分布规律，为理解其生物力学机制并据此改进移植韧带 - 骨界面提供参考。

方法：对 17 例猪 ACL- 股骨界面样本进行固定、脱水、染色、临界点干燥后，用 X 射线显微镜（XRM）对其进行三维扫描，利用 Dragonfly 软件对扫描结果进行定量化测量，测量参数包括钙化纤维软骨（CFC）+ 软骨下骨板（Subchon）厚度、矢状面上纤维角度（包括前后向及上下向），软骨下骨板及骨的各向异性和骨体积分数。利用配对样本 t 检验分析 ACL 两个功能分束（AM vs PL），及两种界面类型（直接 vs 间接）间的差异性。

结果：AM 束界面的纤维向前角度、软骨下骨和骨的各向异性程度、软骨下骨的骨体积分数显著小于 PL 束界面，而 AM 束界面的纤维向下角度显著大于 PL 束界面；间接界面的 CFC+Subchon 厚度、骨的骨体积分数显著大于直接界面，而纤维向下角度、软骨下骨和骨的各向异性程度显著小于直接界面。

结论：原生 ACL- 骨界面的微观结构在不同功能分束间及不同界面类型间均具有显著差异性，这可能与其特殊力传导功能的实现息息相关。

关键字：前交叉韧带；界面；微观结构

S08
类器官与器官芯片
Organoids and Organs-on-Chips

ID 268

Injectable Vascular Organoids for Treating the Critical Limb Ischemia

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Objective: Critical limb ischemia (CLI) is a severe obstruction of the arteries which markedly reduces blood flow to the limbs and has progressed to the point of severe pain, ulcer and even amputation. Therapeutic angiogenesis using implanted vascular cells has been widely investigated to treat the CLI, however, the therapeutic outcome is quite mixed. Since the vasculogenesis potential and paracrine effect of the transplanted vascular cells are the two major driving forces for enhancing the local neovascularization, we hypothesized that stem cell derived vascular organoids (VO) could be the ideal cell sources.

Methods: By using a bioreactor, we are able to massively differentiate pluripotent stem cells into spheroid-like vascular organoids with an average diameter of about 200 micrometers which is easy for loading and injecting with syringes. In contrary to the single vascular cells, VO consist of endothelial cells and smooth muscle cells which organize into the three-dimensional blood vessel-like structure. Moreover, VO show superior engraftment and good vasculogenic potential in the site of kidney capsule. To further test the therapeutic potential of VO for treating CLI, we injected the VO into the muscle site adjacent to the femoral artery ligation site in a nude mice model.

Results: Strikingly, the delivery of VO significantly enhanced the blood perfusion and reduced the amputation ratio compared to the vehicle group. The subsequent histological analysis further validated that the VO formed new blood vessels and reduced the necrosis of muscle cells.

Conclusion: In summary, the stem cell-derived injectable VO could be a promising cell sources for developing the cell therapy to treat the CLI.

Key words: Stem cells; vascular organoid; critical limb ischemia

ID 639

Rapid and Mass Production of Cellular Spheroids via Self-Emulsion of Cell Suspension in Microwell Arrays

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Objective: Three-dimensional spheroids are now widely used as in vitro models to mimic in vivo cellular environment and behaviors. However, mass production of spheroids with homogeneous qualities still remains a challenge. Here, we present an innovative yet simple spheroid formation method using template-guided self-emulsion phenomenon, which can rapidly produce a large number of uniform size and shape spheroids from single cell suspension.

Methods: A high-density star-shaped microwell array was used to spontaneously form defined arrays of ordered monodisperse cell suspension droplets and then produce spherical cell aggregates under gravity. The self-emulsion of cell suspension loaded into star-shaped microwells is based on an oil-assisted, template-guided dewetting phenomenon. Due to different geometrical dimensions, the curvatures of the water/oil interfaces at the sharp tips and center of each star-shaped microwell are notably distinct. Such curvature difference generates Laplace pressure gradient which causes the aqueous liquid to flow toward the microwell center (low pressure region) from the microwell edge (high pressure region), thus forming spherical droplet.

Results: A large number of monodisperse cell suspension droplets were spontaneously formed in the star-shaped microwell array through surface-tension-induced flow. One day after seeding, uniform size and shape spherical cell aggregates were successfully generated in large scale and the obtained spheroids have a very narrow size distribution with a coefficient of variance (CV) below 9.7%. In addition, showed 93.8% viability after culturing for 6 days.

Conclusion: The proposed spheroid production method facilitates obtaining a large number of uniform, viable spheroids with pre-specified average diameters, which has potentially extensive applications in drug discovery, bio-artificial organ development, and regenerative medicine.

Key words: microwell array, self-emulsion, spheroid, mass production

ID 695

Extrusion Bioprinting of Elastin-based Biological Double-network Tough Hydrogels for Complex Elastic Tissue Regeneration

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Objective: Despite recent advances in extrusion bioprinting of cell-laden hydrogels, using naturally-derived bioinks to biofabricate complex elastic tissues with both satisfying biological functionalities and superior mechanical properties is hitherto an unmet challenge.

Methods: Here we meet this challenge with biological tough hydrogel bioinks of double-network structure. The tough hydrogels consisted of energy-dissipative dynamically crosslinked glycosaminoglycan hyaluronic acid (HA-NB) and elastin through Schiff's bases reaction, and free-radically polymerized gelatin methacryloyl (GelMA). Mechanical properties, like uniaxial tensile and compression, loading-unloading, anti-fatigue, and stress relaxation tests, and printabilities were assessed comprehensively. Bioprinted constructs using elastin-based tough double-network hydrogel bioinks were evaluated *in vitro* and *in vivo* by histology staining, quantified analysis, and RNA seq to analyze their biological functionalities.

Results: The double-network design undoubtedly enhanced this naturally-derived hydrogel. The incorporation of elastin further improved the elasticity, stretchability (~170% strain), and toughness (~45 kJ·m-3) of hydrogels due to the random coiling structure. We used this novel hydrogel bioinks to bioprinted several complex elastic tissues with good shape retention. Furthermore, *in vitro* and *in vivo* experiments also demonstrated that the existence of elastin in the biocompatible bioinks facilitates cell behaviors and biological functions of bioprinted tissues, such as cell spreading and phenotype maintenance as well as tissue regeneration.

Conclusion: The Results confirmed the potential of the elastin-based tough hydrogel bioinks for bioprinting of 3D complex elastic tissues with biological functionalities, which can be considered used for elastic tissue regeneration.

Key words: Bioprinting, elastin, double-network, hydrogel, toughness

ID 811

基于微流控技术在凝胶表面固定 RGD 肽浓度梯度用于内皮细胞迁移研究

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目的：精确控制生物分子在生物材料表面的空间分布对调控内皮细胞迁移至关重要。

方法：本文基于微流控技术设计了一种“圣诞树”型浓度梯度发生器，将蜂窝粘附 RGD 肽、甲基丙烯酰化明胶和光引发剂的混合物经过浓度梯度发生器的混合分流后，可在下游细胞培养室内产生 RGD 肽的空间浓度梯度分布。然后，使用紫外光照射固化，可在细胞培养室内形成压缩模量为 4.88±0.622（kPa）且含有 RGD 肽浓度空间分布的水凝胶基底。最后，通过数值仿真、免疫化学定量表征实验以及细胞实验对该方法进行了分析和验证。

结果：结果表明，在 25 s 时即可在下游细胞培养腔内产生稳定的线性 RGD 肽浓度梯度空间分布。使用 FITC 作为荧光探针偶联 RGD 肽得到细胞培养室内 RGD 肽荧光分布曲线，与数值模拟的梯度曲线吻合良好。此外，细胞实验得出内皮细胞在浓度梯度为 4 mg/ml/mm 的凝胶表面的迁移能力相较于浓度梯度为 2 mg/ml/mm 的凝胶表面有显著增强。内皮细胞在凝胶表面顺浓度迁移，且细胞长轴与浓度梯度夹角逐渐减小。

结论：本文结合微流控技术，建立一种制备生化因子浓度随空间变化的明胶基底的方法，为研究各种生化因子浓度梯度对内皮细胞迁移的影响提供了有效的实验平台。

关键字：内皮细胞迁移；微流控芯片；RGD 肽；浓度空间分布；水凝胶

ID 828

用于航天医学研究的人工血管芯片

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目的：长期航天飞行中暴露于微重力环境会导致心血管的结构与功能发生一系列适应性变化，出现一系列心血管系统失调症状，其中以立位耐力不良最为明显。为了研究长期飞行导致的立位耐力不良的细胞学机制并发展有效对抗

防护措施。

方法：本研究基于器官芯片技术构建了可搭载在航天器上的具有内皮 - 平滑肌结构人工血管的器官芯片，通过模拟微重力环境，研究了人工血管在该条件下结构与功能的变化，抗氧化应激化合物对血管重塑的保护作用，以及在微重力条件的立位耐力下降的细胞学机制和有效的对抗防护措施。

结果：结果表明基于器官芯片技术构建的人工血管芯片中血管表现出良好的组织形态和组织功能性。实验观察到微重力模拟条件下血管芯片中组织细胞结构方向性 / 活性 / 细胞外基质 / 细胞骨架蛋白等多方面发生显著变化，以及多个相关信号通路产生表达谱的显著变化；而采用不同种类和浓度的对抗和保护试剂可起到明显的缓解和保护效果，其中针对氧化应激通路的保护性药剂木犀草素显示了最好的保护效果，可显著维持血管组织结构的形态和功能性。

结论：本研究构建的人工血管芯片可以很好的应用于航天医学领域，为未来的航天器官芯片的发展与应用，以及基于器官芯片在空间微重力情况下的药物效果评价奠定技术基础。

关键字：航天；微重力；器官芯片；立位耐力不良；人工血管

ID 1077

器官芯片在骨科疾病建模和药物测试中的应用

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目的：骨科疾病的患者群体极其庞大，仅骨关节炎（OA）在全球的患者数量就已超过 3 亿，其中包括 46.3% 的 40 岁以上的中国人口。包括 OA 在内的多种骨科疾病的发病机制仍不明确，同时缺乏有效的治疗药物。器官芯片技术为解决上述需求提供了极具潜力的新途径。本报告将首先综述骨科器官芯片的发展现状，并以关节器官芯片为例探究器官芯片在骨科疾病建模和药物测试中的应用。

方法：通过分化人体间充质干细胞（MSC）构建骨骼、软骨等不同的三维骨科组织，将其整合于通过 3D 打印制备的微流控芯片中，以构建模拟人体关节的器官芯片。利用促炎性细胞因子构建关节炎症模型，并在此基础上测试四种不同的潜在药物。通过 RNA 测序、Luminex assay 和免疫荧光等手段分析模型中的组织表型，并对比临床及动物模型数据分析模型的生理相关性。

结果：利用促炎性细胞因子干预芯片中特定组织后，其余组织也呈现了降解和炎症表型，表明各组织间存在密切交流。通过两种不同的给药方式所测试的药物能在基因和蛋白水平上降低炎症和降解反应。

结论：利用人体干细胞构建的关节和骨科器官芯片为研究骨科疾病机理、评估骨科药物的安全性和有效性及开发个性化的精准医疗方案提供了一种全新的体外模型。

关键字：器官芯片；骨关节炎；干细胞；体外模型；药物测试；精准医疗

ID 1181

在芯片上利用导电水凝胶电极对三维心肌组织进行连续收缩力和电信号记录

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目的：心脏芯片成为心脏组织工程的潜在工具，概括了心脏病理生理学中的关键生理线索。可控电刺激和提供直接分析功能读数的能力对于评估心脏芯片平台中心脏组织的生理功能至关重要。在这种需求下，我们提出了一种集成两个软导电水凝胶柱电极的新型心脏芯片平台。

方法：我们设计了矩形的培养室，集成了电刺激电极用于给予心肌组织电刺激，两个导电水凝胶柱用于制作心脏组织的单轴排列。心肌细胞和人心脏成纤维细胞形成一个三维心脏组织，机械地锚定在柱电极周围。这种柱状电极的设计考虑了电生理学的因素，可以实时记录心脏组织的局部场电位。同时，利用组织收缩引起的柱状电极周期性位移来量化收缩力。

结果：第 1 天可以在芯片中观察到致密的宏观心脏组织。H&E 和 MT 染色结果显示细胞在整个心脏组织中分布均匀，活 / 死染色显示出良好的生物相容性。培养 1 周后也观察到均匀的纵向排列。受电刺激的心脏组织建立了明显的肌节各向异性和更强的收缩力，同时，受刺激组织表现出明显的波宽缩短，显示出更快速的钙处理能力，并表现出更生理的药物反应。

结论：我们的研究结果证实了该平台在心肌组织培养及信号检测和药物测试方面的适用性。

关键字：心脏芯片；心脏组织工程；水凝胶

ID 1272

皮肤类器官在疑难重症与罕见病致病机制中的研究与应用

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目的：多种人类多能干细胞（hESC/hiPSC）衍生的类器官已被用来建立体外感染模型来研究病毒和宿主的相互作用机制来进行有效的药物筛选；或者模拟因基因突变而导致的临床疑难重症与罕见病致病机制的研究。但是，迄今为止，应用皮肤类器官来研究或解析临床疾病的研究仍然很少。

方法：本研究利用 iPSC 分化体系，创建了一种具有表皮、真皮和皮下组织完整细胞极性的皮肤类器官，并富含毛囊和皮脂腺等附属器及不同神经细胞类型的神经系统。我们利用皮肤类器官进行病毒感染和罕见病（硬皮病）治疗，进一步，我们通过构建出生缺陷的着色性干皮病皮肤类器官结合多组学技术（蛋白质组学和单细胞测序），从细胞内、外环境研究该疾病在生理和病理发育过程中的细胞和蛋白层级的致病机制，

结果：我们发现新冠病毒能够感染皮肤毛囊干细胞和神经系统，从而导致毛发脱落和神经元死亡。此外，类器官移植实现了硬皮病萎缩的表皮附属器和血管的新生，以及着色性干皮病的人源化小鼠模型的构建。

结论：首次为新冠肺炎和脱发后遗症之间的关联提供了证据，并推动类器官在罕见病治疗、致病机制研究和药物筛选中的应用。

关键字：皮肤类器官；病毒感染；罕见病；致病机理；药物筛选

ID 1312

微流控肿瘤仿生芯片系统

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目的：微流控芯片技术是本世纪极具代表性的微型分析平台技术之一。其特点在于，它可以实现常规实验室诸多基本功能的微型化和集成化；同时具有操作简单、高效的优点。该技术的应用涉及多学科交叉研究领域。本世纪以来，该技术在化学合成、疾病诊断、高通量筛选、环境监测等方面都有杰出的表现。尤其是，微流控芯片技术的应用，正逐步向细胞生命科学分析研究领域方向发展。

方法：基于微流控技术，作者实验室开展了系列肿瘤组织及其微环境仿生、细胞操作及分析方法学建立与芯片平台构建研究。

结果：近十年来，实验室完成了包括三维肿瘤重构、肿瘤 - 基质相互作用、肿瘤细胞筛选、药物筛选等不同肿瘤操作与仿生分析平台及方法体系的构建与应用。

结论：所构建平台对于开展多种微流控肿瘤仿生系统设计与建立具有潜在的技术参考和科学价值；同时，这些研究有利于进一步开展包括肿瘤发生与侵袭转移、肿瘤靶向及新药研发等多领域的体外高度仿生研究。

关键字：微流控；微尺度操控；肿瘤仿生；药物筛选

ID 1432

Physics Informed Deep Learning Characterizes Developmental Dynamics of Human Embryonic Organoids

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Objective: Early human embryonic development involves extensive morphogenesis and lineage diversification. Despite its basic and clinical importance, the fundamental understanding of how the embryo generates complex structures and cell-fate patterning is still largely unknown. The limited sources of embryos and ethical issues has hindered the mechanistic investigation of early human embryonic development. The growing knowledge in stem cell research provides promising alternative strategies by coaxing human embryonic stem cells (hESCs) to form organoids in the in vitro systems, which could capture many important developmental processes and atlas.

Methods: Recently, we have developed a 3D suspension culture system of hESCs that can generate post-implantation, pre-gastrulation embryonic organoids. Using this system, we acquired approximately 2000 fluorescent images of the organoids at different developmental states labeled by DAPI, NANOG, GATA3 and T.

Results: A neural network pipeline is developed to map high-dimensional image data to a low-dimensional landscape space. And a physical-informed deep learning model is developed to assist the understanding of the morphological and proteomic variations during the organoid development.

Conclusion: These Results show the possibility of revealing intrinsic dynamics and characteristics of complex organoid systems directly from images, by integrating unsupervised learning and biophysical modeling.

Key words: organoids, physics informed deep learning, image analysis

ID 1532

用于化妆品原料毒性测试的皮肤类器官与器官芯片的应用进展

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目的：由于动物和人存在种属差异常导致毒理学试验结果无法外推至人。随着国际上 3R 原则的推行、化妆品行业提倡的“零残忍”，很多国家全面禁止了化妆品的动物试验，极大促进了体外替代试验模型的发展。随着化妆品新原料和新剂型的出现，亟需能够满足当代化妆品及新原料测试需求的体外模型。

方法：本文首先对化妆品原料毒性测试体外模型的现状做了介绍，然后以皮肤类器官与皮肤器官芯片为例，对其在化妆品原料毒性测试的应用进展做一综述，并对模型的验证和标准化提出了建议，最后结合我国法规和监管现状对类器官及器官芯片在新原料测试的应用前景进行展望。

结果：随着组织工程学的发展，出现了三维重组人工组织模型，并通过了 OECD 的认证认可，以及最新的研究热点——类器官和器官芯片。它们能够被诱导并形成高度分化的组织器官类似物，并构建人体组织细胞真实生长的三维微环境，以更好地模拟人体组织器官真实的结构和功能，更适用于化妆品毒性测试和功效评价，一些类器官和器官芯片还可以实现原料的高通量筛选。进行类器官和器官芯片的实验室间联合验证及技术标准化有助于模型被药品和化妆品监管机构认可。

结论：未来，类器官和器官芯片作为化妆品及原料测试和监管工具，具有广阔的应用前景。

关键字：皮肤 类器官 器官芯片 化妆品原料 毒性测试 安全监管

ID 1704

前列腺癌干细胞、类器官与精准医疗

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目的：前列腺癌是常见男性恶性肿瘤之一，前列腺癌干细胞是导致去势抵抗和耐药性的一个重要原因，然而较少有方法对其进行体外培养，大多数研究仍然利用细胞系，难以满足个体化精准医疗需求。本研究旨在建立前列腺癌干细胞体外培养方法体系，用于构建前列腺癌类器官和人源肿瘤异种移植（PDX）模型，服务于个体化精准医疗。

方法：从前列腺癌转基因小鼠（TRAMP）和临床样本分离干细胞进行体外培养，利用免疫荧光、转录组测序、qRT-PCR 等方法分析其特征基因表达谱，研究其在体外形成类器官以及在 NOG 免疫缺陷小鼠体内成瘤能力，并研究其对药物的反应。

结果：从 TRAMP 小鼠分离得到一种新的去势抵抗性中间态前列腺干细胞（CRIPSCs），可在体外形成类器官，在 NOG 小鼠体内形成前列腺癌组织。在体外去势和恩杂鲁胺处理后，CRIPSCs 的 KLK 蛋白表达升高，与临床耐药表型相似。我们进一步建立从临床样本分离培养人 CRIPSCs 的方法，初步建立青岛地区前列腺癌干细胞和类器官生物样本库，大大提高前列腺癌 PDX 模型成功率。

结论：建立了新的去势抵抗性前列腺癌干细胞培养方法体系，提高前列腺癌类器官和 PDX 模型成功率，将推动前列腺癌个体化精准医疗发展。

关键字：前列腺癌干细胞、类器官、人源肿瘤异种移植模型、耐药性、精准医疗

ID 1770

Microengineered Leukemia-on-a-Chip Microphysiological System for Modelling Leukemia CAR T-Cell Therapy

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Objective: CD19 CAR T-cell is a new immunotherapy for B-cell acute lymphoblastic leukemia (B-ALL), yet, patient responses to this new therapy are variable that largely limits its clinical benefit. We herein developed a microfluidics-based human Leukemia-on-a-Chip to model CAR T-cell therapy.

Methods: The device was fabricated using soft lithography and composed of three functional regions: a central sinus region by endothelial cells (HUVECs), an inner ring region serves as a medullary cavity, an interface of leukemia (Reh) and niche cells (HUVECs and MSCs), and an outer ring channel as endosteal regions infused by osteoblasts, connected with four media reservoirs for cell culture media supplies and waste removal.

Results: To assess the functionality of CD19 CAR T-cell, we real-time monitored the dynamics of CAR T-cell during it extravasated out from the 3D vasculature and infiltrated into the leukemia niche, characterized the CAR T-cell expansion and activation markers, granzyme B and perforin after interaction with leukemia blasts. Importantly, we captured the whole eradication processes of a CD19+ tumor cell by a CAR T-cell, such as patrolling toward, recognizing, and killing of leukemia cells. Next, we replicated CD19- relapse by spiking of CD19- B-ALL into CD19+ population at predefined percentages (1%-90%). Following a chronological observation of CAR T-cell therapy over 3-4 weeks, we found that the ex vivo leukemia system with addition of CD19- leukemia initially demonstrated partial remission then relapse accompanying with expansion of CD19- leukemia. Lastly, we demonstrated a critical role for the B-ALL microenvironment in promoting the emergence of leukemia-supporting monocytes, which may be involved in suboptimal CAR T-cell treatment (therapy resistance and leukemia relapse).

Conclusion: We have established a robust in vitro platform of human leukemia bone marrow model allowing for real-time monitoring of CAR T-cell functionality, which may contribute to improving CAR T-cell therapy and ultimately disease relapse.

Key words: Leukemia, immunotherapy, organ-on-a-chip, tumor microenvironment

ID 1850

Electron Conductive and Transparent Hydrogels for Neural Recording and Neuromodulation

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Objective: Recording brain neural signals and optogenetic neuromodulations open frontiers in decoding brain neural information and neurodegenerative disease therapeutics. Conventional implantable probes suffer from modulus mismatch with biological tissues and an irreconcilable tradeoff between transparency and electron conductivity.

Methods: To address these tradeoffs, we developed conductive and transparent hydrogels with polypyrrole-decorated

microgels as cross-linkers. The optical transparency of the electrodes can be attributed to the special structures that allow light waves to bypass the microgel particles and minimize their interaction.

Results: Demonstrated by probing the hippocampus of rat brains, the biomimetic electrode shows a prolonged capacity for simultaneous optogenetic neuromodulation and recording of brain neural signals. More importantly, an intriguing brain–machine interaction is realized, which involves signal input to the brain, brain neural signal generation, and controlling limb behaviors.

Conclusion: A strategy has been proposed to address the tradeoff between conductivity and transparency suffered by most electron conductive hydrogels, which is a barrier for implantable sensor electrodes used for neurological brain studies.

Key words: flexible electronics, conductive hydrogels, neural signals recording, neuromodulation

ID 1883

基于软骨细胞三维培养与动态压缩构建骨性关节炎微生理模型及抗炎药物评价研究

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目的：目前，骨关节炎（OA）的发病机制尚不明确，造成其产生的原因可能是各种因素的共同作用，而力学环境的改变是诱发 OA 的重要原因之一。为了更好的在体外模拟力学刺激产生 OA 及探究炎症机制，我们在微流控芯片上施加动态力以刺激软骨细胞达到炎症诱导的目的

方法：1）构建能够使软骨细胞生存的体外 3D 微环境（水凝胶包裹软骨细胞球）

2）设计合适的芯片结构培养软骨细胞球

3）动态力学刺激方案及设备搭建（在机械室灌注抽取流体来模拟）

4）动态压缩后，使用 RT-qPCR 及 ELISA 来测定炎症水平

结果：1）通过活死染色，表明芯片上的 3D 环境在一周内能够使软骨细胞球保持良好的活性及状态

2）测定细胞腔室体积的相对变化量，当达到 50% 压缩量时，腔室受到的力能够对细胞产生一定影响

3）检测炎性因子（IL-6,TNF-α 等）的基因和蛋白水平的表达，表明和未压缩刺激的方案有明显的差异

4）对 ATDC5 细胞进行同样的实验，通过基因测序，表明相关基因及炎症因子也有明显的变化

5）药物治疗后，炎症有了明显的减弱趋势

结论：芯片上水凝胶载软骨细胞球是一种可靠的 3D 微环境搭建方案，动态力学刺激后，体外骨软骨微流控芯片产生炎症，在力学上对疾病机制有了更明确的认知

关键字：骨关节炎，疾病机制，组织工程，体外模型，力学刺激

ID 2060

器官芯片的现状及标准化研究

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目的：器官芯片是能够模拟人体器官生理功能的微型细胞培养器件，可用于建立疾病模型、评估和预测药物的药理作用或生物毒性，研究药物代谢机理、化妆品检测、航天医学、环境评估等。器官芯片包括脑、角膜、视网膜、心脏、肌肉、肺、肝脏、胰腺、肾脏、肠道、子宫、卵巢、膀胱、血管、脂肪、骨、软骨和皮肤芯片等。作为一种动物和临床替代模型，器官芯片有望为药物研发和个性化医疗提供新的手段，加速药物研发的速度并降低安全风险。

方法：目前全球器官芯片产业尚在起步阶段，随着器官芯片产业的快速发展，对器官芯片的标准化提出了迫切需求，需要标准为器官芯片产品的生产和应用质量安全提供重要保障，为器官芯片应用产业化发展提供有效支撑。

结果：目前，国际范围有国际微生理系统学会（iMPSS），美国材料与试验协会（ASTM），标准协调机构（SCB）和美国国家标准技术研究所（NIST）正在推进器官芯片的标准化。国内首个器官芯片领域的国家标准也已立项。

结论：我国器官芯片的标准化起步较早，但未来国内器官芯片标准化的发展仍面临诸多挑战，比如：如何定义器官芯片的相关术语，如何保证器官芯片的材料质量，如何准确测量器官芯片的关键参数，以及如何评价器官芯片的相关仪器等。

关键字：器官芯片，标准化

ID 2500

Research on Cardiac Organoid on a Chip Based on Intelligent Biomimetic Materials

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Objective: Cardiovascular disease has become the disease with the highest mortality rate in the world, and cardiomyopathy has become the leading cause of sudden cardiac death in young people， However, there is currently no good in vitro platform to study the disease mechanism and therapeutic targets of cardiomyopathy.Organoids on a chip are the most popular in vitro model building platform in recent years.The purpose of this article is to build a functional visualization cardiac organoid platform with online cultivation and access.

Methods: Through the differentiation of cardiac organoids by human pluripotent induced stem cells, non-contact regulation of cardiac organoids using optogenetics, online functional activity monitoring and evaluation of cardiac organoids can be realized due to the transparent nature of PDMS. In addition, by preparing the diaphragm layer of oriented structural color electrospun fibers and gel-encapsulating, the reflection peak of the structural color fibers is shifted when the myocardial beats, so as to realize the transformation of micromechanical observation into macroscopic optical observation， thus, the functional state of cardiomyocytes was observed in situ at the macroscopic scale.

Results: Successfully constructed a visualization cardiac organoid online cultivation and access platform with optogenetically regulated and structure color electrospun fiber myocardial beating sheet,and achieve online access of cardiac model drugs whether or not have cardiomyocyte toxicity.

Conclusion: This chip realizes the online cultivation、intuitive monitoring and quantitative evaluation of cardiac organoid innovatively, It provides a new platform for mechanistic and pathological phenotypic studies of heart-related diseases and drug screening.

Key words: cardiomyopathy、organoid on a chip、optogenetics、structural color

ID 2544

基于人肺泡类器官模型探究 PM2.5 对肺泡再生修复的影响

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目的：大气颗粒物 (Particulate Matter, PM2.5) 持续暴露可诱发肺泡上皮损伤，是肺泡结构破坏的始发因素。II 型肺泡上皮细胞（AT2）增殖和分化异常所致肺泡再生修复障碍是肺泡不可逆损伤的重要机制；目前肺再生修复机制研究缺乏理想体外模型。本研究采用人源 AT2 细胞构建肺泡上皮类器官模型，为研究 PM2.5 对肺泡再生修复的影响提供有力工具。

方法：分选人源 AT2 细胞形成肺泡类器官，活细胞工作站及 HE 染色观察其结构及功能；免疫荧光染色鉴定细胞组成；PM2.5 暴露肺泡类器官后，通过类器官大小和数量评估肺泡再生能力；通过 AT1/AT2 细胞比例评估 AT2 细胞分化能力。

结果：成功构建人肺泡类器官模型，形态呈薄壁三维球体，具有节律性收缩功能；可稳定传代 7-8 代；一代培养周期为 14-16 天。经鉴定，类器官由 AT1 和 AT2 细胞组成。PM2.5 暴露类器官后，类器官数量随 PM2.5 浓度的增加而减少，大小也随之变小；AT1/AT2 细胞比例减少。

结论：成功构建具肺泡结构和功能的人源类器官模型；采用该模型，发现 PM2.5 抑制 AT2 细胞干性，同时抑制肺泡上皮细胞分化，影响肺泡再生修复。

关键字：肺泡类器官；PM2.5 ；再生修复；

3084

用于药理毒理评价的器官芯片技术

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目的：体外评价方法的仿生性对于提高药物发现的效率至关重要，高仿生评价方法不仅是药效学评价的需求，更是毒效学研究深入开展的基础。因此如何提高体外模型的仿生性一直是新药研究面临的重要问题。

方法：报告人利用器官芯片和 3D 生物打印技术，开发了系列生理和病理模型，并将其应用于药物的药效和毒性评价。

结果：近期的研究进展包括：（1）构建了基于肝芯片、肾芯片和心脏芯片的毒效学评价平台，可实现候选药物不同器官的系统毒效评价。2）开展了不同微流控器官芯片对中药化合物的器官损伤评价研究，发现了化合物在生理状态

下具有损伤、在病理作用下有保护作用的特性。3）利用肝器官芯片，评价了肝毒性药物可通过激活免疫细胞增强肝损伤的特性。

结论：器官芯片技术可以帮助我们获得更多的药效学、毒效学信息。

关键字：肝 / 肾 / 心脏毒性评价、中药肝 / 肾 / 肠 / 脑 / 心脏的系统毒性评价，免疫介导肝毒性

ID 3201

基于肿瘤团簇按需打印的血管化肝细胞癌模型构建技术及应用研究

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目的：肝癌的分期将影响临床治疗策略的制定。重构不同发育阶段下肿瘤 - 微血管的相互作用是肝癌病理研究和药物筛选的迫切需求。目前体外模型中肿瘤团簇、癌旁微血管和分期特征的缺失都导致抗肿瘤药物作用效果的偏差。因此，本研究开发了一种新型细胞团簇按需打印策略，并应用于分期血管化肝癌模型的构建上来。

方法：分别利用透氧性微孔板和半开放微流控芯片构建肝癌团簇和微血管网络。通过 3D 打印技术实现团簇在微血管网络中的精确定位，并通过团簇可控融合和 TGF-β 的诱导实现不同阶段下血管化肝癌模型的构建。

结果：开发的团簇按需打印工艺具有良好的可控性，能够满足结构单元在时间和空间维度上的可控排布，并保证团簇的存活率和完整性。细胞团簇的可控融合模拟了肝癌从发生到发展阶段的体积变化，荧光和切片染色证实了打印结构在团簇状聚集和癌旁微血管分布上呈现出高度组织相似性。TGF-β 诱导的模型展现出了细胞团簇的分散，并在蛋白和基因水平上验证了 EMT 发生。最后，不同阶段模型也呈现了差异的药物响应。

结论：所开发的技术实现了肿瘤团簇与微血管网络的可控排布，再现了不同阶段的肝癌特征，为未来抗肿瘤治疗策略的开发和评估提供可靠实验平台。

关键字：细胞打印，微流芯片，肿瘤分期

ID 3324

机械拉伸通过激活 Wnt/β-Catenin 通路促进肠类器官生长

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目的：肠上皮细胞在生理过程中经历着挤压、拉伸等一系列复杂的机械力作用。机械拉伸能影响细胞增殖、分化、分泌、染色质重构和基因表达等，对肠上皮稳态维持的重要性不言而喻。然而，由于体内生理力学环境的复杂性，以及长期以来缺乏理想的研究模型，机械拉伸对肠上皮稳态的作用仍不清楚，亟须通过建立理想的体外模型探究拉伸调控肠上皮稳态的作用及机制。肠类器官包含肠上皮所有的细胞类群，保留了“隐窝 - 绒毛”形态结构，在肠发育、疾病建模和再生医学等领域展现出巨大潜力，也为探索肠上皮生物力学环境提供了理想的研究模型。

方法：我们利用组织力学加载装置，将循环机械拉伸引入肠类器官 3D 培养体系。

结果：相比静态培养的类器官，施力组展现出更强的隐窝分裂能力和细胞增殖水平。通过对肠干细胞特征

性基因富集分析，结合免疫组化和定量 PCR 检测，发现施力组类器官具有更强的干性。从培养基中减掉生长因子 R-Spondin1，发现机械拉伸有效挽救了由于 R-Spondin1 缺失而导致的 Wnt/β-Catenin 信号通路水平降低。

结论：本研究建立了机械力诱导的肠类器官培养模型，并证明机械拉伸通过增强肠干细胞的自我更新潜能促进肠类器官的生长。

关键字：机械拉伸；肠类器官；Lgr5+ 干细胞；组织更新；Wnt/β-Catenin 信号通路

ID 3360

Microfluidic 3D Model of Articular Cartilage for the Study of Inflammation Induced by Hyperphysiological Mechanical Stress

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Objective: Inflammation induced by mechanical injury plays a vital role in the pathology of arthritis. However, due to the complexity of micro-environment of cartilage, current experimental models lack the capability of elucidating the initiating phases and correlation between local inflammation and mechanical stress. To overcome this challenge, we developed a multifunctional cartilage-on-a-chip to recapitulate mechanical stress in micro-environment of articular cartilage for studying the local inflammation in initiating phases of arthritis.

Methods: We developed a microfluidic cartilage-on-a-chip with two-layer configurations. This design enables the integration of 3D cell culture and mechanical loading. The primary chondrocytes isolated from mice were embedded within a hydrogel inside the 3D cell culture channel, while the mechanical loading was controlled through separated gas channels. We used the cartilage-on-a-chip to introduce different levels of mechanical loading to chondrocytes located in different parts of the channel. We used confocal imaging and immunofluorescence to characterize the local inflammation induced by hyperphysiological mechanical stress.

Results: We demonstrated the effectiveness of our design by the chondrocyte viability and cartilage damage. The chondrocytes maintained good viability after 14 days. The damaged chondrocytes showed increased expression of MMP13 and ADAMTS5 and decreased expression of collagen II and aggrecan when subjected to hyperphysiological mechanical stress for 14 days. We also found that the inflammation was limited within the region subjected to the hyperphysiological mechanical stresses, which indicated the inflammation of chondrocytes was strongly associated with the mechanical stimulation.

Conclusion: We developed a novel microfluidic cartilage-on-a-chip, and successfully established a cartilage injury model induced by hyperphysiological mechanical stress. More importantly, we used the cartilage-on-a-chip to study the effect of mechanical stimulation on the initiating phases of cartilage damage. Future work focuses on dynamic observation of inflammatory activation. Our work provides a novel platform to study the role of mechanical stimulation on the pathogenesis and therapeutic strategies of arthritis.

Key words: Microfluidic chip; Articular cartilage damage; Inflammation; Hyperphysiological mechanical stress

ID 3405

利用仿生微肺芯片研究百草枯诱导的肺纤维化

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目的：百草枯是一种高效的除草剂，如进入人体会导致严重的肺纤维化致使呼吸衰竭死亡。目前，仍没有有效的干预和治疗方法，且发病机理尚不清楚。动物模型是肺纤维化研究的主要手段，由于动物实验成本高、存在种属差异，其并不是理想的研究模型。器官芯片可以在体外构建器官组织结构、模拟人体生理微环境，具有极大的发展潜力。因此，我们旨在构建一种具有肺上皮和肺间质界面的微型肺器官芯片用于研究百草枯诱导的肺纤维化现象。

方法：首先利用软光刻技术制作微肺器官芯片。通过生物水凝胶的优化实现细胞的三维培养，利用细胞活死、免疫荧光技术和流式细胞术评估芯片中细胞的生长状态和特性和肺纤维化现象。

结果：在该模型上筛选了多种百草枯浓度，5 天后，高百草枯浓度处理的芯片中的细胞存活率小于 30%。75 μM 百草枯处理后，共培养 A549 和 MRC-5 细胞在 A549 细胞中诱导更严重的 EMT。

结论：该模型为在细胞水平上研究百草枯诱导的肺纤维化提供了一个三维微环境平台。肺上皮细胞和成纤维细胞之间的相互作用防御百草枯对模型的损伤。我们的微型肺芯片可用于研究百草枯诱导的肺纤维化的病原体发生，并可用于开发治疗百草枯中毒后的潜在药物。

关键字：微肺器官芯片，百草枯，肺纤维化，上皮 - 间质转化

ID 3451

通过人诱导多能干细胞构建脑类器官模型研究铅的神经毒性作用

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目的：利用人诱导多能干细胞构建脑类器官来评价铅暴露引起的神经发育毒性，探索其毒性机理，为体外研究大脑的发育机理和促进神经发育毒性研究提供更科学、更高效的体外模型。

方法：利用 hiPSCs 诱导分化为 EBs 并构建脑类器官模型，用醋酸铅处理 60 天。通过流式细胞术、RT-qPCR、免疫荧光等技术，系统评价铅对脑类器官的神经发育毒性及其分子机制。利用全外显子测序进行单核苷酸多态性（SNP）、插入缺失标记（InDel）、染色体结构变异（SVs）和融合基因分析。

结果：醋酸铅导致 hiPSCs 凋亡增加及细胞周期阻滞在 G1 与 S 期；影响 hiPSCs 多能性因子及 EBs 三胚层各 mRNA 的表达。外显子测序发现醋酸铅染毒 EBs 组增加了 2632 个 SNP 突变；InDel 检测共发现 1502 个插入缺失；SVs 变异检测发现增加 83 个结构变异；脑类器官 GFAP, MAP2, GABA, VGLUT1, CTIP2, SATB2, BRN2, TBR1 神经标志物表达均出现不同程度的下调。

结论：研究提示脑类器官可应用于研究其他具有潜在神经发育毒物，该模型有望补充或替代动物模型，在神经毒性研究、药物筛选、个性化医疗、安全性评价等多个领域有广阔的应用前景。

关键字：人诱导多能干细胞；脑类器官；醋酸铅；全外显子测序

S09
纳米医学与工程
MicroNano-Bioengineering

ID 108

Studies on Cell Nucleus-Targeting Delivery of Peptide-based Nanomedicine and Related Applications in Lung Cancer Therapy

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Objective: The cell nucleus has been an important target for many anticancer drugs, and the major technical challenge that needs to be addressed is how to deliver drugs precisely to the nuclei of tumor cells for targeted therapy. The development of cell nucleus-targeting peptide drugs has attracted extensive attention due to their outstanding binding affinity and diversity of design. Studies on the mechanism of the interaction between peptide drugs and multiple biological barriers, such as tumor tissue, tumor cell and nucleus *in vivo* are of great significance for their clinical application.

Methods: EZH2 is an overexpressed nuclear protein associated with relatively poor survival and chemoresistance in lung cancer. In this study, a nucleus-targeting peptide antagonist EIP103 capable of penetrating cell membrane and nuclear envelope was identified, and has high binding affinity towards EZH2 localized in the nucleus of lung cancer cells. To improve the stability and therapeutic efficacy of EIP103, PEG-PE micelle encapsulated EIP103 (M–EIP103) was successfully conducted.

Results: *In vitro* Results indicated that M–EIP103 exhibited better stability, higher intracellular uptake and stronger cytotoxicity than free EIP103 in H446 and A549 cells. Mechanistic studies suggested that M–EIP103 inhibited proliferation by down-regulating the H3K27me3 expression level in cancer cells. *In vivo* assays further confirmed that both EIP103 and M–EIP103 significantly inhibited lung cancer progression. Notably, enhanced therapeutic efficacy of EIP103 by PEG-PE micelle encapsulation could be identified.

Conclusion: The observed anti-tumor activity of EIP103 and M–EIP103 demonstrated a promising therapy to improve clinical treatment of lung cancers as well as other EZH2-overexpressing malignant cancers. This study also illustrates the feasibility of developing targeted delivery of therapeutic peptides to nucleus for cancer therapy.

Key words: Nucleus-targeting, Antagonistic peptide, Nanomicelle, Cancer therapy

ID 181

Cell-mediated Biomimetic Delivery Systems with Navigation for Photothermal-immunotherapy by Precise Delivery

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Objective: Tumor precision therapy and prevent tumor recurrence and metastasis are the main challenge to tumor eradication. Immunotherapy has opened up an attractive strategy for tumor treatment. It is a potential strategy to develop a suitable delivery system for precise delivery and tumor microenvironment regulation. Based on cell hitchhiking, we designed cell-mediated biomimetic delivery system for precise delivery and tumor microenvironment regulation .

Methods: The cell-mediated biomimetic delivery system consisted of IR820-apoptotic bodies and R848-loaded nanoparticles. The in vitro evaluation, in vivo tumor targeting capability as well as photothermal effect were investigated. 4T1 tumor-bearing mouse models were established to evaluate in vivo tumor photothermal-immunotherapy of functionalized drug-loaded apoptotic bodies.

Results: The apoptotic body vehicle targeted delivery drug to the tumor site by macrophage-hitchhiking and fluorescent imaging navigation. Stimulatory signals from photothermal therapy accompanied with R848 effectively promoted the maturation of DC for antigen presentation, simultaneously polarized macrophages and MDSC cells to regulate the immunosuppressive microenvironment. What's more, CD47 blockade would enhance macrophages phagocytosis and stimulate the secretion of various stimulating factors, which in turn further activated DC maturation. Thus, the inherent immunization activated by phagocytic cells further enhanced T cell-mediated adaptive immunity, forming a positive feedback cycle. Finally, the apoptotic body vehicle performed excellent therapeutic efficacy for primary tumor, distant tumor, metastasis and recurrence prevention through inducing the strong immune response and regulating the immunosuppressive microenvironment.

Conclusion: Cell-mediated biomimetic delivery system with imaging navigation was successfully engineered. The strategy the functionalized biomimetic delivery system combined with photothermal therapy induced a strong and long-term anti-tumor immune response, and further prevented tumor recurrence and metastasis, which provided a potential strategy for prevention of tumor combination treatment.

Key words: Biomimetic delivery system; Imaging navigation; Precise delivery; Tumor-targeted; Photothermal-immunotherapy

ID 188

Cell Membrane Camouflaged Metal Oxide-black Phosphorus Biomimetic Nanocomplex Enhances Photo-chemo-dynamic Ferroptosis

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Objective: Despite availability of various treatment options, the inherent complexity of tumor significantly impairs therapeutic efficacy. Recently, the combination treatment exhibits great anticancer potential due to low cross-resistance and good therapeutic additivity.

Methods: Herein, a photoactive metal oxide-black phosphorus biomimetic nanocomplex (photophage) is developed for improving antitumor combination of ferroptosis and photodynamic therapy (PDT). Photophage is composed of M1 macrophage membrane camouflaged MnO2 and Fe3O4 nanoparticles anchored black phosphorus nanosheets (BPNs), which together trigger a synergistic antitumor action.

Results: Fe3O4 acts as an iron source to activate Fenton reaction-dependent ferroptosis, which can be further strengthened by BPNs mediated PDT. Besides original antitumor effects, PDT also generates reactive oxygen species to enhance lipid peroxidation and glutathione depletion, which in turn reinforce ferroptosis and PDT efficacy. Importantly, MnO2 can in situ generate oxygen to relieve tumor hypoxia, and consequently leverage cell behaviors to improve therapeutic responses. Particularly, M1 macrophage membrane modification endows photophage with good tumor targeting capability and tumor penetration, which promotes synergistic ferroptosis and PDT to destroy tumors while reducing systemic side effects, resulting in prolonged survival of tumor-bearing mice.

Conclusion: Therefore, we present a biomimetic nanoplatform for overcoming tumor barriers and advancing tumor targeted treatment.

Key words: biomimetic strategy, cell membrane-camouflaged black phosphorus nanocomplex, combined treatment, ferroptosis, photodynamic therapy

ID 293

Edible and Cation-free Kiwi fruit Derived Vesicles Mediated EGFR-targeted siRNA Delivery to Inhibit Multidrug Resistant Lung Cancer

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Objective: Clinically, activated EGFR mutation associated chemo-drugs resistance has severely threaten NSCLC patients. Nanoparti-cle based small interfering RNA (siRNA) therapy represent-ing another promising alternative by silencing specific gene while still suffered from charge associated toxicity, strong immunogenicity and poor targetability. Herein, we reported a novel EGFR-mutant NSCLC therapy relying on edible and cation-free kiwi-derived extracellular vesicles (KEVs), which showed 7-fold enhancement of safe dosage compared with widely used cationic liposomes and could be further loaded with Signal Transducer and Activator of Transcription 3 interfering RNA (siSTAT3).

Methods: siSTAT3 loaded KEVs (STAT3/KEVs) could be easily endowed with EGFR targeting ability (STAT3/EKEVs) and fluorescence by surface modifi-cation with tailor-making aptamer through hydrophobic interaction.

Results: STAT3/EKEVs with a controlled size of 186 nm displayed excellent stability, high specificity and good cyto-toxicity towards EGFR over-expressing and mutant PC9-GR4-AZD1 cells. Intriguingly, the systemic administration of STAT3/EKEVs significantly suppressed subcutaneous PC9-GR4-AZD1 tumor xenografts in nude mice by STAT3 medi-ated apoptosis.

Conclusion: This safe and robust KEVs has emerged as the next generation of gene delivery platform for NSCLC thera-py after multiple drug-resistance.

Key words: Kiwi, Extracellular vesicles, RNA aptamers, Targeted siRNA delivery, Non-small cell lung cancer

ID 376

黑磷基纳米复合材料的肿瘤光疗增效研究

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目的：以光动力治疗（PDT）和光热治疗（PTT）为主的光疗技术具有精准空间定位、迅速光学响应、合适穿透深度、以及无侵入性等优点，在肿瘤精准治疗中愈发得到重视。而其治疗效率也受到肿瘤乏氧环境、细胞耐热性及材料稳定性等限制。

方法：为提高光疗效果、拓展 PTT-PDT 作用新机制，通过将铁酸锰纳米粒（SMFN）锚定在黑磷纳米片（BPNS）上，然后用 RGD 肽修饰，构建了一种高生物相容性和靶向递送的 PTT-PDT 自协同纳米平台 RGD-BPNS@SMFN。

结果：该平台的光热转化效率达 33.6%，DPBF 在 30 分钟内消耗率达 75%，具有极佳的光热响应和光动力性能，显示出协同增强的 PTT-PDT 效应。这归因于其温度依赖的类过氧化氢酶（CAT）行为：在近红外激光照射下启动 PTT，瘤区温度提高，CAT 活性增强，加速 O2 生成，促进 PDT；同时 PDT 生成的 ROS 也提高了 PTT 对肿瘤细胞的热敏感性，改善了 PTT。

结论：该平台与已报道的一些黑磷基纳米材料相比也体现出一定的治疗优势。该研究为协同光疗提供了极具应用前景的候选纳米药物，丰富了抗肿瘤纳米酶的研究思路。

关键字：黑磷基纳米酶，光疗纳米剂，协同增强治疗

ID 397

线粒体原位自组装用于增强癌症治疗研究

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目的：本研究旨在开发一种线粒体原位自组装纳米体系，实现选择性抑制肿瘤生长并调控肿瘤免疫微环境的双重目的。

方法：以氯尼达明为模式药物，利用固相合成法构建了聚乙二醇修饰的肽基聚合物。体外通过 Bio-TEM 验证了原位自组装的可行性及线粒体自噬体形成，并应用免疫荧光、流式细胞术以及 western 验证了其能否引起 ICD。此外，通过 trans-well 实验以及 ELISA 分析了其对巨噬细胞极化及相关炎症因子表达的影响。体内通过建立小鼠 4T1 肿瘤模型研究了纳米药物的抑瘤效果及其免疫调节作用，并进一步研究了其分别与放疗以及 PD-L1 抗体联合治疗的疗效。

结果：该体系所负载药物通过原位组装诱导的滞留效应显著增强了线粒体损伤，有效诱导了线粒体促死亡自噬，使胞内 ROS 急剧升高并触发了内质网溶胀，最终诱导了肿瘤细胞 ICD。同时，肿瘤细胞双重能量代谢途径均受到抑制，有效缓解了肿瘤细胞乏氧并降低了乳酸的生成，最终显著改善了肿瘤免疫微环境并增强了放射治疗以及免疫治疗疗效。

结论：本研究构建的线粒体原位自组装体系能够将免疫“冷”肿瘤有效转化为免疫“热”肿瘤，为增强肿瘤多模式治疗疗效提供了一种普适性的新型策略。

关键字：原位自组装　线粒体促死亡自噬　药物递送　癌症治疗

ID 488

Spontaneously Right-Side-Out-Orientated Coupling-Driven ROS-Sensitive Nanoparticles on Cell Membrane Inner Leaflet for Efficient Renovation in Vascular Endothelial Injury

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Objective: Biomimetic cell membrane camouflaged technology has drawn extensive attention as a feasible and efficient way to realize the biological functions of nanoparticles from the parent cells. As the burgeoning nanotherapeutic, the right-side-out orientation self-assembly and pathological dependent "on-demand" cargo release of cell membrane camouflaged nanocarriers remarkably limit further development for practical applications.

Methods: In the present study, a spontaneously right-side-out-orientated coupling-driven ROS-sensitive nanotherapeutic has been constructed for target endothelial cells (ECs) repair through the synergistic effects of spontaneously right-side-out-orientated camouflaging. This condition resulted from the specific affinity between the intracellular domain of key transmembrane receptors band 3 on cell membrane inner leaflet and the corresponding P4.2 peptide-modified nanoparticles without the additional co-extrusion. The "on-demand" cargo release resulted from the pathological ROS-cleavable prodrug. Particularly, the red blood cell camouflaged nanotherapeutics (RBC-LVTNPs) can enhance target drug delivery through low oscillatory shear stress (LSS) blood flow in the injured ECs lesion.

Results: Both in vitro and in vivo Results collectively confirm that RBC-LVTNPs can restore the damaged ECs and function with the recovered vascular permeability and low inflammation microenvironment

Conclusion: The findings provide a powerful and universal approach for developing the biomimetic cell membrane camouflaged nanotechnology.

Key words: Biomimetic cell membrane, right-side-out orientation self-assembly, ROS sensitive, low oscillatory shear stress, endothelial injury repair

ID 489

Prodrug Integrated Envelope on Probiotics to Enhance Target Therapy for Ulcerative Colitis

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Objective: Ulcerative colitis (UC), affecting millions of patients worldwide, is associated with disorders of the gut microbiota. Probiotics-based therapy positively regulating the community structure of gut microbiota has been regarded as an efficient intervention for UC. However, oral probiotics delivery has been restricted by limited bioactivity, short retention

time, complex pathological condition, and single therapeutic efficacy.

Methods: A multifunctional prodrug coating was constructed to protect the bioactivity of the probiotics and the coating possessed an excellent anti-inflammatory capacity.

Results: The Results of UC mice induced by dextran sulfate sodium (DSS) demonstrated that the intrinsic features of the fabricated coating integrated gut microbes protection, colon-targeted drug release, prolonged drug retention, and inflammation regulation. In parallel, the probiotics Lactobacillus rhamnosus GG (LGG) could regulate the composition of the gut microbiota and improve epithelial barrier function, thereby synergistically ameliorating UC.

Conclusion: These Results provide ample shreds of evidence of the therapeutic effect on UC, therefore, demonstrate a great promise as the potential therapeutic strategy for UC treatment.

Key words: Lactobacillus rhamnosus GG (LGG), oral delivery, prodrug, surface decoration, ulcerative colitis

ID 713

Iron Oxide Nanoparticles Cause Endothelial Cell Ferroptosis Dependent on Surface Coating and Core Chemistry

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Objective: Iron oxide nanoparticles (IONPs) are mostly intended to be administrated intravenously, understanding the interaction of IONPs with vascular endothelial cells is extremely crucial for developing safe application regimes of IONPs.

Methods: In this work, interactions of three kinds of IONPs to endothelial cells were investigated both in human umbilical vein endothelial cells (HUVECs) and in healthy mice. The cell viability was measured by Real-time cellular analysis (RTCA). The uptake of nanoparticles by the endothelial cells was analyzed by Prussian blue staining and phenanthroline spectrophotometric method. The gene and protein expression were analyzed by RT-PCR and western blot. After the administration, the mice tissues were analyzed by hematoxylin and eosin (H&E), Prussia blue and immunohistology staining.

Results: Both meso-2,3-dimercaptosuccinic acid (DMSA) coated Fe_3O_4 NPs (DMSA-Fe3O4 NPs) and DMSA-Fe_2O_3 NPs induced cell growth inhibition, while polyglucose sorbitol carboxymethyether coated Fe_2O_3 NPs (PSC-Fe_2O_3 NPs) did not. The PSC coating inhibited the cellular uptake of the IONPs. Both DMSA-Fe_3O_4 and DMSA-Fe_2O_3 NPs induced ferroptosis of HUVEC through upregulating phospholipid peroxides, which could be inhibited by typical ferroptosis inhibitors ferrostatin-1, Trolox and deferoxamine. Moreover, transforming growth factor beta 1 (TGFβ1) was upregulated by DMSA-Fe3O4 NPs at protein and gene level. The inhibitor of TGFβ1 receptor LY210 could reduce the effect. When being intravenously injected in mice, DMSA-Fe3O4 NPs were observed locating in the liver, increased the levels of lipid peroxidation (4-hydroxynonenal), acyl-CoA synthetase long-chain family member 4 (ACSL4) and TGFβ1, indicating ferroptosis occurrence *in vivo*.

Conclusion: The ferroptosis of vascular endothelial cells in exposure with IONPs depended on the surface coating and core chemistry of the NPs. Both DMSA-Fe3O4 NPs and DMSA-Fe_2O_3 NPs could induce the ferroptosis of endothelial cells, while PSC-Fe2O3 NPs did not induce ferroptosis and apoptosis possibly due to the very low cellular uptake. DMSA-Fe_3O_4 NPs and TGFβ1 formed feedforward loop to induce ferroptosis.

Key words: iron oxide nanoparticles, ferroptosis, endothelial cell, TGFβ1, lipid peroxidation

ID 1012

界面工程调控多肽蛋白高效包载的机制研究及应用

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目的：微球因其长效缓释的特点，是延长多肽蛋白类药物体内表观半衰期的常用制剂手段。由于该类药物与载体材料相容性差，导致包载效率低，极大限制了微球制剂的临床应用。

方法：本项目从聚合物结构设计出发，通过胶体表面吸附测定、界面扩张流变、药物跨界面扩散实时监测、固化过程调控等手段，探究不同结构聚合物分子组装形成的胶体表面层和油水界面膜的结构特性对药物跨界面扩散、乳滴固化以及药物释放的影响。

结果：通过表征两亲性聚合物在胶体表面及油水界面的吸附作用，明确聚合物抑制胶体颗粒相转移的规律，提出“界面膜阻塞”假说。从通用性、稳健性等方面对该假说进行验证；从界面流变学及分子动力学角度对该假说进行机制阐释。制备高载药微球的载药量高达 60.7%，且呈现较长时间的平稳释放。在 1 型和 2 型糖尿病大鼠模型中，所制备高载药微球将胰岛素的平均滞留时间从 3.1 h 延长至 4.6 d，艾塞那肽的平均滞留时间从 0.9 d 延长至 15.5 d。在保证相同治疗效果的条件下，聚合物用量可减少 1889 倍，大幅降低注射部位炎症反应。

结论：本研究加深了对微球载药机制的理解，有力指导连续流装置设计，为兼具高药和药物可控释放微球的生产提供理论基础。

关键字：包埋；微球；传质扩散；缓释；界面自助装

ID 1055

免疫对冲的静电纺纤维膜呈递再生信号引导组织修复

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目的：对冲组织损伤后速发形成的应激型区域免疫特征带来的组织修复风险，进一步解除免疫风险所致的再生信号屏蔽是实现保护残存功能细胞和激活内源性修复的关键。在有效对冲其组织修复风险的基础上，更进一步地引导风险信号向再生信号转换和实现早期信号放大，可能有帮助于激活损伤组织的内源性修复过程。

方法：利用 PLGA 电纺纤维水解后表面接枝 NH2-PEG-DSPE 的磷脂改性电纺纤维，捕获 CD11b+/CD68+ 巨噬细胞膜，构建携带相关信号受体和对冲区域风险的免疫对冲微米纤维膜 Him-MFM。

结果：Him-MFM 显著对冲炎症诱导的肌腱细胞应激压力和高度偏向的 I 型极化，同时提供腱膜肌腱干细胞再生的修复信号。在动物实验中，Him-MFM 可对冲炎症反应造成的病理损伤，保护原位肌腱细胞，实现免疫起源的再生信号引导下的腱膜覆盖的胶原纤维修复。

结论：基于 Him-MFM 的免疫对冲策略显著对冲炎症诱导的肌腱细胞应激压力和高度偏向的 I 型极化，能够抵消损伤后免疫风险因子带来的免疫损伤。免疫对冲的静电纺丝纤维在抑制免疫损伤基础上更提供专性的组织再生线索，直接提供腱膜处肌腱干细胞再生的修复信号，是一种呈递炎症起源再生信号的新策略。

关键字：免疫对冲，再生修复，静电纺丝纤维

ID 1144

肝细胞特异性锰铁氧体纳米对比剂的设计、开发及大动物肝胆成像应用研究

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目的：原发性肝细胞癌是最常见的高致命性恶性肿瘤，具有发病隐匿、进展迅速等特征，其早期诊断是临床最棘手的难点之一。磁共振肝胆成像被认为是目前最灵敏的肝癌影像诊断手段，其中肝细胞特异性对比剂（也称肝胆对比剂）的灵敏度和特异性决定了其对早期肝癌诊断效果。然而，目前临床应用的肝细胞特异性对比剂（主要为钆塞酸二钠，Gd-EOB-DTPA）信号增强低，亲和力差，特异性不足，对肝癌微小病灶难以定性检出，难以满足临床肝癌早期诊断和及时干预的需求。因此，发展高灵敏、高特异性肝细胞特异性对比剂对肝癌的早期诊断、改善预后具有重要的临床意义。

方法：将肝细胞亲和性的超小锰铁氧体纳米颗粒和特异性的乙氧苯配体结合，构建了双靶点协同靶向肝细胞的新型纳米对比剂 ($MnFe_2O_4$-EOB-PEG)。

结果：$MnFe_2O_4$-EOB-PEG 对比剂的准顺磁结构内外球协同的 T1 弛豫增强作用，其 T1 弛豫效能提高两倍；基于其双靶点协同靶向作用，其对肝细胞的特异性提升 1.8 倍。

结论：双靶点协同靶向的 $MnFe_2O_4$-EOB-PEG 对比剂，实现了快速、灵敏、高分辨的磁共振肝胆成像，将亚厘米级肝癌病灶检出率从 48% 提高至 92%，为肝癌早期发现提供了新的影像诊断工具。

关键字：磁性纳米材料，磁共振成像，纳米对比剂

ID 1186

磁热调控在体氧化铁纳米颗粒蛋白冠的研究

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目的：网状单核吞噬系统是纳米材料进入血液后面临的第一个也是最主要的屏障。绝大多数的纳米材料一经进入血液就立即被它扣留。导致上述结果的主要原因是纳米材料在进入血液后会快速吸附蛋白冠，特别是调理素蛋白。调控纳米材料蛋白冠组分已被证明是一种能够帮助纳米材料逃离 MPS 的策略。以往的方法主要通过改变颗粒的尺寸、形貌及表面化学（配体、电荷及疏水性等）等使其具有特定的蛋白冠组分，但体外所设计的蛋白冠组分往往与体内形成的不一致。因此，迫切需要发展一种适应复杂、动态生理环境的、可体内原位调控纳米材料蛋白冠组分的方法。

方法：利用磁性纳米颗粒介导交变磁场所产生的微观热，原位调控体内磁性纳米颗粒蛋白冠组分，并进一步探究磁场强度对体内颗粒蛋白冠组分的调控规律。

结果：磁热调控可导致磁性颗粒蛋白冠中，调理素蛋白含量下降，非调理素蛋白含量上升。受益于蛋白冠的调控，磁场处理的磁性颗粒具有更长的血液循环时间（2.53 倍提高），更低的肝（下降 60.4%）、脾组织富集（下降 56.3%），最终实现高效的肿瘤治疗。

结论：本研究发展了一种可定量化调控体内磁性纳米颗粒蛋白冠组分的磁热调控方法，这将使原位改变纳米药物体内命运而实现高效的肿瘤治疗成为可能。

关键字：蛋白冠；氧化铁纳米颗粒；磁感应热效应；网状单核吞噬系统；肿瘤递送

ID 1189

涡旋磁纳米氧化铁介导的高效磁热神经调控技术

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目的：构建兼具精准靶向与优异磁热性能的涡旋磁氧化铁纳米材料，揭示磁热效应活化神经的机制，建立高效安全的磁热神经调控新技术。

方法：利用可原位实时进行光谱分析、共聚焦显微镜成像、活体神经信号光纤记录、小动物行为学分析的神经磁热调控研究平台，通过神经元钙瞬变、神经信号光纤记录、C57 鼠恐惧行为分析，开展涡旋磁氧化铁磁热效应的神经调控研究。

结果：我们设计构建了一种靶向性、产热高的新型涡旋磁纳米氧化铁，利用其介导交变磁场产生的磁热效应，激活细胞膜上温度敏感型离子通道 TRPV1，诱发 Ca2+ 瞬时流入神经元，从而实现了快速安全的神经活化作用与 C57 鼠恐惧行为干预，揭示了磁场参数、材料剂量与磁热神经调控效能的时空量效关系，建立了高效安全的磁热神经调控新技术。

结论：相比于已有文献结果，涡旋磁纳米氧化铁可在较低材料剂量与磁场强度下，实现高效、安全的磁热神经调控，为实现非侵入式、远程无线的神经疾病治疗和脑科学研究等提供了实验基础与理论依据。

关键字：氧化铁纳米颗粒，涡旋磁，磁热效应，神经调控

ID 1414

Construction of Chitosan-based Drug/Gene Dual Delivery System and Study on its Synergistic Anti-tumor Effect

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Objective: At present, several new treatments have been applied to non-small cell lung cancer (NSCLC) and the gene/drug combination therapy has been proved to be an effective treatment method. The efficient gene and drug delivery vector is the key factor affecting its therapeutic effect. In this paper, a novel multifunctional micelle of vitamin E succinate-chitosan-methoxypolyethylene glycol-histidine (VCPH) was synthesized by hydrophilic and hydrophobic block modification of chitosan, which could realize the co-delivery of genes and drugs.

Methods: The DOX/VCPH/pDNA nanoparticles were formed by combining the recombinant plasmid pGPU6/GFP/Neo STAT3-shRNA (pDNA) with positive and negative charge, and encapsulating doxorubicin by self-assembly. The structure, particle size and morphological characteristics were observed. By using of the fluorescence spectra, the LC, EE, molecular interaction, and drug release behavior were studied. The cytocompatibility and anti-tumor effect *in vitro* were studied using L929 and A549 cells. The anti-tumor effect *in vivo* was studied by use of nude mouse tumor model.

Results: The Results showed that the VCPH had typical nanostructures. The LC was 31.58% and the EE was 84.21%. There was strong π-π stacking interaction between DOX and VCPH. Drug release experiments implied good pH sensitivity and sustained-release effect. The DOX/VCPH/pDNA nanoparticles could be efficiently taken up by cancer cells and the tumor inhibition rate was up to 62.4% *in vitro*. The DOX/VCPH/pDNA reduced the tumor volume and weight efficiently with a TIR of 40.12% in vivo, with no damage to normal organs. The RT-PCR and WB Results showed that the expression of STAT3 in

DOX/VCPH/pDNA group were 50.12% and 54.58% of that in physiological salt group, respectively.

Conclusion: The study demonstrated that the novel VCPH vector played a significant and synergistic effect in delivery and could be a promising drug/gene co-delivery carrier, which provided new ideas and Methods for the treatment of NSCLC.

Key words: dual delivery, multifunctional, STAT3, NSCLC

ID 1452

Sulfide-modified Nanoscale Zero-valent Iron as a Novel Therapeutic Remedy for Septic Myocardial Injury

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Objective: Myocardial injury is a serious complication in sepsis with high mortality. Zero-valent iron nanoparticles (nanoFe) displayed novel roles in cecal ligation and puncture (CLP)-induced septic mouse model. Nonetheless, its high reactivity makes it difficult for long-term storage.To overcome these obstacles and improve therapeutic efficiency, a surface passivation of nanoFe was designed using sodium sulfide.

Methods: We prepared iron sulfide nanoclusters and constructed CLP mouse models. Then the effect of sulfide-modified nanoscale zero-valent iron (S-nanoFe) on the survival rate, blood routine parameters, blood biochemical parameters, cardiac function, and pathological indicators of myocardium was observed. RNA-seq was used to further explore the comprehensive protective mechanisms of S-nanoFe. Finally, the stability of S-nanoFe-1d and S-nanoFe-30 d, together with the therapeutic efficacy of sepsis between S-nanoFe and nanoFe was compared.

Results: The Results revealed that S-nanoFe significantly inhibited the growth of bacteria and exerted a protective role against septic myocardial injury. S-nanoFe treatment activated AMPK signaling and ameliorated several CLP-induced pathological processes including myocardial inflammation, oxidative stress, mitochondrial function. RNA-seq analysis further clarified the comprehensive myocardial protective mechanisms of S-nanoFe against septic injury. Importantly, S-nanoFe has a good stability and a comparable protective efficacy to nanoFe.

Conclusion: The surface vulcanization strategy for nanoFe has a significant protective role against sepsis and septic myocardial injury. This study provided an alternative strategy for overcoming sepsis and septic myocardial injury and opened up possibilities for the development of nanoparticle for infectious diseases.

Key words: S-nanoFe; Sepsis; Myocardial injury; Oxidative stress; Inflammatory response

ID 1931

血脑屏障细胞旁路径调控及神经胶质瘤协同治疗

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目的：神经胶质瘤是中枢神经系统的原发性实体瘤，具有另类的“三高”特点——高复发率、高致残率、高死亡率。因受到血脑屏障阻隔，相关治疗药物难以进行有效递送，临床尚无明确解决方案。因此，开发神经胶质瘤血脑屏障特异性调控与治疗方法成为未来研究重要方向。

方法：针对血脑屏障细胞旁路径中紧密连接蛋白，设计构建可同时调控紧密连接蛋白表达水平和递送协同治疗剂的纳米治疗系统 BBB-MT。该系统由肿瘤微环境高水平 ROS 和 GSH 响应的高分子为载体，以 fingolimod 和 Lexiscan 为紧密连接调节剂，结合磁性纳米颗粒的磁热性能和声敏剂的自由基生成能力，可实现血脑屏障通透性调控与肿瘤治疗双功能。

结果：经过 BBB-MT 调节后的神经胶质瘤血脑屏障细胞旁通路被打开，并允许 50 纳米以下颗粒高效进入肿瘤组织，纳米颗粒累积量是未调节对照组的 15 倍；磁热疗和声动力治疗通过热和自由基形式有效缓解肿瘤耐药性，肿瘤小鼠模型中位生存期得以延长 90%。

结论：该研究成果将为神经胶质瘤及其它脑部疾病的递送治疗提供新的理论指导和实施方式。

关键字：血脑屏障；紧密连接；神经胶质瘤；磁感应热疗；声动力治疗

ID 2419

A Rational Design of Metal-Organic Framework Nanozyme with High-Performance Copper Active Centers for Alleviating Chemical Corneal Burns

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Objective: Chemical ocular burns occur in 10-22% of all ocular trauma, which cause oxidative stress from large amounts of ROS on the ocular surface. The present study aimed to propose a straightforward and robust procedure to fabricate excellent copper active centers in metal-organic frameworks (MOFs) for alleviating chemical corneal burns.

Methods: A series of MOFs with different halogen-coordinated copper nodes (Cu-X MOFs, X = Cl, Br, I) were constructed by the facile self-assembly of Cu ions, halogen ions, and 4,4'-bipyridine.

Results: Experimental and theoretical Results strongly support that precisely tuning the coordination of halogen atoms directly regulated the enzyme-like activities of Cu-X MOFs by influencing the spatial configuration and electronic structure of the Cu active center. The optimal Cu-Cl MOF exhibited excellent superoxide dismutase-like activity with a specific activity one order of magnitude higher than the reported Cu-based nanozymes. More importantly, by performing enzyme-mimicking catalysis, the Cu-Cl MOF nanozyme can significantly scavenge reactive oxygen species and alleviates oxidative stress, thus effectively relieving ocular chemical burns. Mechanistically, the antioxidant and antiapoptotic properties of Cu-Cl MOF are achieved through the regulation of NRF2 and JNK or P38 MAPK pathways.

Conclusion: This study proposes a new idea to optimize the catalytic performance of MOFs-based nanozymes and establishes a structure-activity relationship that directly regulates the catalytic effect of the metal active centers. Furthermore, the developed highly active Cu-Cl MOF nanozymes can present a potential therapeutic option for treating severe corneal disease.

Key words: Metal-organic frameworks nanozymes, superoxide dismutase, chemical ocular burns, corneal diseases

ID 2590

A Microfluidic Chemiluminescent Immunoassay Platform for SARS-CoV-2 Binding and Neutralizing Antibody Evaluation

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Objective: The abundance and quality of binding and neutralizing antibodies are crucial biomarkers for the evaluation of the immune response after SARS-CoV-2 infection or preventative vaccination. Traditional quantitative detection Methods such as ELISA require a relatively large amount of sample (>100 μL of serum), which leads to the necessity of venous blood sampling.

Methods: Here we present a novel microfluidic chemiluminescent immunoassay platform that can rapidly (in <15 min) and sensitively quantify IgG with high SARS-CoV-2 S1 binding affinity, using only 8 μL of serum sample.

Results: Using this approach, we have identified several "super donors" for COVID-19 convalescent serum therapy during the 2020 outbreak in New York. In addition, our microfluidic immunoassay platform can also be used to quantitatively evaluate the inhibitory efficacies of neutralizing antibodies in vitro. Finally, we demonstrated that our assay enables the rapid identification of immune-evasive mutations of the SARS-CoV-2 spike protein, utilizing a set of nanobodies with known binding epitopes.

Conclusion: Our method shows a bright prospect for using minimal-invasive samples such as fingertip blood or saliva for performing antibody level evaluation. It has a strong potential for facilitating vaccine efficacy studies from both humoral and mucosal immunity perspectives.

Key words: Chemiluminescent; Immunoassay; Microfluidics; Biosensor; COVID-19

ID 2746

ApoEVs Degrade ATP And cGAMP Via The Surface Molecule ENPP1 to Improve Colitis

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Objective: Implanted stem cells undergo apoptosis and release apoptotic extracellular vesicles(apoEVs) in promoting tissue regeneration, but the role of apoEVs is largely unknown.Here, we explored their effect on colitis mice.

Methods: First, apoEVs were obtained by gradient centrifuge, followed by scanning electron microscopy(SEM) to observe the morphology and particle size distribution of the apoEVs. Then,2.5%DSS was used to induce colitis in mice, and these mice were systematically injected with apoEVs. The effects of apoEVs on colitis mice were determined by monitoring the changes in body weight, observing the colonic length and HE staining results,and detecting the content of ATP in serum samples of mice. Finally,WesternBlot was used to identify proteases that promote the degradation of ATP by apoEVs,and its related biochemical properties were detected.

Results: SEM showed that apoEVs was spherical in structure and its particle size was concentrated in 200-500nm. Subsequently,in mice with colitis,we found that DSS treatment resulted in gradual weight loss and significant colon shortening with severe congestion and ulcers, while systematic infusion of apoEVs partially restored colon length and relieved diar-

rhea, blood in the stool,rectal detachment,and weight loss. Consistently,histopathological analysis showed that DSS treatment induced enormous transmural inflammatory cell infiltration, crypt damage,and loss of mucosal epithelial integrity in the colon, which was mitigated by apoEVs. Additionally, we found that the serum ATP concentration of colitis mice was higher than that of normal mice, but treatment with apoEVs reduced ATP concentration, and at the molecular level, we found that apoEVs degrade ATP via ENPP1 protease on their membrane surface. At the same time,studies have shown that ENPP1 can also degrade cGAMP.In vitro, we demonstrated that apoEVs can degrade cGAMP, thus inhibiting STING pathway activation and IFN expression.

Conclusion: we revealed that apoEVs can degrade eATP and cGAMP through ENPP1 on the membrane surface, inhibit STING pathway activation, and thus improve colitis.

Key words: apoEVs; ENPP1; ATP; cGAMP; colitis

ID 2848

近红外光诊疗纳米探针与活体生物医学应用

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目的：光学成像（如荧光和光声）具有高灵敏度、高瞬时分辨率、实时监测、价格低廉、高效低毒以及设备简便灵活等特点，可以克服许多传统的医学成像手段面临着一些问题，包括分辨率不高，早期诊断效果有限，病灶特异性差和缺乏功能性等。

方法：通过调节有机分子探针的化学结构，得到分子结构与性能之间的关系，提出了调节能量转换过程促进探针性能，分子内运动提高光学成像信号，结构可控转变实现最优化的多种成像模式等策略，得到了具有长波长高亮度、高选择性以及兼具多种功能的近红外有机纳米探针。

结果：研究了高分辨率大深度活体脑部血管造影与血管相关疾病成像诊断，重大疾病原位诊疗一体化和发生发展过程追踪，以及手术不同阶段的精准导航与治疗等。

结论：该研究提高了重大疾病的精准诊疗效果。

关键字：光学成像探针；纳米医学；生物医学工程；聚集诱导发光；精准诊疗

ID 3211

放射衍生材料和肿瘤免疫治疗

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目的：针对临床放射治疗无法适用于广泛转移性肿瘤的问题，聚焦放疗经典现象的解析，构建新型放疗衍生材料，提出了以放疗产物为基础的间接放疗新概念，为临床无法实施放疗的肿瘤患者提供了新的治疗思路。

方法：通过基因工程、水凝胶复合，以及自组装等策略，研究放射衍生物的免疫调控，直接抗肿瘤和作为个体化疫苗的潜力。

结果：放疗肿瘤微颗粒（RT-MPs）可通过铁死亡介导靶细胞死亡，重塑肿瘤细胞免疫原性。将 RT-MPs 与 PD-1 联

合用于肿瘤治疗，实现了 chemo-free 的疗法。阐明了 RT-MPs 可通过重塑肺组织免疫微环境预防肿瘤细胞肺定植的机制；放疗后肿瘤细胞的分泌物可高效刺激树突状细胞的活化和成熟，采用新型蜂毒肽水凝胶可大幅度提升其免疫调节功效；发现 USP7 调控巨噬细胞重编程；负载 USP7 抑制剂可重编程中枢神经巨噬 / 小胶质细胞，用于治疗肺癌脑转移模型；放疗后的肿瘤细胞膜具有独特性能，可复合成纳米材料，作为预防性和治疗性新型个体化疫苗。

结论：提出了一个新的研究方向 - 放射衍生物和肿瘤免疫治疗，提出了一个新概念 - 肿瘤的间接放疗，部分解释了放疗的远隔和旁观者效应，发现了多个新的免疫调控靶点，开发了多种具有临床转化潜力的免疫治疗新材料。

关键字：生物材料，肿瘤免疫，细胞外囊泡，肿瘤微环境

ID 3225

基于 DNA 纳米结构的顺序响应肿瘤靶向递药系统

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目的：基于核酸适体（aptamer）的靶向递药系统引起了越来越多的关注。核酸适体可以赋予递药系统一定的肿瘤靶向能力，然而，由于靶蛋白在正常组织中也有低表达，因此适体修饰的纳米递药系统通常会存在一些非特异性靶向。因此，有必要提高靶向效率，基于此，我们开发了一系列肿瘤环境响应性的 DNA 纳米结构，用于智能性的肿瘤顺序响应靶向和药物释放，提高肿瘤靶向效率和治疗效果。

方法：设计与构建 DNA 纳米结构并对其进行表征，该设计涉及适体抑制 / 激活转换的策略，响应后由于结构改变，核酸适体靶向能力恢复。通过评价其对肿瘤微环境多参数的响应性能，细胞的靶向效率，响应性药物释放，及对肿瘤的抑制效果，从而开发出肿瘤靶向效率更高的递药系统。

结果：DNA 纳米递药系统可通过对肿瘤微环境的 pH、肿瘤细胞膜受体等因素，进行顺序性响应并发生结构改变，实现对肿瘤细胞的更精准的靶向，大大降低了与非靶细胞的非特异性结合，提高了对肿瘤细胞的靶向能力，实现了响应性药物释放及肿瘤的抑制。

结论：我们成功构建了一系列肿瘤微环境顺序响应的 DNA 纳米结构靶向递药系统，肿瘤靶向效率更高，该策略可拓宽肿瘤靶向智能 DNA 纳米结构的设计和应用，具有重要的科学意义与临床应用价值。

关键字：核酸适体 ; DNA 纳米结构 ; 肿瘤微环境 ; 响应性 ; 肿瘤诊疗

ID 3470

谷胱甘肽响应和 MRI 可视化的金属有机框架用于细胞内释放 IDO 抑制剂和 NO 增强肿瘤免疫治疗

韩世松 *

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目的：由于肿瘤发展出多种免疫逃逸和免疫耐受机制，瘤内的效应 T 淋巴细胞浸润不足，严重限制了免疫治疗的效果。为了取得高效的肿瘤免疫治疗效果，需要优化设计免疫治疗策略并高效输送相关药物。

方法：设计了一种谷胱甘肽敏感的纳米药物，通过联合吲哚胺 -2,3- 双加氧酶（IDO）抑制和 NO 治疗来介导对三阴性乳腺癌的协同免疫治疗。制备了基于金属有机框架的纳米载体 (BMS-SNAP-MOF) 表面修饰聚醚 F127，以提高其在

生物体内的稳定性和生物相容性。这种多功能纳米载药系统具有较高的 T-1 弛豫度，可用于体内磁共振成（MRI）可视化的药物递送。

结果：当纳米药物到达肿瘤细胞，细胞内高浓度的谷胱甘肽与金属有机框架材料发生级联反应，减弱了材料内部的配位作用，引起金属有机框架降解并迅速释放 IDO 抑制剂分子，同时在肿瘤细胞内产生大量 NO 气体。由此，IDO 抑制剂和 NO 气体协同调节了免疫抑制肿瘤微环境，显著增加了效应 T 细胞和减少了调节性 T 细胞，从而实现一种高效的免疫协同治疗。

结论：该纳米诊疗系统在小鼠乳腺癌的皮下瘤和远端瘤模型中展现了良好的治疗效果，显示出该免疫治疗策略和纳米药物体系在肿瘤免疫治疗中的良好潜力。

关键字：肿瘤免疫治疗，IDO 抑制，NO 气体治疗，MOF 载体

S10
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Tissue Engineering and Regenerative Medicine

ID 173

A Modified Small Intestinal Submucosa (SIS) Patch with Multifunction to Promote Scarless Repair and Reinvigoration of Urethra

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Objective: Reconstruction and rehabilitation of functions of long urethra in males is one of the difficult tasks in urological treatment. The acellular matrix graft used in clinic is mono-functional and causes a series of complications including stricture, fistula formation, foreign body response and blockage of the urethra. As a result, these graft materials cannot meet the increasing demand for multifunctionality in the field of urethral tissue engineering.

Methods: In this thesis, the authors designed a multifunctional urethral patch with appropriate hydrophilicity, desirable antioxidant capacity and anti-inflammatory property to meet the growing needs of patients with urethral defects. By mixing PCA, a naturally-occurring building block, with small intestinal submucosa (SIS) under an alkaline condition to enable cross-link, the multifunctional PCA/SIS patch was fabricated.

Results: The PCA/SIS patch exhibited outstanding mechanical strength, suitable hydrophilicity, good in vitro biodegradation property, excellent biocompatibility, antioxidant activity, and anti-inflammatory property. More significantly, this patch could remarkably promote the adhesion, proliferation and directional extension of rabbit bladder epithelial mucous cells (R-EMCs) as well as rabbit bladder smooth muscle cells (R-SMCs), and upregulate the expression of keratin in EMCs and contractile protein in SMCs in vitro. In addition, in vivo Results indicated that the PCA/SIS patch significantly improved scarless repair of urethral defects of the rabbits by facilitating smooth muscle regeneration, reducing excessive collagen deposition and accelerating re-epithelialization and neovascularization.

Conclusion: In general, the obtained Results affirmed the newly developed multifunctional PCA/SIS patch as a promising candidate for urethral regeneration.

Key words: PCA/SIS patch; multifunctional; urethral repairing; re-epithelialization; neovascularization

ID 195

Anticoagulant and 19F MRI Visualizable Bi-layered Zwitterionic Hydrogel Tube as High-performance Small-diameter Vascular Graft

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Objective: The clinical performance of small-diameter vascular grafts (SDVGs) (ID<6 mm) was still disappointing, which was mainly restricted by the thrombosis, anastomotic hyperplasia, and immune rejection, due to the cascade thrombo-inflammation and foreign body reactions.

Methods: Herein, based on the molecular design of materials, structural design of artificial blood vessel and their relationship with vascular functions, we proposed the design of biomimetic bi-layered hydrogel tube as artificial SDVG. The inner layer was composed of zwitterionic fluorinated hydrogel, which enabled excellent resistance to the adhesion of plasma proteins and platelet in the whole blood, so as to avoid the formation of mural thrombus. Meanwhile, the zwitterionic fluorinated hydrogel enabled the visual feedback on the position and morphology of the artificial SDVG through fluorine-19 magnetic resonance imaging (19F MRI) with no interference of endogenous background signals and no requirement of contrast media. The outer layer was comprised of poly(N-acryloyl glycinamide) (PNAGA) hydrogel, which provided matched mechanical properties especially the compliance through the regulation of hydrogen bond density.

Results: It was found that the well-designed bi-layered hydrogel tube demonstrated great hemocompatibility and histocompatibility, maintaining great patency (>90%) and stable morphology after carotid artery replacement on porcine for 9 months with feeding of anticoagulant drugs for only the first 7 days, which was significantly superior than that of VENAFLO®II product.

Conclusion: Collectively, such structural design and functional distribution enabled the development of well biocompatible and long-term patency SDVG with accurate morphological visualization capacities, having great potential for benefiting patients with cardiovascular disease.

Key words: small-diameter vascular graft; zwitterionic hydrogel; 19F MRI; long-term patency

ID 328

仿生拓扑化丝素蛋白人工神经移植物的制备及评价

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目的：周围神经损伤（PNI）的快速有效修复是尚未解决的医学难题之一。周围神经系统含有由施万细胞包鞘的平行轴突束，各向异性拓扑结构有望通过接触引导募集施万细胞并促使其沿拓扑方向排列迁移、促进轴突的定向伸长来促进周围神经的再生。仅有少量研究表明二甲双胍在坐骨神经压伤模型中可以促进神经的再生，其在修复 PNI 中仍有巨大潜力。将微纳复合拓扑结构与二甲双胍结合，有望加速长距离 PNI 的再生。

方法：将丝素蛋白和二甲双胍溶于甲酸与六氟异丙醇的混合溶液中，通过静电纺丝与微模塑技术制备了具有微纳复合拓扑结构的仿生人工神经支架。对支架进行 SEM、AFM 等形态结构的观察及力学性能、湿润性等表征，并在支架上培养施万细胞和背根神经节，评估其对神经细胞取向性及轴突延伸的影响。

结果：通过优化工艺参数，制备了具有各向异性微纳复合拓扑结构的丝素支架。其具有良好的机械性能和缓慢的体外降解速率，可以有效支撑周围神经的再生。二甲双胍的加入改善了支架的亲水性和生物相容性，并可以更好地引导神经细胞的定向生长。

结论：体外实验表明，该移植物可以显著促进神经细胞的增殖和定向生长迁移。该研究有望为治疗长距离周围神经损伤开拓一条新的方法与思路。

关键字：丝素蛋白；微纳复合拓扑；周围神经损伤

ID 329

光热响应性可注射水凝胶载药微球支架用于脊髓损伤修复的研究

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目的：脊髓损伤快速有效修复是亟待解决的世界性难题之一。水凝胶微球凭借其优势，在脊髓损伤修复方面应用广泛。单纯的水凝胶微球构建的物理微环境促脊髓再生能力有限，还需要进一步结合各种生物活性因子或药物。因此，开发可控药物释放的智能响应性水凝胶微球具有重要意义。

方法：首先在多壁碳纳米管上装载促轴突再生和血管生成的药物，然后复合到温敏水凝胶中，通过微流控法制备水凝胶微球支架。对支架的理化性能等进行表征。最后，我们将支架和神经干细胞共培养，对细胞分化情况进行评价。

结果：通过对修饰前后碳纳米管进行表征，紫杉醇和血管内皮生长因子已经成功装载到碳纳米管上。优化微流控相关参数后，制备了具有不同尺寸、可注射性和光热响应性释放药物的多孔结构的微球。支架和细胞共培养的结果表明，微球可以为神经干细胞的生长提供更好地微环境。

结论：本研究成功制备了同时具有可注射性和可控释放光热智能响应性水凝胶微球。研究表明，该微球具有良好的生物相容性、可注射性、和光热响应性，与神经干细胞的共培养实验表明，促进神经干细胞分化为神经元。该研究有望为脊髓损伤修复提供重要的实验和理论依据。

关键字：脊髓损伤修复；碳纳米管；温敏水凝胶；光热；微球支架

ID 353

仿生的糖基纳米粒子调控巨噬细胞 M2 极化用于放射性肠损伤的防护治疗

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目的：放射性肠损伤是放疗给盆腔恶性肿瘤患者带来的严重危害，如何在保证疗效前提下减少对正常组织的放射损伤是放疗在临床工作中面临的难题。本研究提出构建仿生型糖基纳米颗粒，调控巨噬细胞 M2 极化，促进放射性肠损伤修复的研究策略。

方法：本项目利用葡甘露聚糖和聚丙硫醚共价键连接合成两嵌段共聚物，在水溶液中通过共价键和非共价键作用自组装形成化学性质稳定、粒径均一的纳米颗粒。一方面通过调控巨噬细胞代谢重编程发挥抗炎促修复的核心作用；另一方面利用聚丙硫醚的不饱和化学键结构有效清除辐射后细胞内的 ROS 以降低肠上皮细胞氧化应激损伤，二者协同促进小鼠放射性肠损伤修复。

结果：该仿生型糖基纳米粒子通过 stat3 信号通路诱导巨噬细胞向 M2 型极化，分泌一系列抗炎因子和促进愈合的细胞生长因子以抑制炎症，促进血管新生并创造一个再生的微环境；通过消耗 ROS，降低氧化应激损伤，减轻炎症反应，进而促进肠损伤的修复。

结论：仿生型糖基纳米粒子对放射肠损伤具有一定的修复能力，可以抑制肠道组织的凋亡，减轻细胞 DNA 损伤；促进照射后肠细胞的增殖。有望为辐射防护提供无细胞无因子的新生物技术治疗方法，为放射损伤修复提供新思路。

关键字：仿生材料；糖基纳米粒子；巨噬细胞极化；放射性肠损伤；组织修复

ID 355

Click Method Promises the Therapeutic Activities of Peptide-activated Hydrogels for the In-situ Bioprinting Facilitated Vessel Regeneration Via PI3K Pathway

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Objective: Peptide-functionalized hydrogel is one of commonly used strategies for vessel regeneration. In spite of many studies for the highly bioactive peptides (or ligands) for regeneration, the study on the conjugating Methods for the hydrogel functionalization is limited.

Methods: We studied the vasculogenic efficacy of the peptide-functionalized hydrogels fabricated by two common methods, EDC and Click methods, through cell models, organ-on-chips models, animal models, and RNA-Seq analysis. To further improve the therapeutic effects of Click-boosted hydrogel, we also performed an in-situ bioprinting with the peptide-functionalized hydrogels by Click Methods in the ischemic hindlimb model.

Results: Human endothelial cells and the human mesenchymal stem cells have been cultured on the hydrogel substrates made by EDC/Click methods, showing the greater vasculogenic activities on the hydrogels made through Click method while the eliminated activities of the peptides on the ones manufactured by EDC Methods. The vascular organ-on-a-chip model further revealed that hydrogels made through Click method promoted a greater vascular network formation. In an ischemic hindlimb model, only the peptide-functionalized hydrogels made by Click method successfully rescued the ischemic limb, significantly promoted blood perfusion, and boosted the hindlimb functional recoveries. RNA-seq studies revealed that the hydrogels prepared by the Click method significantly activated the PI3K-Akt pathway compared to the hydrogels prepared by the EDC method. The hydrogels prepared by Click method have further promoted the therapeutic effects in the ischemic hindlimb through in-situ bioprinting.

Conclusion: In conclusion, Click method promises the therapeutic activities of peptide-activated hydrogels for the in-situ bioprinting facilitated vessel regeneration. The mechanism of the therapeutic effects is through PI3K-ARK signaling pathway.

Key words: Regenerative medicine, Click method, EDC method, Hydrogel-induced vessel regeneration, In-situ bioprinting

ID 426

Regulation of Vascular Branch Formation in a 3D Bioprinting Tissue using Mechanical Confined Force

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Objective: Wound healing is of major concern in wound repair. Tissue-engineered skin is characterized by an abundant supply and low immunogenicity, making it a potentially ideal material for clinical use in repair of wounds. Current commercial skin has been popularized in clinic. However, application is limited by the occurrence of ischemia necrosis after

transplantation.This is caused by the lack of vascular system in the commercial skin itself. Thus, solving the problem of blood circulation after tissue-engineered skin transplantation is a prerequisite for the promotion of tissue-engineered products to clinical application.

Methods: In this study, Polycaprolactone (PCL) was used as the frame structure of printed tissue, human umbilical vein endothelial cells (HUVECs) and fibroblasts were used as seed cells, and gelatin, hyaluronic acid, and fibrin were used as scaffold materials to construct the 3D printed vascular tissue. A co-culture of fibroblasts and HUVECs, mixed with fibrin hydrogel, was confined by PCL frame and suspended in a medium after culture. A micro-spring structure was designed for the measurement of the forces involved in this system.

Results: The Results showed that the tensile force was about 2.4 mN in the L6 group and about 4.3 mN in the L10 group. The immunofluorescence Results showed that with the increasing size of the framework, the force was larger and the formatted vessels tended to be more linear with fewer branches.The YAP expression was increased in the experiment group compared to the control group detected by the immunofluorescence staining and PCR. FITC-dextran was detected in the formatted luminal structure in the transplanted construct, which further verified that the perfusion function of the engineered vessels.

Conclusion: Together, our findings indicate that vascularization of engineered skin tissue is a complex yet controllable process,and precise mechanical control can lead to effective vascular network generation.

Key words: Vascular; Branch formation; 3D bioprinting; Skin regeneration

ID 500

Bioprinted Skin with Human Adipose Tissue-derived Microvascular Fragments Promotes Wound Healing

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Objective: The separation procedures and conditions of microvascular fragments derived from adipose tissue after skin flap thinning were clarified to provide a new raw material for the construction of vascularization tissue engineering tissue.

Methods: Microvascular fragments from adipose tissue were isolated by enzyme digestion. The activity of cells in the printed tissue was detected using a live/dead cell staining kit. Immunofluorescence was used to observe the expression of CD31 marker molecules in isolated microvascular fragments, and the expression of CD31 and SMA in printed tissues. The effect of prevascularization tissue on wound healing was observed in back wound model of nude mice.

Results: Microvascular fragments isolated from adipose tissue after skin flap thinning were observed under light microscope, most of which were 50-200μm in length and 15-30μm in diameter. Immunofluorescence Results showed that isolated microvascular fragments CD31 and SMA were positive, and immunofluorescence Results of printed tissue showed complete angiogenesis. The Results of back wound model in nude mice showed that the prevascularization tissue can promote wound healing, and can promote wound skin reepithelialization, vascularization and collagen deposition.

Conclusion: We successfully established a method for the isolation of vascular fragments of human adipose tissue origin and encapsulated them in a hybrid hydrogel of GelMA, HAMA and fibrin. As well as exhibiting high vascularization ability, the hydrogel also exhibits acceptable biocompatibility to support the growth of vascular fragments and exhibits some mechanical properties. It accelerates the healing of skin wounds and accelerates the vascularization of skin tissues to avoid necrosis of skin tissues at the wound site due to insufficient blood perfusion. In vivo evaluation also confirmed the effectiveness of 3D bioprinted skin for wound healing. In short, HaMVFs have excellent vascularization ability and can accelerate wound healing.

Key words: GelMA, fibrin, Microvascular fragments, 3D bioprinting, Wound healing, human adipose tissue

ID 563

nHA/DMOG 复合纳米纤维支架的构建及其理化活性探究

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目的：生物活性材料是目前促进骨缺损修复的有效途径，但大面积骨缺损部位仍存在血管形成缓慢，营养物质不足，导致骨缺损修复效果不佳。因此，提升生物材料成骨活性的同时，增强其血管形成能力，实现血管重建与骨重塑，对大面积骨缺损的治疗具有重要意义。

方法：通过静电纺丝将诱导血管生成的 DMOG 和骨诱导活性的 nHA 整合至 PCL 纳米纤维中，构建多功能复合纳米纤维支架；使用扫描电镜对其形态结构和元素分布情况进行观察，使用红外光谱仪，接触角仪等对其组成与结构，亲疏水性进行分析。

结果：DMOG/nHA 复合纳米纤维支架呈交错纤维结构，表面形态光滑，且无串珠或断股结构，直径在 150nm；元素分析结果显示 Ca 和 P 的含量分别是 7%、11%，表明 nHA 已成功嵌入 PCL 纳米纤维；DMOG/nHA 组的红外光谱特征峰与纯 PCL 组相似，意味着表面化学性质不受静电纺丝过程的影响。接触角结果显示加入两种生物活性物质后，纤维膜的接触角降低到 66.825±0.098°，可见 DMOG 和 nHA 的加入提高了纳米支架的亲水性。

结论：基于静电纺丝成功构建载 nHA/DMOG 复合纳米纤维支架，其具有良好亲水性，能够持续释放活性药物，可为骨组织工程材料的研发提供参考。

关键字：骨组织工程、静电纺丝、成骨 - 成血管化、DMOG、nHA

ID 566

Human Pluripotent Stem Cells Derived Engineered Heart Tissue as a 4D Physiology Model For Cardiac Scarring In Vitro

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Objective: Engineered heart tissue models were applied to mimic various cardiac development and disease. The functional cardiac organoid and tissue model are well established to value the cell maturation, contractility, and electrical physiology characters. However, a cardiac scarring model is lacking to study the ischemic heart disease process and screening treatment to enhance cardiac tissue healing and functional recovery.

Methods: Here we established a novel cryoinjury-scarring model on the human pluripotent stem cell-derived engineered heart tissue patch (hEHT) to mimic the stageable regional fibrosis and myocardium conduction arrhythmia. Single-cell RNA sequencing(scRNA-seq) towards scarring hEHT under different self-healing periods revealed critical identity shift in cardiomyocytes and non-cardiac population. Moreover, we achieved batch and standardized comprehensive evaluation of 17 fibrosis-related intervention targets excavated from scRNA-seq data.

Results: We established a novel myocardium injury-scarring model based on hEHT which could reproduce the staged pathological remodeling process in vitro including myocardium hypoxic stress and fibrosis response, and also the fibrotic Results of

abnormal electrical conduction function. Bulk and single-cell transcriptomics analysis towards this process revealed the role of multiple signaling pathways in regulating key biological processes such as fibroblast subpopulation switching, extracellular matrix deposition, and functional remodeling of myocardial electrical conduction. The heartlet array system based on this model further provided a powerful platform for batch evaluating the role of specific signaling pathway intervention in anti-fibrotic/pro-myocardial regeneration. Based on the re-screening Results of electrical conduction function evaluation, we proposed a multi-targeted, phased myocardial injury repair strategy targeting ROCK/Rho, WNT/βcatenin, and TGFβ1/ALK5, which demonstrated greater advantages of promoting myocardial functional regeneration compared to single factor treatment.

Conclusion: Our studies have established a multidimensional human cardiac scarring model in vitro and defined the model's time-related tissue healing and electrical transmission dynamic characteristics. These provide a novel tool for studying heart scarring pathogenesis and evaluating the heart regeneration drug's pharmacodynamics.

Key words: human pluripotent stem cell, engineered heart tissue, ischemic heart disease, cardiac scarring

ID 655

Optical Perception of Thrombolysis Progress for Point-of-care Diagnosis and Feedback-regulated Accurate Therapy of Vascular Thrombosis

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Objective: Theranostic of cardiovascular and cerebrovascular diseases such as ischemic stroke and heart disease have been facing challenges due to the short "golden time" of 4-6h, the limited targeted thrombolysis ability of clinical drugs and the individualized differences between patients. To realize effective thrombolysis therapy, potent thrombolytic strategy with instantly perceptible therapeutic effect is urgently needed.

Methods: Nano-patrol were constructed based on mesoporous polydopamine nanoparticles, integrating with aptamer as the targeting unit and urokinase as thrombolytic drug. The nano-patrol navigating in the blood vessel, automatically anchoring at the thrombosis site and release urokinase under the stimulation of local microenvironment or external NIR signal to dissolve the clot. During the thrombolysis progress, the nano-patrol generate artificial reporters whose level is strongly associated to the complexity of the thrombolysis. The artificial reporters are detected by optical sensors to help making medication decisions for personal treatment.

Results: The combination of photothermal thrombolysis and drug thrombolysis enhanced the thrombolytic efficiency. Immediate perception of thrombolysis progress can be realized by facilely optical sensing of the artificial reporters to achieve point-of-care diagnosis and personalized treatment.

Conclusion: The feedback-regulated thrombolytic strategy shows improved therapeutic effect and reduced bleeding risk in both in vitro and in vivo test, indicating the great potential for the theranostic of vascular thrombosis.

Key words: Targeted Thrombolysis; Optical Perception; Thrombus; Accurate Therapy; Feed-back Regulation

ID 990

结合热疗的微针贴片调控细胞和微环境治疗椎间盘退变

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目的：椎间盘退变（IDD）在中青年人群中越来越普遍，是全世界慢性疼痛和残疾的常见原因。由于 IDD 与细胞凋亡之间的联系，我们提出了一种结合热疗和双氯芬酸钠 (DCs) 的复合微针系统，以防止大鼠 IDD 的进展。聚多巴胺纳米粒子（PDA）是一种优良的光热剂，具高效负载 DCs 的特性。此外，得益于 DCs 的释放，IDD 的炎症微环境可以得到有效缓解。

方法：利用 PDMS 模具制备出水凝胶基微针贴片。通过脂多糖处理纤维环细胞（AFCs）模拟椎间盘退变的炎症微环境。微针贴片治疗经皮穿刺大鼠尾椎椎间盘针刺损伤退变模型。通过 PCR、免疫荧光、活体影像学以及组织学切片等方法检测微针贴片在体内外的作用。

结果：微针贴片可以下调 AFCs 炎症相关基因及蛋白的表达，同时上调细胞外基质合成相关基因及蛋白的表达。活体影像结果显示，微针贴片能够较好地维持损伤节段椎间高度，并保持髓核组织较高的含水量。组织学切片评估结果证明微针贴片在椎间盘退变的治疗中取得了良好的效果。

结论：我们构建了一个复合微针体系。光热治疗（PTT）一方面控制药物释放，另一方面可促进组织修复，并在椎间盘退变的动物模型中取得了明显的效果。这一策略为 PTT 在椎间盘组织工程中的应用开辟了新思路。

关键字：光热治疗；微针；椎间盘；组织工程

ID 992

静电纺丝支架结构和力学特征通过 CAV1/YAP 调控纤维环源干细胞分化

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目的：纤维环组织是非均一性的组织，其沿径向由内至外各区域呈典型的梯度变化。在本研究中，我们同时探究了纺丝支架的微观结构和力学特性对 AFSCs 的双重影响。

方法：我们分别构建了四种聚氨酯纺丝支架（低弹性，小直径；低弹性，大直径；高弹性，小直径；以及高弹性，大直径）来影响干细胞的黏附及分化。骨架染色和扫描电镜观察细胞的形态特征，PCR 检测干细胞分化标志基因表达情况，免疫荧光及 WB 检测 AFSCs 相应的蛋白表达情况。

结果：支架的弹性模量和微观结构对 AFSCs 的分化具有重要的影响，随着纤维硬度和直径的增加，纤维环外区细胞分化标志基因表达增高，而内区细胞分化标志基因表达降低。同时，支架的微观结构和弹性模量都可以通过影响 CAV1-YAP 的激活以及 YAP 核转位来影响 AFSCs 的分化，纺丝支架弹性模量的升高和直径的增加都可以激活 CAV1/YAP 并且促进 YAP 核转位。

结论：静电纺丝支架的弹性模量及微观结构都可以调节 AFSCs 的分化，两者具有一定的协同作用，并可以通过影响 YAP 的激活以及核转位来影响 AFSCs 的分化，提示其作用机制可能与 CAV1/YAP 相关。

关键字：纤维环源干细胞；力学特征；微观结构；干细胞分化 ; YAP

ID 994

可视化及调控骨损伤部位的 H2O2 促进骨修复

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目的： 骨折后，损伤部位活性氧自由基（ROS）水平升高，抑制骨修复，而增加损伤部位的氧含量会促进骨修复。因此，降低骨折过程中 H_2O_2 含量并同时提高氧含量，是促进骨组织再生的关键。

方法： 首先用探针检测骨损伤部位的 H_2O_2 含量变化，然后利用模板法制备得到空心二氧化锰纳米粒子（hMNP），将 BMP-2 多肽载入 hMNP 中，接着将载有 BMP-2 多肽的 hMNP 加入 GelMA 中，制备 BhMNP/GelMA 水凝胶。通过 TEM 观察 hMNP 的微观形貌；通过体外成骨实验考察水凝胶的成骨性能；将复合水凝胶植入大鼠颅骨损伤部位，考察其体内促骨修复效果。

结果： hMNP/GelMA 水凝胶可显著清除骨损伤部位的 H_2O_2，并可促进细胞增殖。结果提示，hMNP/GelMA 可保护细胞免受 H_2O_2 引起的氧化应激损伤。加载 BMP-2 多肽后，BhMNP/GelMA 水凝胶具有优异的体内外成骨性能。

结论： 骨损伤部位的 H_2O_2 含量显著高于健康组织，hMNP 可响应酸性微环境，分解 H_2O_2 产生 O_2。hMNP/GelMA 水凝胶可有效清除损伤部位的 H_2O_2，为损伤部位提供充足的 O_2，从而改善骨损伤微环境，提高骨修复效果。

关键字： 过氧化氢；水凝胶；骨修复

ID 1005

粘蛋白 - 三斜磷钙石复合材料介导免疫调控促骨再生

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目的： 与传统骨修复材料不同，骨免疫生物材料通过调节宿主的免疫反应，使其更有利于骨愈合，提高治疗效果。粘蛋白是人体固有免疫的组成部分，基于粘蛋白构建的材料可触发非常轻微的补体激活，并抑制巨噬细胞的释放和激活。在本研究中，我们制备了具有免疫调节功能的粘蛋白 - 三斜磷钙石复合材料（Muc-Mon），探讨其在骨愈合过程中的免疫调控作用。

方法： 我们制备了三斜磷钙石多孔颗粒，将其与粘蛋白复合得到 Muc-Mon 水凝胶。采用 SEM 和 XRD 等手段对 Muc-Mon 的形貌、物相进行表征。随后，利用大鼠颅骨缺损模型，我们检测了 1 周和 2 周时巨噬细胞的极化、血管形成以及促炎因子分泌，最后，在 6 周和 12 周时，采用 Micro-CT、组织形态学染色和免疫组化评价骨再生能力。

结果： Muc-Mon 水凝胶具有优异的生物相容性，并且在骨愈合早期，Muc-Mon 能抑制促炎因子的分泌，促进巨噬细胞向 M2 型分化。进一步结果表明，Muc-Mon 能促进骨再生和成熟，表现为新骨体积、骨桥蛋白和 I 型胶原蛋白表达的显著提高以及新生血管形成。

结论： Muc-Mon 具有很好的骨免疫调控和促骨再生功能。基于粘蛋白构建的的生物材料为骨修复材料的开发和设计提供了新的可能。

关键字： 粘蛋白；骨免疫调控；骨再生

ID 1047

水凝胶 / 电纺纤维复合防粘连膜定向递送 siRNA 颗粒预防肌腱粘连

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目的：肌腱粘连目前缺少有效的方法完全避免，本课题通过制备复合防粘连膜定向递送 siRNA 颗粒，抑制肌腱外周成纤维细胞增殖和胶原沉积，防治肌腱粘连并保护肌腱愈合。

方法：将 TGF-β siRNA 与基因载体复合后载入到疾病微环境响应性水凝胶，与静电纺丝纤维膜复合后，植入到损伤肌腱周围，预防粘连。

结果：TGF-β siRNA 转染复合物在成纤维细胞上表现优异的转染效率，负载到水凝胶后在内侧致密纤维膜的阻隔下可单向释放到肌腱外周，抑制肌腱外周胶原分泌和粘连，同时利用微环境中过表达的 MMP 反馈调控 siRNA 复合物的释放，可达到按需治疗效果。然而，肌腱在活动过程中挤压腱周组织，会导致防粘连屏障破损失去屏障功能，且产生的碎片会引发巨噬细胞浸润加重炎症，不利于肌腱粘连防治。利用自愈合的透明质酸水凝胶制备复合防粘连膜，其在肌腱滑动的压力下仍保持其物理屏障的完整性，并降低了局部的炎症反应，同时负载的 siRNA 单向释放定向抑制 TGF-β/Smad 信号通路减少胶原分泌，协同提高了肌腱防粘连效果。

结论：该复合防粘连膜能够利用病理信号的变化，响应性调控 siRNA 定向释放，在抑制粘连的同时不影响内侧肌腱自身愈合。

关键字：防粘连膜，肌腱粘连，siRNA

ID 1048

可分级释药调控炎症微环境的核 - 壳纳米纤维支架的制备及促进纤维环内源性修复的研究

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目的：近年来，组织工程技术的发展为纤维环的修复及再生提供了新的方法。选择何种组织工程支架成为了解决问题的关键。纳米纤维支架是一种较为理想的纤维环修补材料。使用静电纺丝法可构建符合纤维环生物力学与结构特性的纳米纤维支架，充分模拟纤维环的层叠取向结构。核壳纳米纤维支架可进行药物的控制释放。利用此结构实现纤维环结构的充分仿生和布洛芬的早期抗炎以及转化生长因子 β3 的持续促细胞外基质分泌作用，最终实现纤维环的修复。

方法：分别构建了四种负载不同药物的核壳纳米纤维支架。将纤维环细胞（AFC）培养在四种基材上，通过细胞骨架染色和扫描电镜观察细胞的形态特征，WB 及 RT-PCR 检测 Col-I、Col-II、Aggrecan 及相关炎性基因的基因表达情况。

结果：细胞骨架染色和扫描电镜分析结果显示，AFC 在纤维支架上均为取向排列。Western Blot 及 RT-PCR 检测结果表明负载 IBU 的纳米纤维支架具有抗炎作用，负载 TGFβ3 的支架具有促细胞外基质分泌的作用。

结论：载药的取向核壳纳米纤维支架不仅模拟纤维环的生理性层叠结构，具备优异的生物力学强度，还可控制释放促进纤维环修复的生长因子和抗炎药物，调节局部微环境，从而实现纤维环的修复。

关键字：组织工程；纤维环；核壳纳米纤维；控制释放；修复

ID 1056

可注射水凝胶微球促进骨和软骨修复

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目的：细胞移植可促进骨科相关疾病后组织修复，但移植后细胞存活、分化率低，大大降低了治疗效率。水凝胶和植入性支架常作为三维基质用于细胞的移植，但水凝胶缺乏大孔径，不利于营养物质的交换和组织的血管化，限制了细胞的存活；而植入性支架因为其不可注射性，需进行创伤手术进行支架埋置，增加了感染的风险，限制了其在临床上的应用。我们采用微流控技术制备一种载有间充质干细胞的明胶微球，并以其为基础模块构建一种可注射的大孔径水凝胶，促进了骨组织的再生。

方法：采用微流控技术制备一种载有间充质干细胞的明胶微球，并以其为基础模块构建一种可注射的大孔径水凝胶，促进了骨组织的再生。

结果：我们从而制备系列高通量、高性能、高生物适应性的载干细胞的多孔径透明质酸微球，从微观结构和材料性能两方面模拟松质骨、关节、髓核、神经等不同微环境，为细胞的存活、粘附生长、营养传递及细胞间通讯提供更适宜的外界环境，并以此为干细胞和活性因子的运输载体，向不同损伤区域分别局部注射载有干细胞和活性组分的透明质酸微球，研究其对干细胞的存活、分化及组织功能的影响和机制。

结论：该类可注射水凝胶微球将为应用干细胞和活性分子载体对局部组织重建提供新的治疗策略及理论依据。

关键字：微流控技术，微球，骨与软骨修复

ID 1061

调控巨噬细胞在促进小口径工程血管内皮化和抗内膜增生中的作用研究

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目的：早期血栓形成和中远期内膜增生严重是小口径组织工程血管（sdTEVGs<6mm）临床应用的两大瓶颈问题。巨噬细胞（MΦ）被发现是浸润入 sdTEVGs 早中晚期的主要免疫细胞，所引发的急慢性炎症反应是血栓和内膜增生的重要诱因，故我们将 MΦ 作为重要调控靶点进行研究。

方法：首先，通过层层自组装的方式构建了 Netrin-1 修饰的 sdTEVGs，体内外检测 netrin-1 对浸润巨噬细胞表型转化作用。此外，使用逐层静电自组装方法将 H4000-CD25 封装的 dCas9 系统连接到 sdTEVGs 外膜上，并合成了双层包裹 DENND1A 和 netrin-1 的响应型水凝胶并修饰于 sdTEVGs。

结果：netrin-1 可调控 MΦ 由促炎表型向抗炎表型转化，进而及时调控 sdTEVGs 炎症消退促进早期内皮化抑制血栓；基因编辑系统可在体激活 treg 细胞来调控 CCR2- 巨噬细胞表型和数量，后者分泌适量 IL-6 促进了神经轴突生长和髓鞘形成；而双层响应型水凝胶系统可在 30d 后有效诱导神经纤维长入工程血管外膜并促进神经外泌体释放维持血管平滑肌正常收缩表型。

结论：有效干预巨噬细胞可促进工程血管的早期内皮化和抑制中远期内膜增生，维持长期通畅

关键字：巨噬细胞 内皮化 内膜增生 在体基因编辑系统 响应型水凝胶

ID 1105

Construction of Patient-derived Breast Cancer/paracancerous Organoids as A Platform for Personalized Medicine

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Objective: It is hard to predict the clinical outcome of breast cancer (BC) patients because of heterogeneity and variability of prognostic patterns. Therefore, an effective preclinical model for the selection of alternative individualized therapies is urgently needed. Patient-derived BC organoids that retain tumor heterogeneity, have been emerged as a robust tool for drug testing and screening of breast cancer patients. However, drug sensitivity evaluation based on BC organoids effectively determined the cytotoxic effect of chemotherapeutic agents, but failed to provide drug safety information. An equally efficient platform for pharmaceutical safety evaluation is still lacking despite the importance of the drug safety information.

Methods: BC and paracancerous organoids were established and cultured based published protocol with appropriate adjustments. H&E staining, immunofluorescence staining, immunohistochemical staining and transmission electronic microscope were employed for morphological assessment. For identification of genetic characterization of breast cancer and paracancerous organoids, whole genome sequencing and RNA sequencing analysis were conducted. To evaluate the reliability of the in vitro platform for drug and compound screening, their viability under standard therapies were tested.

Results: Here, patient-derived paracancerous organoids was successfully constructed in parallel of BC organoids. The overall success rate of BC/paracancerous organoids was improved adopting optimized constructing protocol. The Results of histopathology staining and comparative genomics approach confirmed the consistency between breast cancer/paracancerous organoids and original tissues. Then paired organoids were utilized as a drug screening platform towards finding alternative breast cancer chemotherapeutics including a traditional Chinese medicine Huaier, with improved safety and efficacy profiles.

Conclusion: We successfully established a technical protocol for constructing patient-derived breast cancer/paracancerous organoids with high efficiency in vitro, and demonstrates the feasibility to simultaneously assess safety and antitumor effects of drugs. Our platform could provide a more comprehensive basis for predicting BC disease outcomes and pathological processes and mechanisms BC.

Key words: breast cancer; organoids; 3D culture; individualized treatment; drug screen

ID 1197

三维有序干细胞凝胶构建及其脊柱脊髓损伤再生修复应用

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目的：脊柱脊髓损伤的治疗是再生医学领域内的重大难点，而重建损伤后脊柱脊髓的三维有序组织结构与细胞种类被认为是实现功能再生的重要途径。基于水凝胶的干细胞疗法已被广泛用于脊柱脊髓的再生修复，但如何调控注射后水凝胶的三维微观定向结构仍面临着巨大挑战。

方法：本项研究期望通过创新干细胞组装手段，构建三维有序干细胞凝胶体系，并研究其在脊柱脊髓损伤再生修复中的功能。首先，我们优化了二维和三维干细胞培养体系下纳米材料与干细胞的相互作用预测模型。然后，通过建

立低维纳米材料组装干细胞的 3D 凝胶，我们以纳米材料为媒介，利用力、电、磁等物理调控手段，促进注射过程中水凝胶结构定向排列，进而调控干细胞的分化及其他功能，从而逐步构建多功能三维有序干细胞凝胶体系。

结果：我们已实现了干细胞定向调控纳米结构的高通量筛选，以及三维体系下纳米材料对干细胞的可控组装，初步构建了干细胞凝胶体系。纳米材料复合凝胶注射到脊髓和脊柱损伤模型后，成功地促进了组织再生和功能恢复。

结论：我们的结果表明，纳米材料可作为物理结构和微环境因子调控的重要媒介来实现三维有序干细胞凝胶的构建，进而促进脊柱脊髓损伤后的组织与功能再生修复。

关键字：干细胞；脊髓损伤；脊柱损伤；纳米技术；水凝胶

ID 1220

钛表面掺铜磷酸钙微 / 纳米仿生纤维涂层制备及免疫调控

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目的：细菌感染与无菌性松动是导致植入物失败的重要因素。鉴于铜离子良好的抗菌、促血管作用以及微纳米结构对免疫细胞的调节作用，有利于增强钛植入体骨整合功能，本研究拟在钛植入体表面构建含铜磷酸钙微 / 纳米仿生纤维涂层，以期增强临床植入体抗感染及骨整合能力。

方法：通过碱热处理和溶剂热沉积两步水热法构建掺铜磷酸钙微纳仿生纤维涂层，采用 SEM、XRD、TEM 和 XPS 等对涂层形貌及成分进行了表征。同时采用平板涂布法进行了抗菌评价，并评估了体外该涂层对炎性行为、成血管及成骨性能影响。

结果：通过碱热处理，成功在钛表面构建多孔钛酸盐纳米线。然后通过溶剂热沉积，在钛酸盐纳米线原位沉积了约 20nm 球状掺铜磷酸钙颗粒。该仿生纤维涂层对金黄色葡萄球菌和大肠杆菌均具有抑制作用。体外实验表明该涂层能够促进血管生成，并增强巨噬细胞的激活，下调炎症反应，促巨噬细胞向 M2 表型极化，有利于增强骨整合。

结论：钛表面掺铜磷酸钙微 / 纳米仿生纤维涂层具有抗菌、协调血管生成和骨免疫调节作用，有望促进骨整合。

关键字：钛表面；掺铜磷酸钙；血管生成；微纳仿生涂层；骨整合；

ID 1251

Coupling of Shear Stress and Stretch in a Biomimetic Liver Regeneration Chip (LRC)

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Objective: Liver regeneration is regulated by blood flow which exerts two major forces, circumferential stretch and shear stress on the liver sinusoidal endothelial cells (LSECs). LSECs transduce the mechanical stimuli into angiocrine secretion to modulate vasculature and promote hepatocyte proliferation. However, the *in vivo* approaches usually undergo varied blood flow without decoupling shear stress and mechanical stretch, and the *in vitro* assays are hard to recapitulate the

physiological structure and only mimic one type of forces. To elucidate the underlying mechanisms that how two types of forces synergistically regulate liver regeneration, we developed a liver regeneration chip to recapitulate the liver sinusoidal structure and its mechanical microenvironment.

Methods: The LRC was fabricated by filling collagen gel into a needle-inserted microfluidic device to create a tubular channel for cell seeding. Primary murine LSECs and hepatocytes were isolated by collagenase perfusion and MACS sorting. LSECs were seeded through the tubular channel while hepatocytes were seeding into a plate form by side. Mechanical forces were applied by a pressure driven pump system. Cells were identified by immunofluorescent staining. Regeneration related cytokines and genes were examined by ELISA and qPCR.

Results: In the LRC, LSECs were able to form a tubular monolayer with intact cell junctions and barrier function. Hepatocytes grew into a confluent monolayer with canaliculi formed between cells. The synergistic mechanical loading was recapitulated by modulating flow rate through the deformable endothelial channel, which was enlarged with increasing flow. Compared with static control, the LSECs in LRC under flow expressed higher genes of secretory factors such as HBEGF to promote hepatocytes proliferation.

Conclusion: Thus, this work demonstrated that the LRC not only recapitulate liver sinusoid structurally and functionally, but also revealed the synergy of shear stress and mechanical stretch.

This work was supported by National Natural Science Foundation of China grant 32130061.

Key words: microfluidic, liver regeneration, flow, LSEC

ID 1269

基于动态培养体系诱导人胚胎干细胞向巨核系细胞分化

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目的：利用多能干细胞诱导制备巨核细胞及血小板是解决临床血小板制品供应不足的新策略。然而，建立扩展性良好的体外规模化培养系统，实现巨核细胞高效制备是一个巨大挑战。本研究拟基于三维动态培养模式构建人胚胎干细胞（hESCs）向巨核细胞高效分化的培养体系。

方法：通过筛选培养装置和培养参数建立优化的巨核细胞分化体系，开展细胞表型及功能评价以明确分化细胞的生物学特征及产板能力，结合高通量测序技术及分子生物学实验研究动态培养模式调控巨核细胞分化命运选择的分子机制。

结果：本研究基于折流瓶动态培养装置构建了一套 hESCs 向巨核细胞分阶段诱导分化的体系。分化细胞具有典型的巨核形态特征及分子表型，能够在特定培养条件下分化成熟并产生功能性血小板。我们发现特定的动态培养模式能够显著加快 hESCs 早期造血分化命运的启动并促进巨核细胞分化偏向性。对分子机制研究表明，动态培养模式能够显著提高培养基内溶氧量，增强分化细胞的线粒体功能，并通过氧化磷酸化途径产生 ATP 用于支持 hESCs 形成向巨核细胞分化的倾向性。

结论：本研究将有助于开发利用生物反应器体外规模化制备人多能干细胞来源的功能血细胞制品，并为其应用于临床细胞治疗提供技术基础。

关键字：人胚胎干细胞，巨核系细胞，动态培养体系，定向分化，线粒体

ID 1270

Biofabrication of Highly Active Tissue-Engineered Cartilage Constructs Through Faraday Wave Bioassembly of Cell-laden Gelatin Microcarriers

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Objective: Faraday wave bioassembly, as an emerging bottom-up method for constructing tissue-engineered constructs, has been applied to fabricate cell-rich tissue analogues such as heart and liver tissues in vitro by bioassembly of sphereoids. However, sphereoid-based bioassembly is not suitable for the construction of cartilage tissue because it has a low cell density and abundant extracellular matrix. Herein, tissue-engineered cartilage constructs were biofabricated through Faraday wave bioassembly of cell-laden gelatin microcarriers, which recapitulated the structural features of cartilage tissue, i.e., adequate extracellular matrix surrounding chondrocytes.

Methods: Two different assembly modules were first prepared by incorporating BMSCs and ATDC5 into gelatin microcarriers, respectively. The superior biocompatibility and porous microstructure of gelatin microspheres were conducive to cell adhesion, proliferation and migration. Patterned structures were then formed by Faraday wave bioassembly of the cell-laden microcarrier modules. And the tissue-engineered cartilage constructs were subsequently obtained from the patterned strcutures by induction differentiation culture for 28 days.

Results: Due to the mild noncontact assembly process and the protective and supportive effects of microcarriers, cells in the patterned structures maintained high activity and proliferation rates. The cellular morphological changes and cartilage-specific gene expression implied the chondrocyte differentiation, which was also coincided with the decreased gene expression responsible for cell–cell connections in BMSCs. Furthermore, section-staining analysis demonstrated that abundant cartilage matrix components were deposited, which together with the good cartilage phenotypes at the cellular level indicated that highly active cartilage tissue constructs were obtained. Finally, implantation studies with a rat cartilage defect model proved that these highly active tissue-engineered cartilage constructs were beneficial for promoting the repair of cartilage damage in vivo.

Conclusion: In conclusion, it provides an effective strategy based on Faraday wave bioassembly for fabrication of highly active tissue engineered cartilage constructs, which may act as potent implants for cartilage replacement and repairing.

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Key words: acoustic manufacturing, bioassembly, Faraday wave, microcarrier, tissue-engineered cartilage

ID 1306

Embryonic Stem Cells-derived Extracellular Vesicles Rejuvenate Senescent Cells and Antagonize Aging in Mice

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Objective: Aging is a degenerative process that leads to tissue dysfunction and death. Embryonic stem cells (ESCs) have great therapeutic potential for aging-related diseases with the ability of self-renew and plasticity. However, the application of ESCs in clinical treatment is limited due to immune rejection, tumorigenicity and ethics issues. Extracellular vesicles (EVs) derived from ESCs may deliver therapeutic effects that are comparable to ESCs and avoid unwanted effects. Here, we completely evaluate the role of ESC-EVs in rejuvenation.

Methods: Firstly, EVs were isolated from ESCs to treat aged-MEF cells (mice embryonic fibroblast cells), the anti-aging effects were evaluated by RNA-seq. Then we use microRNAs-seq to identify the factors enriched in ESC-EVs. We found that miR-15b-5p and miR-290a-5p, the most enriched microRNAs in ESC-EVs, are potent rejuvenate factors of aging. Then, we identified Ccn2 as the downstream target of miR-15b-5p and miR-290a-5p by dual-luciferase reporter system and RNA interference. Finally, we injected ESC-EVs into aging mice (18 months) to evaluate the anti-aging effect of ESC-EVs in vivo.

Results: We found that ESC-EVs effectively rejuvenated the aged phenotype in vitro. Mechanistically, we identify miR-15b-5p and miR-290a-5p strongly enriched in ESC-EVs as potent anti-senescence regulators. ESC-EVs rejuvenate senescence partly by transferring these miRNAs to senescence cells and then silencing of the Ccn2-mediated AKT/mTOR signaling pathway. We found that ESC-EVs efficiently antagonize mice aging in vivo. The Results showed that ESC-EVs successfully ameliorated the pathological age-related phenotypes and rescued the transcriptome profile of aged mice.

Conclusion: Our finding shows that ESC-EVs treatment could rejuvenate senescence both in vitro and in vivo and suggests the therapeutic potential of ESC-EVs as a novel cell-free alternative to ESCs for aging-related diseases.

Key words: Embryonic stem cell (ESC); Extracellular vesicles (EVs); Cellular senescence

ID 1371

多功能磷酸氢铜纳米酶用于难愈合创面修复的研究

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目的：细菌感染、糖尿病等多种原因都有可能导致皮肤创面长时间无法愈合，甚至会引起截肢、器官坏死等严重不良事件。因此，迫切需要开发一种兼具高效抗菌活性和促伤口愈合生物活性的新型治疗策略。

方法：采用简单的一步沉淀法结合超声机械剥离获得多功能磷酸氢铜纳米酶，并将其作为活性组成与临床广泛使用的海藻酸水凝胶复合用于感染性创面和糖尿病创面的治疗。

结果：磷酸氢铜纳米酶呈片状结构，具有优异的近红外光热转换性能、类过氧化物酶 / 类过氧化氢酶催化活性、以及持续的铜离子释放能力。以其为核心的复合水凝胶表现出高效的抗菌性能和优异的成血管活性。控制光照产生 40° C 左右温热能够进一步提高材料的生物活性，增强了材料对感染伤口和糖尿病伤口的治疗效果。

结论：新合成的磷酸氢铜纳米酶具有多种功能，且相互结合能够产生高效的抗菌和促伤口愈合活性，该研究为难愈合创伤修复材料的设计提供了新思路。

关键字：纳米酶、光热、生物活性、难愈合创面

ID 1484

基于丝素蛋白的有机 / 无机杂化水凝胶在慢性伤口中的应用

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目的：慢性伤口无法通过正常有序修复过程实现有效的愈合，已成为临床治疗的巨大挑战。感染，低氧，炎症等因素形成的复杂微环境是慢性伤口难以修复的原因。目前，慢性伤口的常规处理包括伤口敷料、抗生素治疗和氧疗。然而，由于复杂的伤口微环境，单一的治疗效果往往有限，迫切需要开发新型的、多功能的伤口敷料。

方法：本研究针对慢性伤口不同的护理需求，开发了一系列具有抗感染、持续性供氧、免疫调节和促伤口愈合等功能的新型有机 - 无机杂化水凝胶敷料。我们将无机金属镓离子掺入到丝素蛋白网络中，以血红蛋白为交联剂，制备具有抗感染、缓解低氧功能双交联的杂化水凝胶体系。此外，我们通过锌离子与甘草酸配位，并与光交联的丝素蛋白结合制备具有内源性免疫调节功能的双网络杂化水凝胶体系。

结果：对水凝胶的理化特征进行了一系列的表征，并对其抗菌性能、缓解低氧和免疫调节性能进行了研究，证明这些新型的丝素有机 - 无机杂化水凝胶作为伤口敷料的多种功能。

结论：基于丝素蛋白的有机 - 无机杂化水凝胶结合了无机金属强大的性能与有机蛋白的修复优势，作为慢性伤口或者其他细菌感染伤口敷料，具有巨大的应用潜能。

关键字：慢性伤口修复，有机 - 无机杂化，丝素蛋白，水凝胶

ID 1505

一种抗炎、抗氧化、促血管化的多酚修饰的脱细胞基质材料用于创面修复的实验研究

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目的：脱细胞猪小肠黏膜下层（Small Intestinal Submucosa, SIS）具有良好的组织修复能力，但存在免疫调节和抗氧化应激能力不强的问题。本研究采用具有抗菌、抗炎和抗氧化性能的表没食子儿茶素没食子酸酯（Epigallocatechin gallate, EGCG）多酚材料对 SIS 进行修饰，以期达到抗炎、调节创面微环境、促进胶原沉积、促血管化、加速创面再生修复的效果；并用巨噬细胞清除模型，进一步加以验证。

方法：采用一步法制备 E-SIS 材料。体外采用材料表征方式、细胞学及分子生物学方法等评价 E-SIS 的理化性质、生物相容性及生理学功能；体内构建大鼠巨噬细胞清除模型和全层皮肤缺损模型来评价 E-SIS 的修复效果。

结果：体外实验结果表明 E-SIS 具有良好的生物相容性，能有效降低细胞内氧化应激水平和炎性因子的表达，能

诱导巨噬细胞向 M2 型极化并具有良好的促血管生成和胶原合成能力；体内实验证实 E-SIS 可改善创面微环境，促进血管生成，增强胶原合成能力，从而加速皮肤修复与再生。

结论： EGCG 修饰 SIS 赋予其抗氧化、免疫调节功能，通过改善局部免疫微环境有效加速创面愈合，是极富潜力的改性方式。

关键字： EGCG、猪小肠黏膜下层、免疫调节、创面修复

ID 1586

掺杂矿化胶原的可降解丝素支架诱导大鼠颅骨缺损骨再生

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目的： 可降解生物材料降解产生的空腔可被新骨组织爬行取代，这反过来促进了骨缺损的快速修复。在本研究中，我们结合了矿化胶原蛋白（MC）和丝素蛋白（SF）两种材料的优点，通过特定的结构设计，构建了具有双组分 SF-MC 系统的三维多孔仿生复合支架，并评价了其在促进骨再生方面的优势。

方法： 采用 SEM,TEM 和 FTIR 等技术对复合支架的性能进行了分析。借助 CCK8 和 RT-qPCR 技术对支架的体外细胞生物相容性进行评估。借助大鼠颅骨缺损模型的复合支架原位植入实验，通过 OCTA，Micro-CT，组织学染色和免疫组织化学染色技术评估复合支架在促进骨再生和血管再生方面的特点。

结果： MC 的球形矿物团聚体均匀分布在 SF 骨架的表面和内部，在调节支架降解速率的同时，确保了良好的力学特性。SF-MC 支架对 BMSCs 和 MC3T3-E1 具有良好的成骨诱导作用，并促进了 MC3T3-E2 细胞的增殖。体内颅骨缺损修复实验证实，与 SF-C 支架相比，SF-MC 支架刺激血管再生，并通过原位再生促进体内新骨再生。

结论： 我们认为这种低成本的 3D 多孔仿生复合支架有望用于临床转化，我们希望这种基于 SF 和 MC 的复合支架设计将为骨组织工程领域的学者提供更多启示。

关键字： 可生物降解材料，丝素蛋白，矿化胶原，骨再生，颅骨缺损

ID 1605

CGRP 受体介导的信号通路激活骨和神经再生促进肌腱 - 骨愈合

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目的： 血管生成和神经支配有促进骨微环境骨再生的能力。前期成果证实 CGRP 可诱骨生成，但其半衰期短。因此，本研究应用基因调控来调节 CGRP 可能信号轴，并基于骨改建过程分泌因子与 H 型血管和神经轴突的密切关联，提出假说：CGRP 介导的信号轴可能调控神经支配与 H 型血管形成来促进腱骨界面（TBI）愈合。

方法： 首先，以含不同组分的成骨诱导培养基对 BMSC 培养后，进行 qRT-PCR 与 WB 检测。其次，对小鼠进行 ACL 重建，并分别注射 PBS，Adv-shCalcrl 以及 Adv-Calcrl，对步态，力学，TBI 组织学，影像学及神经轴突及 H 型血管分布等进行比较。

结果： 经 CGRP 处理的细胞 p-CREB 水平和 PKA 水平显著提高，成骨分化程度更高，且能抑制 H-89 引起的 Shh，JunB 水平下调。过表达组显著促进 TBI 愈合，并伴随神经纤维、Shh 和 H 型血管数量增加。与 Adv-shCalcrl 组相比，Adv-Calcrl 组最大失效载荷以及松弛位移显著改善，步长、脚印面积显著提高，且骨量显著增加。

结论： CGRP 介导的信号轴 PKA/CREB/JunB 的激活能增强 TBI 愈合，且与 H 型血管和神经轴突形成呈高度正相关，有望成为新的治疗策略。

关键字： 前交叉韧带重建；腱骨愈合；降钙素基因相关肽；水凝胶微球；基因治疗

1653

快速自组装构建具有体内功能的生物人工肝

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目的： 构建生物人工肝受制于两个难点：一方面难以获得足够数量、安全可靠的功能肝细胞；另一方面缺少快速成型的构建方法。生物 3D 打印肝脏虽然可以实现快速成型，但仍需在体外培养 1 周以上来重建细胞间的紧密连接和功能化。本研究希望通过突破原代肝细胞的体外规模化扩增培养技术和细胞快速自组装技术，快速构建生物人工肝脏，并实现其体内功能。

方法： 通过小分子和信号通路筛选，实现原代肝细胞的体外连续扩增培养。通过模拟凝血过程，由纤维蛋白原引导肝细胞快速自组装形成具有细胞间紧密连接的生物人工肝。24 小时后，将形成的生物人工肝通过肠系膜移植到小鼠腹腔。30 天后，对小鼠进行 90% 肝切，评估自组装形成的生物人工肝的体内肝功能。

结果： 本研究建立的原代肝细胞体外扩增培养体系实现了大于 30 代的连续扩增培养。体外扩增的肝细胞可在 12 小时内快速自组装构建具有细胞间紧密连接、具有分泌白蛋白、储存糖原等肝功能的生物人工肝。将其移植到小鼠体内 10 天后形成血管网络。30 天后对移植小鼠进行 90% 肝切除，生物人工肝可显著提高肝切除小鼠存活率和肝功能。

结论： 我们建立了一种快速自组装构建生物人工肝的方法，并实现了生物人工肝的体内移植治疗急性肝损伤小鼠。

关键字： 生物人工肝；自组装；肝实质细胞；肝脏移植；急性肝损伤

ID 1687

双因子时序递送的聚醚酮酮基复合支架用于骨组织修复

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目的： 骨愈合过程与炎症反应高度相关。骨修复由促炎反应开始，巨噬细胞的前期募集和顺序极化对骨愈合过程至关重要。本研究基于聚醚酮酮支架，负载单核细胞趋化蛋白（MCP-1）和具有免疫调节作用的锶、铈离子，探索趋化因子和功能性离子的时序递送对骨组织的修复效果。

方法： 采用熔融沉积成型技术制备聚醚酮酮 / 锶铈生物玻璃复合支架，并填充含 MCP-1 的晶胶。通过 Micro-CT、ELISA、趋化实验、流式细胞术和细胞增殖分化实验等来研究支架的结构、释放行为、对巨噬细胞的调控作用和对干细胞的诱导分化作用。

结果：复合支架具有相互连通的多孔结构。体外释放实验显示，MCP-1 在前 4 小时的释放量（250.97ng）约占总释放量（255.29ng）的 98.31%。与空白组相比，巨噬细胞的募集数量增加了约 4 倍。流式细胞术结果表明，支架能促进巨噬细胞由 M1 向 M2 极化。此外，间充质干细胞在支架上的粘附效果良好，增殖和成骨分化效果明显。

结论：本研究制备了一种填充晶胶的聚醚酮酮 / 生物玻璃复合支架，实现了趋化因子和功能性离子的时序递送。支架能够原位募集巨噬细胞，并诱导其向 M2 极化，加速炎症反应进程，同时有利于间充质干细胞的成骨分化，有望促进骨愈合。

关键字：聚醚酮酮；趋化因子；生物活性玻璃；原位募集；巨噬细胞极化

ID 1697

CD73+ Human Adipose Mesenchymal Stem Cells Promote Angiogenesis by Regulating HIF-1α/VEGFA Expression through the PI3K/Akt Signaling Pathway in Diabetic pressure sore mice

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Objective: Diabetic wound healing has become an urgent challenge. Stem cell therapy offers new hope for improving impaired wound healing in diabetes. The purpose of this study was to explore the effect of adipose tissue derived mesenchymal stem cells (ADMSCs) on wound healing in diabetic pressure sore mice.

Methods: A mice model was prepared by magnetic disc compression method. hADMSCs and CD73siRNA hADMSCs were injected intra-dermally around the wounds of treatment group. PBS was applied to vehicle group as control. The wound healing rate was measured every other day after transplantation. Scratch wound healing assay was used to evaluate the ability of cellular products to support angiogenesis in vitro. The expression of HIF-1α, PI3K,Akt and VEGFA in hADMSCs was observed to explore the molecular mechanism of CD73 promoting wound healing in diabetic pressure sore mice.

Results: hADMSCs could accelerate wound healing, and the mechanism was related to the promotion of angiogenesis by high expression of CD73. CD73 was involved in the regulation of VEGFA expression induced by hypoxia through HIF-1α-dependent way. The activation of PI3K/Akt pathway was regulated by CD73 expression to accelerate wound healing rate in diabetic pressure mice.

Conclusion: CD73+ADMSCs promote angiogenesis by regulating HIF-1α/VEGFA expression through the PI3K/Akt signaling pathway in diabetic pressure sore mice.

Key words: CD73，ADMSCs，HIF-1α，VEGFA

ID 1712

制备一种新型人源 II 型胶原 - 胶原纳米羟基磷灰石（Col II- Col II & nHA）双层复合支架用于软骨及软骨下骨缺损修复

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目的：关节软骨是滑膜关节中一种特殊类型的透明软骨，其表面光滑具有优良的抗压及抗磨损属性，是人体关节重要的负重组织。关节软骨由于缺乏血供，一旦损伤难以自愈，至今仍无有效根治软骨损伤的策略。因此，我们通过模拟其成分来修复关节软骨及软骨下骨缺损。

方法：基于这一目标，本研究重组表达了人源 II 型胶原蛋白，以此为来源组装了 Col II- Col II & nHA 双层复合支架，模拟仿生软骨 - 软骨下骨结构。

结果：细胞水平评价结果显示 Col II- Col II & nHA 双层复合支架上层能有效的促进骨髓间充质干细胞（BMSCs）向软骨细胞分化和软骨细胞表型的维持，下层能促进 BMSCs 向成骨细胞分化。动物实验结果显示，双层复合支架组与单层支架组和空白对照组相比，能观察到连续光滑的新生软骨形成。此外，还评估了新生软骨的压缩特性和糖胺聚糖（GAG）含量，总分级量表表明，双层复合支架组的平均得分显著高于单层支架组。

结论：综上所述，Col II- Col II & nHA 双层复合支架可以通过促进 BMSCs 的成软骨分化和成骨分化来有效地修复关节软骨及软骨下骨缺损，有望成为彻底恢复关节功能的新型软骨组织工程材料。

关键字：双层复合支架；重组 II 型胶原；纳米羟基磷灰石；软骨及软骨下骨修复；关节软骨；

ID 1912

聚合物纤维增强型生物管 - 自体组织工程血管

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目的：依靠机体对异物的包裹反应（FBR）制备的生物管具有良好的血管重塑潜能。然而，其常因力学性能不足而移植失败。本研究发展了一种具有良好力学性能和血管再生活性的聚合物纤维增强型生物管（PB）。

方法：制备聚己内酯纤维骨架（PS）。将 PS 植入皮下，利用机体的 FBR 制备 PB。通过爆破压、缝合强度以及大鼠腹主动脉移植评估 PB 的力学特性和血管再生。通过犬颈动脉移植和羊动静脉造瘘评估 PB 的临床应用潜能。

结果：PB 具有良好的力学特性，其爆破压、缝合强度均能满足血管移植要求。在大鼠腹主动脉（口径 2mm，长 1.1cm）植入中，PB 展现出了优异的通畅性（100%）和拟天然再生。在一年的犬颈动脉（口径 3mm，长 3.5cm）植入中，PB 展现出了良好的力学性能，优异的通畅性（100%），并且无膨胀、动脉瘤、血栓、内膜增生、钙化和感染等不良现象，血管内皮、平滑肌和细胞外基质实现了拟天然再生和重塑，具备了类似于天然动脉的顺应性和生理活性。在羊动静脉造瘘（口径 5mm，长约 16cm）中，PB 可即可穿刺，能够快速止血。

结论：PB 能够在动物皮下成功制备，并在大鼠、犬和羊自体血管移植中，表现出了优异的通畅性和血管再生性能，展现了很强的临床转化潜能。

关键字：组织工程血管；生物管；血管移植物；动静脉造瘘；血管再生

ID 1915

化学诱导肌肉组织修复与再生

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目的：急性创伤和遗传性疾病会导致肌肉的再生修复能力下降或者完全丧失。近年来，干细胞技术为衰老或DMD 等肌肉疾病的治疗带来了巨大希望，但仍然面临一个重大的挑战是难以实现肌肉干细胞的分离、体外培养和大量扩增，从而导致肌肉干细胞的供应不足，严重限制了干细胞疗法的临床应用。

方法：研究通过筛选大量的小分子药物，发现两个特异的小分子药物可高效诱导扩增皮肤及肌肉组织来源的肌肉干细胞。研究进一步采用心肌毒素损伤的小鼠的胫骨前肌为模型，开展了诱导干细胞治疗和载药递送治疗病损肌肉的体内实验。

结果：当把体外小分子诱导扩增的肌肉干细胞注射到损伤肌肉一个月后，移植的干细胞可以生成新的肌肉纤维，并成功融合到损伤肌肉中，显著地促进肌肉的功能性修复。研究也发现载药颗粒可显著地刺激组织驻留的原位肌肉干细胞的扩增，从而成功地实现了成年小鼠和老年小鼠肌肉的原位再生修复。

结论：该研究发现了一组化学小分子药物可高效诱导扩增体内 / 原位肌肉干细胞，成功促进了老龄化和杜氏肌肉营养不良型病损肌肉组织的修复效果，有望为肌肉疾病的临床治疗提供新的方法和策略。

关键字：肌肉干细胞，小分子化合物，肌肉组织修复与再生

ID 2071

通过调控神经生长促进血管稳态逐层构建小口径工程血管

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目的：据 WHO 最新统计，全球心血管疾病的发病率和死亡率逐年攀升。随着中国老龄化进程加快，心血管疾病也成为老龄社会的高发病。然而小口径血管移植物至今没有替代物。原因是移植后极易发生失稳态导致移植失败。我们先前的研究发现神经的长入与血管稳态维持息息相关，促进神经再生可能是维持小口径组织工程血管稳态，维持长期通畅的新策略。

方法：

1）通过 CRIPR/dCas9 在体靶向重编程的小口径组织工程血管。在体靶向活化 Tregs 促进神经重建，调控平滑肌重建。

2) 构建 DENND1A 与 Netrin-1 复合修饰的程血管通过诱导神经长入工程血管，促进神经调控平滑肌生理功能。

结果：

CD4+CD25+Tregs 在体靶向活化，促进神经重建，调控平滑肌正常重建。

DENND1A 与 Netrin-1 复合修饰诱导神经长入工程血管，促进神经突触分泌外泌体调控工程血管平滑肌正常功能。

结论：

针对小口径工程血管失稳态现象，通过激活 Treg 细胞亚群，抑制过度免疫排斥，促进工程血管神经重建，调控平滑肌功能，提出促进神经突触释放外泌体抑制高糖诱导的小口径组织工程血管钙化、保持长期通畅的新策略。

关键字：组织工程血管；免疫调控；神经再生

ID 2133

一种基于锌 / 铜掺杂介孔二氧化硅 / 槲皮素复合微针贴片的雄激素脱发联合疗法

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目的：雄激素脱发（AGA）是最常见的脱发原因之一，严重影响着患者的身心健康。目前，临床上的药物往往是以缓解症状为主，且伴随副作用，急需开发药效佳且副作用小的新型毛发再生策略。

方法：使用溶胶 - 凝胶法制备锌 / 铜双掺杂介孔二氧化硅纳米微球，并以聚二甲基硅氧烷（PDMS）为模板制备所需的复合微针贴片（ZCQ/MN）。通过 AGA 小鼠模型验证了复合微针贴片促进脱发区域毛囊再生的生物活性。

结果：所制备的 ZCQ/MN 成阵列排布，单个微针的高度为 600μm，与皮肤真皮层厚度相近。因此，复合微针贴片可以顺利刺入小鼠皮下，并逐渐溶解，释放 ZCQ 纳米微球。ZCQ 纳米微球可以在皮下长期释放锌离子、铜离子与槲皮素，协同促进 AGA 小鼠脱发区域毛囊再生。

结论：本研究，设计了一种含有锌 / 铜双离子与槲皮素的复合微针贴片。该复合微针贴片可以有效治疗 AGA 小鼠模型，而锌离子、铜离子与槲皮素产生的协同作用是材料促进毛囊毛发生长的关键。

关键字：雄激素脱发、微针、铜 - 锌掺杂介孔二氧化硅、槲皮素、毛囊再生

ID 2218

适用于 ACL 重建的新型可降解镁界面螺钉的研发

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目的：腱骨界面（TBI）组织结构复杂且异质性高，而现有界面螺钉因生物惰性或诱发炎症，是引起患者手术翻修的关键原因。报道显示 H 型血管和神经支配对重构骨微环境再生极为重要，且课题组前期已证实 CGRP 与诱导 H 型血管和神经轴突再生呈正相关，同时也发现镁能刺激 CGRP 分泌，故提出假说：可降解镁界面螺钉或通过介导 TBI 界面神经支配和 H 型血管形成促进其愈合。

方法：因镁力学强度较低，故首先借助有限元模拟（FEA）和实际测试优化了该器械结构设计，以满足临床需要；其次，建立了小鼠和兔等动物 ACL 重建模型（对照组：聚乳酸和聚醚醚酮钉），基于步态行为学、影像学、组织学和生物力学等评估镁界面螺钉对 TBI 愈合的影响，并验证假说。最后，建立山羊模型，评估临床应用前景。

结果：FEA 和实测结果均证实了新型结构力学扭矩性能的优异性，比传统结构提升近 3 倍。此外，兔和山羊动物模型数据显示：相比于现有植入器械，该镁界面螺钉显著性加速促进肌腱的骨融合，改善步态行为。基于小鼠模型结果：镁离子干预 TBI 愈合途径或与神经支配和 H 型血管形成有关。

结论：镁界面螺钉因在 TBI 修复过程中展现出来的出色生物活性功能，有望成为新一代肌腱移植物固定器械应用于 ACL 重建。

关键字：ACL 重建；镁界面螺钉；结构设计；力学性能；腱骨愈合

ID 2297

GDF-5 修饰磁性磷酸钙微载体促进成骨前体细胞生长研究

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目的：磷酸钙（CaP）作为人体硬组织的主要无机成分，因其良好的生物相容性和生物活性而被广泛应用于骨缺损修复。生长分化因子 -5（GDF-5）作为骨形态发生蛋白的一员，在软骨及骨组织修复领域表现出良好的应用潜力。为了实现骨组织周围生长因子的有效释放，促进骨再生。本文利用双磷酸盐修饰 GDF-5 沉积于磁性磷酸钙表面并探讨其对细胞生长的影响。

方法：首先，利用水热法制备了具有纳米结构表面的磁性磷酸钙微球，并将 GDF-5/ 双磷酸盐复合物靶向沉积在磁性磷酸钙表面。然后，将磁性磷酸钙作为微载体与成骨前体细胞共培养。应用 XRD、SEM、TEM 观察颗粒形态，使用 XPS、FTIR 进行元素成分分析。利用 CCK-8 检测细胞增殖，利用染色检测细胞碱性磷酸酶分泌及钙结节沉积情况。同时，利用 PCR 检测细胞成骨相关基因表达情况，进而评估微载体对细胞生长的影响。

结果：制备的磁性磷酸钙为具有纳米结构的微球，直径 ~5 μm，具有顺磁性；双磷酸盐修饰的 GDF-5 与磁性磷酸钙结合率提升，有利于实现在体内的靶向沉积及有效释放。同时，GDF-5 修饰的磁性磷酸钙微载体有利于细胞的快速增殖及成骨分化。

结论：携载 GDF-5 的磁性磷酸钙有望成为理想的骨修复微载体。

关键字：磁性磷酸钙；GDF-5 ； 双磷酸盐；成骨分化

ID 2325

电刺激生物材料与组织再生

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目的：包括皮肤、神经和骨骼等在内的组织缺损是临床常见疾病，对其治疗新方法的探索具有重要意义。经皮电刺激可有效调节组织愈合过程，已被用于临床治疗。但经皮途径限制了对深层组织的刺激效率，制约了其疗效。突破传统经皮途径，探索电刺激生物材料促进组织损伤再生的新策略已成为生物医学领域亟待解决的难题之一。

方法：发展了纳米发电机与生物材料结合的思路，获得了多个具电刺激作用的新型组织再生调控用智能器件 / 系统。通过理化表征、细胞 / 分子实验和动物实验，系统研究了这类新型电刺激生物材料器件 / 系统的体外及体内修复皮肤、神经和骨的性能，并探索了其分子作用机制。

结果：体外和体内实验结果表明新型电刺激生物材料器件 / 系统可有效促进皮肤、神经和骨的再生。电刺激过程可通过影响缺损部位的再生微环境，包括调节免疫环境、促进血管化及干细胞功能性分化，达到促进缺损组织再生的目的。在具体机制上，该器件 / 系统调控不同组织再生的分子机制上存在差异，均涉及到多个信号通路的交互作用。

结论：针对新型电刺激材料系统构建方法的探索及其作用机制的研究，不仅有望为组织再生用生材料的构建提供新思路，而且为皮肤、神经和骨骼等组织损伤的临床治疗提供了新策略。

关键字：生物材料、组织再生、电刺激、纳米发电机

ID 2528

VEGF modRNA 结合 hiPSC-CPCs 改善大鼠急性心梗的研究

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目的： 制备 VEGF modRNA 转染 hiPSC-CPCs，在体外评估其促血管生成能力的基础上，移植到大鼠急性梗死的心肌中，以促进移植细胞的存活及心肌分化整合。

方法： 体外诱导 hiPSCs 分化为 CPCs 及 CMs，分析其形态结构及分化效率。利用 modRNA 转染 hiPSC-CPCs 评价其转染效率及蛋白表达水平。利用 VEGF modRNA 转染 hiPSC-CPCs，测定 VEGF 的分泌动力学，评估其体外促血管生成的能力后，注射治疗大鼠 MI，通过心脏彩超、组织形态学染色、免疫荧光染色通评估疗效。

结果： 体外诱导可以高效获得大量的 hiPSC-CPCs，modRNA 可以安全高效地转染 hiPSC-CPCs 并表达目的蛋白；VEGF modRAN 转染 hiPSC-CPCs 后体外促血管生成效果明显，体内移植显著提高心功能；减轻心肌纤维化，维持心室壁的厚度；提高移植细胞存活率；分化成熟为心肌细胞。

结论： VEGF modRNA 转染的 hiPSC-CPCs 体内移植后可以显著提高心梗区域移植细胞的存活率，改善心功能，促进心梗后的心肌修复。

关键字： 细胞移植；心脏再生；hiPSC-CPCs；VEGF modRNA；心肌梗死

ID 2550

3D 打印定制关键生物材料基因用于骨再生研究

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目的： 再生医学的快速发展为疾病个性化治疗带来了新的机遇。目前关键材料因素，如材料类别、结构和性能的选择和筛选效率相对较低。筛选过程需要大量的材料、人力、时间和金钱。骨再生的关键材料因素集中于材料的组成、结构、表面形态、添加剂等。本研究通过 3D 打印技术实现生物材料基因组学的设计和筛选，该技术对于骨组织工程支架实现骨诱导和骨传导至关重要。

方法： 我们提供了一种通过数字光投影制造的骨再生测试芯片，用于高通量筛选用于骨再生的生物材料基因组学。骨测试芯片包含形成两个通道的各种测试单元：一个用于筛选骨传导生物功能，另一个用于筛查骨诱导。它有效地实现了再生医学中特定生物功能的高通量筛选。

结果： 成功地制备了复杂的个性化骨修复多孔结构材料，骨测试芯片包含八个测试单元，它们形成两个通道：一个用于测试骨传导，另一个用于检测骨诱导。这些测试单元可以通过类似的榫卯结构制造和成形，最后使用骨测试芯片发现 400μm 的孔最有利于异位成骨。结果表明该高通量骨测试芯片可以加速骨修复材料的开发。

结论： DLP 技术的工艺精度促进了骨测试芯片的制造水平。随着未来 3D 打印成形技术的发展，骨测试芯片将在骨修复材料筛选中具有重要的意义。

关键字： 3D 打印，骨修复支架，组织再生，材料基因

ID 2562

新型负载亚精胺的双动态交联粘弹性水凝胶促牙周膜再生修复的研究

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目的：牙周膜再生是牙周炎治疗的主要障碍，植入抗炎水凝胶是促进牙周膜再生的一种有前景的治疗方法。牙周膜具有典型的粘弹性，但该特征在牙周膜再生修复中的作用有待进一步探索。

方法：利用酰胺化反应合成苯硼酸修饰的海藻酸，通过硼酸酯键和 B-N 配位键与抗炎剂亚精胺结合，开发一种新型亚精胺交联粘弹性水凝胶，使用流变仪表征水凝胶的刚度、粘弹性、可注射性和自愈合性，使用高效液相色谱法测量亚精胺的缓释水平；使用水凝胶二维和三维培养牙周膜细胞评价生物相容性；ELISA 法检测水凝胶的抗炎能力；将水凝胶应用于牙周炎大鼠牙周缺损区域，马松染色观察胶原纤维产生情况，用 HE 染色评估胶原纤维分布方向。

结果：成功合成了 Alg-PBA/Spd 水凝胶；水凝胶刚度约 1kPa，半应力松弛时间 <50s ；水凝胶具备良好的可注射性、自愈合性、粘附性；水凝胶可降解并持续缓释亚精胺达 5 天；牙周膜细胞二维培养存活率 >90%，三维培养存活率 >70% ；水凝胶可以降低牙周膜细胞炎症水平；体内实验证明水凝胶能减少牙周组织炎症，并促进牙周膜胶原的沉积与纤维有序再生。

结论：粘弹性 Alg-PBA/Spd 水凝胶是一种具有良好的促牙周再生修复能力的力化耦合仿生修复材料。

关键字：牙周再生，粘弹性水凝胶，机械 - 生化协同治疗，力学微环境

ID 2778

基于神经因子的原位细胞培养促进骨缺损再生的研究

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目的：大尺寸的骨缺损通常会导致骨组织非均质性愈合甚至是不愈合，其治疗仍然存在组织功能恢复和结构重建的挑战。

方法：通过负载神经因子的 3D 打印水凝胶微球原位细胞培养系统局部移植，探究其促进大尺寸骨缺损的修复再生。

结果：基于 DLP 技术 3D 打印构建的负载干细胞的水凝胶微球单元，在体外软骨分化诱导条件下进一步组装为”骨痂样“微组织，并表现出与发育时期骨骼高度相似的转录组特征，以及细胞增殖和分化的同步活跃状态。神经肽能协同提高 BMP-2 在体外促进骨髓间充质干细胞的成骨分化能力。基于 3D 打印的神经肽、BMP-2 进一步构建微骨组织，发现其原位移植能实现有效的体内大尺寸骨缺损的再生。

结论：基于 3D 打印负载干细胞和神经肽可控释放的生物活性单元构建微骨组织，能实现有效的体内骨缺损再生。

关键字：3D 打印；微骨组织；骨缺损再生

ID 2896

The Semi-interpenetrating Network Hydrogel Loaded with Oridonin and DNase-I on Healing of Chemotherapy-Induced Oral Mucositis

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Objective: The semi-interpenetrating network hydrogel system (IPN) equipped with oridonin（ORI）and DNase-I（ORI/DNase-I/IPN）were fabricated for treatment of chemotherapy-induced oral mucositis.

Methods: The binary copolymer PMD was synthesized by the reaction of N, N-dimethylacrylamide and maleic anhydride, and ε-Polylysine (ε-PLL) quickly reacts to form hydrogel (PMD-PLL), and then form IPN with starch derivatives (HES), which is loaded with ORI and DNase-I. The chemical structures, thermal stability and surface morphology of the IPN were revealed by the FTIR, DSC and SEM respectively. We evaluated the cytotoxicity and the cell migration in L929 and HUVEC cell lines. The antibacterial activity of ORI/DNase-I/IPN against E. coli and S. aureus were tested by the spread plate method. The chemotherapy-induced oral mucositis of Sprague–Dawley mice was constructed to evaluate the therapeutic efficiency of ORI/DNase-I/IPN as a wound therapy agent.

Results: The encapsulation rate of ORI and DNase-I were (97.2 ± 2.2)% and (95.1 ± 6.4)% respectively, and the drug loading were (5.3 ± 0.4) % and (1.4 ± 0.2) %, respectively. The hemolysis rate of different concentrations of IPN is less than 5% and MTT showed that cell viability was higher than 85%. ORI/DNase-I/IPN displayed significant antibacterial activity, and the inhibition rates against S. aureus were 70.2% and 91.4% after incubation for 3h and 6h, respectively. With ORI/DNase-I/IPN 7days treatment, the relative mucositis area decreased to (21.4±2.8)%, significantly lower than that of the ORI/ IPN group ((54.6±8.4) % and DNase-I/ IPN group (42.2±6.6)%. Compared with the ORI/ IPN and DNase-I/ IPN group, the content of TNF-α, IL-6 and IL-1β in the mucositis area were significantly decreased by ORI/DNase-I/IPN treatment ($P < 0.05$).

Conclusion: We successfully developed a hydrogel system which can sustained release DNase-I and ORI orderly, and effectively accelerated oral mucositis healing. Thus, it is expected to provide innovative strategies for treatment of chemotherapy-induced oral mucositis.

Key words: semi-penetrating network hydrogels; oral mucositis; chemotherapy; chronic wounds.

ID 2920

Initial Tissue Adhesive Cell Coat Improves Engraftment Efficiency of Stem Cell Therapy in Osteoarthritis

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Objective: Cell engraftment is one of the key factors affecting the efficacy of cell therapy. However, most injected stem cells were unable to anchor on the damaged microenvironment within a short time, and these dissociated cells undergo anoikis. In this study, we engineered the surface of adipose-derived mesenchymal stem cells (ADSCs) with a tissue adhesive coating (TAC) that enables the cells to anchor in the target region within 1 min.

Methods: This tissue adhesive coating consists of ortho-nitrophenyl groups attached to a biotin-streptavidin-biotin-binding complex. Upon activation by UV light irradiation, the o-nitrophenyl group was converted to an o-nitrobenzaldehyde

group and cross-linked with amino groups on the tissue surface, resulting in rapid cell anchorage at the target site.

Results: we engineered a biotin-streptavidin amplified o-nitrobenzene (NB) system as a general tissue adhesive coat for stem cells. This tissue adhesive coat has no adverse effect on stem cell viability and function and enables rapid cell adhesion to difficult-to-adhere tissue surfaces such as cartilage. The tissue adhesive coat modified stem cells enhanced the colonization and prolonged retention time in joint cavity. Through the rabbit cartilage defect model and the mouse OA model, we verified that tissue adhesive coat wearing adipose-derived stem cells (TAC-ADSCs) could better adhere to the target position and thus have a better cell therapy effect.

Conclusion: This method of stem cell surface modification is fast, convenient, and relatively safe, which may provide a new strategy for improving the efficiency of cell therapy.

Key words: tissue adhesive coating, cell therapy, osteoarthritis, cartilage defect

ID 2948

低强度超声促进移植的人源性脑类器官发育和环路整合

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目的：探究低强度超声（LIUS）对脑类器官发育和环路整合的作用。

方法：构建异常纺锤体样小头畸形相关蛋白基因（ASPM）敲除的发育障碍脑类器官模型。实验分为 4 组：对照组、超声组、ASPM 组、超声刺激 ASPM 组。采用免疫荧光、单细胞测序等方法检测脑类器官全发育周期的变化。将 36 只 NOD-SCID 小鼠分为 3 组：Ctrl-BO 移植组、LIUS-BO 移植组、聚焦超声在体调控组，每组 12 只，移植位置为初级感觉皮层。移植后 2 个月和 5 个月检测脑类器官与宿主整合能力的变化。

结果：相较于对照组，超声组光镜下尺寸增大 31.1%，神经祖细胞比例增加 25.5%，皮质板厚度增加 67.4%，增殖细胞比例增加 42.0%，凋亡细胞比例减少 67.4%（均 $P < 0.05$）。相较于 ASPM 组，超声刺激 ASPM 逆转其神经发生缺陷。相较于 Ctrl-BO 移植组，LIUS-BO 移植组和聚焦超声在体调控组在宿主体内血管化程度更高，宿主来源的小胶质细胞浸润度更高，投射更广泛，与宿主的突触连接数目更多。

结论：低强度超声可促进脑类器官发育成熟，逆转小头畸形神经发生缺陷，并增强移植的人源性脑类器官与宿主的整合能力。

关键字：低强度超声、脑类器官、小头畸形、在体移植、发育

ID 2957

Treatment of Renal Ischemia Reperfusion Injury via Dual-targeted Delivery of Extracellular Vesicles from Engineered Adipose Mesenchymal Stem Cells through Antibody-conjugated Magnetic Nanoparticles

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Objective: Mesenchymal stem cells derived extracellular vesicles (MSC-EVs) are considered as a potential nano-therapy and gradually entering the clinical field of kidney diseases. However, the efficacy of MSC-EVs therapy for renal ischemia reperfusion injury (IRI) likely depends on the numbers of EVs that home to ischemia area.

Methods: In this study, we engineered MSC-EVs expressing P-selectin glycoprotein ligand-1 (PSGL-1), which bind to the damaged endothelial cells. Meanwhile, the nanoparticles consist of a Fe3O4 that is decorated with poly ethylene glycol conjugated an antibody, which bind to CD63 antigens on the surface of EVs. Under the application of a local magnetic field, the nanoparticles binding with MSC-EVs were accumulated in the kidney and MSC-EVs bind to damaged endothelial cells in rat model of renal IRI.

Results: We found that PSGL-1 was expressed on the surface of MSC-EVs via lentiviral transfection. In addition, dual-targeted delivery of EVs from engineered adipose MSC through antibody-conjugated magnetic nanoparticles significantly enhanced MSC-EVs homing to the damaged endothelial cells in ischemic kidney as well as improved renal functions and angiogenesis according to the EX vivo fluorescent imaging and immunofluorescence imaging. These were consistent with Results from in vitro flow chamber assays in which the compound system significantly increased the numbers of EVs and promoted EVs uptake.

Conclusion: Our strategy of dual-targeted delivery of MSC-EVs could increase the efficiency of EVs recruitment in kidney and improve the renal functions after renal IRI. The approach potentially be used to increase the effectiveness of EVs therapy for renal IRI.

Key words: ischemia reperfusion injury; extracellular vesicles; mesenchymal stem cells; magnetic nanoparticles

ID 3015

Rapid Printed Double-layer Scaffold with Ultra-small Nano-Oligomers for Osteochondral Regeneration

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Objective: Avascular articular cartilage has poor self-regeneration capacity. If damage on cartilage is untreated, it might extend further into the subchondral bone, causing pain and osteoarthritis (OA). Due to structural and biological heterogeneity of articular cartilage and subchondral bone, it is still challenging to develop an integrated scaffold that synchronously fulfills the requirements for osteochondral defects regeneration. Nano-hydroxyapatite (HANP), although widely used for bone regeneration, could be "isolated" by the bone matrix because of large size, so we need to develop smaller subnanometer bone apatite crystals.

Methods: Here, we use gelatin methacrylate (GelMA) hydrogel to simultaneously develop a bilayer scaffold with different

structures via digital light processing (DLP) technology. The upper layer hydrogel has both lotus- and radial-distribution pores to facilitate the migration and distribution of cells, while the lower hydrogel has lotus-like pores to guide the migration of bone marrow mesenchymal stem cells (BMSCs) to the upper space. In the lower layer hydrogel, the incorporation of 1nm-sized conformational precursor oligomers (CPO) of calcium carbonate endowed the GelMA hydrogel with a higher osteogenic capacity.

Results: Biocompatibility of the composite CPO/GelMA hydrogel was also verified. Additionally, in both subcutaneously and in situ implanted scaffolds, cells infiltrated into both lotus-like and radical pores, which is conducive for the repair of cartilage defect. 16 weeks post implantation in the rabbit osteochondral defect model, simultaneous cartilage and subchondral bone regeneration were achieved in CPO/GelMA group. The BV/TV value of the CPO/GelMA group (47.28%±5.932%) was significantly improved compared with the blank group (21.52%±5.845%) (P=0.0027). Moreover, SEM Results showed that the regenerated cartilage of the CPO/GelMA group was more similar to normal with a smoother microsurface.

Conclusion: It is expected that this rapid printed bilayer scaffold with ultra-small nano-oligomers can become a new strategy for osteochondral regeneration.

Key words: conformational precursor oligomers; DLP bioprinting; bilayer scaffold; osteochondral regeneration; cartilage engineering

ID 3032

Customized scaling up of Mitobank MSCs for Osteoarthritis Therapy

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Objective: Osteoarthritis (OA) is a common degenerative joint disease characterized by the breakdown of joint cartilage. Mitochondrial dysfunction of the chondrocyte is a risk factor for OA progression. Mitochondria are complex and dynamic organelles, whose main function is energy production for the maintenance of cellular homeostasis. Mitochondrial transplantation enhances ATP synthesis, oxygen consumption, and cell viability, thereby improving systemic function. However, the acquisition of active mitochondria remains a major challenge for tissue regeneration. Also, the therapeutic role of mesenchymal stem cells (MSCs)-derived mitochondria in osteoarthritis is not yet known.

Methods: Mitobank MSCs were generated by screening medium components to promote cell proliferation and mitochondrial activity. Self-renewal ability was analyzed by cell proliferation assay, immunofluorescence staining, and colony formation unit assay. Metabolic activity was measured by ATP production capacity and Seahorse cellular metabolic assays. RNA sequencing was performed on Mitobank MSCs and MSCs. MSCs, Mitobank MSCs and their mitochondria were applied in the destabilization of the medial meniscus (DMM) mouse OA model.

Results: Mitobank MSCs generated by customized medium show stronger self-renewal ability and higher metabolic levels. Transcriptome revealed that increased proliferative capacity and metabolic activity of Mitobank MSCs were due to activation of the AMPK pathway. Mitobank MSCs showed better therapeutic efficacy than MSCs treatment in a mouse OA model. Further, MSCs could transfer mitochondria to chondrocytes ex vivo and in vitro. Mitochondria from Mitobank MSC corrected energy imbalance and restored cellular metabolism to improve cartilage homeostasis and protect against the pathological progression of OA.

Conclusion: Mitobank MSCs and their mitochondria as a potential therapeutic approach for OA treatment.

Key words: Osteoarthritis; Mesenchymal stem cells; Mitochondria.

ID 3103

Intelligent Multifunctional Polymeric Biomaterials for Spatio-temporal Drug/growth factor Release and in situ Tissue Regeneration

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Objective: Functional loss of cells, tissues, or organs due to trauma, injury, or other diseases causes enormous complications. Cell-based therapies offer promising options; however, intensive *in vitro* cell manipulations may hinder this approach. Intelligent multifunctional polymeric biomaterials offer an alternative paradigm to orchestrate host's own reparative responses by inducing/recruiting endogenous stem cells and progenitor cells. The Objective of this research was to design intelligent multifunctional biomaterials platforms for in situ (cell-free) regeneration of different types of tissues, including blood vessels, heart, nerves, skin, patellar tendon, and bone/cartilage.

Methods: Cytokines and chemokines, such as substance P (SP), stromal cell-derived factor-1 alpha (SDF-1α), vascular endothelial growth factor (VEGF), and MSC-affinity peptide were incorporated into biomaterials either by tethering with polymers in bulk or by encapsulation. Cytocompatibility, hemocompatibility, cell migration, and drug/GFs release were studied. *In vivo* evaluations were performed in different animal models, like abdominal aorta, sciatic nerve defect, patellar tendon; excisional defects. Explants were analyzed by histological and immuno-histochemical assays.

Results: Modified biomaterials afforded spatio-temporal release of bioactive cues as well as showed good cell mobilization and recruitment, hemocompatibility, cytocompatibility, and GFs sequestration/retention in vitro. Explanted materials showed superior effect of instructive biomaterials for the in situ regeneration of different types of tissues, including blood vessel, nerves, bone/cartilage, patellar tendon, skin, and infarcted myocardium than that of unmodified materials. Host stem/progenitor cells were recruited into bioactivated polymers either from the bone marrow (BM), peripheral circulation, or from the surrounding tissues and were found to be differentiated into targeted cell types, including CD31+ endothelial cells (ECs) and alpha smooth muscle actin (α-SMA)-positive smooth muscle cells.

Conclusion: Taken together, instructive polymeric biomaterials may promote *in situ* tissue repair through an endogenous mobilization and recruitment of host stem/pronator cells, which may have great application prospect for regnerative medicine and tissue engineering (TE) as well as related disciplines.

Key words: In situ tissue repair, nerve regeneration, vascular grafts, cytokines/chemokines, wound healing, cytokines and chemokines, tissue engineering, biomaterials

ID 3155

基于生物正交与点击反应的组织工程原位快速细胞化策略

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中国医学科学院生物医学工程研究所

目的：开发一种实现组织工程支架原位特异性快速细胞化的新策略

方法：基于生物正交点击反应与糖代谢工程手段，首先制备合成 DBCO 改性的 PCL-PEG-DBCO 聚合物，进而通过静电纺丝法制备 PCL/PCL-PEG-DBCO 复合纤维膜材料。利用糖代谢工程手段标记巨噬细胞，获得叠氮基团标记的巨噬细胞。利用体外细胞实验以及大鼠腹腔埋植模型，验证细胞与材料表面原位点击反应的发生、生物安全性以及该策略实现组织工程支架原位特异性快速细胞化的可行性。

结果：该研究成功制备获得 PCL/PCL-PEG-DBCO 复合膜材料，Azide-Cy5 染色证明 DBCO 基团暴露于纤维材料表面；DBCO-Cy5 染色证明叠氮基团成功修饰巨噬细胞；细胞特异性选择实验证明 DBCO 改性的复合材料相比不改性组，（+）巨噬细胞细胞选择性粘附比例显著增加。小动物体内实验证明 N3 的小分子化合物与目标细胞可在体内原位靶向 PCL/PCL-PEG-DBCO，证明了该策略的体内有效性。

结论：基于生物正交法与点击化学反应，提出了一种绿色安全有效的可促进原位细胞化的组织工程策略。

关键字：生物正交；点击化学反应；组织工程；原位细胞化

ID 3166

基于主客体光敏水凝胶的涂层式内承压策略

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目的：血管承压能力不足是当前生物 3D 打印组织 / 器官迈向体内移植的一大瓶颈，本工作设计了一种涂层策略，提高了低浓度水凝胶血管化组织的承压能力，以满足血管化组织连接大鼠颈动静脉血流的需要，同时支持血管发生。

方法：在血管化组织基质材料中加入 CD-HA，并完成血管化组织的构建。随后，在血管中通入 ADNor-HA、多肽交联剂、引发剂，通过主客体吸附作用在管道内壁涂层。通过纳米压痕实验、细胞增殖实验、内皮细胞粘附出芽实验、动物体内移植等手段，综合评估涂层策略对血管承压能力和血管发生能力的影响。

结果：合成了高取代度 ADNor-HA 和 CD-HA，其中 ADNor-HA 作为承压材料涂层于血管内壁，CD-HA 分散于基质材料。结果表明，ADNor-HA 承压层机械强度显著高于基质材料。经涂层处理过后，血管化组织可承受大鼠颈动静脉 12 ml/min 血流，并完成血管吻合移植。涂层材料生物相容性好，支持血管内皮细胞贴附、延展、增殖、出芽。

结论：基于主客体光敏水凝胶的涂层式内承压策略具有适用性广、分辨率高、生物活性可控、支持血管发生的特点，有效提高血管化组织的承压能力，满足了大鼠体内移植的承压需求，有潜力实现更多大尺寸血管化组织的体内移植。

关键字：生物 3D 打印、血管化组织、血管承压策略

ID 3400

A Powerful Photo-responsive Hydrogel for Rapid Healing in Digestive Tract Leakage

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Objective: Colon leakage is one of the most serious complications of abdominal trauma or abdominal surgery. Considering that the sealing stability of sutures in dealing with colon leakage is still limited, we proposed a photosensitive hydrogel, which could realize quick cure and suture-free repair of colon leakage.

Methods: The HAMA and HANB were mixed in different proportions to test rheological properties, Young's modulus, degree of optical crosslinking and bursting pressure to determine the optimal ratio of mixed hydrogels. *In vitro* , we implanted NCM460 and Caco-2 cells in HAMA/HANB medium, Live/dead staining, scratch test, cck8 cell viability test and flow cytometry were used to detect the viability of cells. *In vivo*, a rabbit colon leakage model was established to compare the efficicy of HAMA/HANB, suture and fibrin gel.

Results: When HAMA:HANB=3:1, the degree of optical crosslinking and burst pressure of the mixed hydrogels reached the maximum. *In vitro*, HAMA/HANB has powerful physical stability to tolerate diverse conditions. Meanwhile, HAMA/HANB has good chemical stability and is not easy to degrade. *In vitro* cell experiments verified that HAMA/HANB has an excellent biocompatibility. *In vivo*, collected samples showed the best healing degree in HAMA/HANB group. H&E indicated that the healing degree of injured mucosa was the best and the degree of inflammatory cell infiltration around injury was significantly the lowest. Morover, HAMA/HANB had the lightest abdominal adhesion score, and the least collagen fiber content was found around the damaged margin of tissues.

Conclusion: HAMA/HANB hydrogels have controllable mechanical properties, ductility, adhesion stability and chemical stability. The colon leakage model indicated that HAMA/HANB had the best effect of occluding colonal content leakage at the incision site and the effect of incision healing and inhibiting inflammation was measured during sample collection. And the hyaluronic acid (HA) in HAMA/HANB can effectively reduce the degree of postoperative abdominal adhesion.

Key words: colon leakage; photo-responsive hydrogel; powerful adhesion; rapid healing

ID 3510

级联酶催化活性的多功能水凝胶促糖尿病伤口愈合

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目的：开发能够主动调控糖尿病伤口部位高血糖、止血、有效抗感染、在伤口愈合后期补充氧气、保湿且能够自适应贴合伤口的多功能水凝胶敷料对促进糖尿病伤口组织的修复和重建具有重要意义。

方法：通过共自组装将葡萄糖氧化酶（GOx）和超小 Fe2O3 粒子装载于 ZIF-8，形成一种具有级联酶催化活性的可降解纳米粒。然后将该纳米粒与含有醛基的氧化透明质酸和水溶性羧乙基壳聚糖共聚形成一种多功能水凝胶。

结果：该水凝胶可利用其 GOx 催化糖尿病伤口部位高浓度的葡萄糖产生葡萄糖酸和 H2O2，一方面可降低伤口部位的血糖浓度；另一方面可促使水凝胶和纳米颗粒的降解，释放锌离子，进而暴露 Fe2O3 颗粒，使其在酸性条件下催化伤口部位过量的 H2O2 发生芬顿反应产生羟基自由基，实现协同抗菌。而在伤口愈合后期，随着其 pH 的提升，暴露

Fe2O3 颗粒又可催化伤口部位过多的 H2O2 分解产生氧气，缓解伤口部位缺氧。

结论：该工作可为糖尿病伤口修复的提供一种潜在的新生物材料与技术平台。

关键字：纳米酶；活性氧；抗菌；糖尿病伤口；水凝胶

S11
生物材料产业化及临床应用
Industrialized Development and Clinical Application of Biomaterials

ID 65

Preparation and Research of a Novel Antibacterial Collagen-based Corneal Repair Material

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Objective: Cornea disease is a major clinical problem affecting millions of people worldwide. Keratoplasty is an effective method to treat corneal blindness. However, the risk of developing bacterial keratitis after corneal transplantation is very high, which may directly affect the repair effectiveness or even Results in transplant failure.

Methods: In this study, we developed a novel artificial antibacterial collagen film (ColCA-GM) for corneal repair. Gentamicin-modified collagen membrane (ColCA-GM) is produced using a three-step process, including: (i) the collagen solution was cross-linked and air-dried to form a collagen (Col) membrane by 1-ethyl-3 - (3-dimethylamino-propyl) carbodiimide (EDC) and n-hydroxysuccinimide (NHS). (ii) The amides and carboxyl groups on the Col surface were generated by citric acid. (iii) The Col with carboxyl groups was modified by gentamicin grafting.

Results: The modified ColCA-GM film has good hydrophilicity and biocompatibility. The water absorption rate of Col film is about 92%, Col-GM films is about 91%, ColCA-GM film is about 96%. The cells completely covered the entire surface of ColCA-GM membrane after 72h of inoculation. It can be concluded that the application of citric acid and gentamicin can improve the moisturizing properties of Col films. This is attributed to the fact that citric acid and gentamicin contain a large number of carboxyl groups, hydroxyl groups and other hydrophilic groups. Besides, it was obvious that citric acid grafted gentamicin significantly improved the antibacterial properties of Col membranes. Compared with Col-GM films, the CFU of E. coli and S. aureus in ColCA-GM AGAR culture dishes was significantly lower than that of Col-GM samples.

Conclusion: Our preliminary Results indicate that this gentamicin-modified low-cost prepared membrane has potential applications in corneal tissue engineering.

Key words: Corneal; Collagen; Antibacterial; Tissue engineering

ID 102

Promotion of Subtotal Uterine Reconstruction by a Tissue-engineered Uterus Biomimeticing Structure and Extracellular Matrix Microenvironment

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Objective: A variety of diseases may lead to uterine injuries and even hysterectomies, resulting in uterine-factor infertility. Bioengineered uterine tissue could provide a therapeutic option for such conditions. Uterus is a special organ capable of a periodically regenerating the endometrium and a contractile myometrium. Considering the substantial difference in the structure of endometrium and myometrium, it is difficult for a single-layer scaffold to meet the functional and mechanical requirements of uterine wall repair at the same time. By imitating the structure and microenvironment of the uterus, it may be possible to achieve the functional regeneration of full-thickness uterine wall. Herein, we have constructed a tissue-engineered uterine scaffold (ECM-SPS) biomimeticing uterine structure and extracellular matrix (ECM) microenvironment.

Methods: To construct the bionic scaffold (SPS), small intestinal submucosa (SIS) and polyurethane/SIS (PU/SIS) are respectively selected as the biomimetic endometrium and myometrium. Subsequently, a biomimetic microenvironment is built by seeding tissue-specific cells, epithelial cells and smooth muscle cells, onto the SIS and PU/SIS, and decellularizing to produce tissue-specific ECM.

Results: The ECM-SPS scaffold thereby possesses ECM signatures of both endometrium and myometrium, which promotes adhesion, proliferation and lineage-directional differentiation of MSCs in vitro and enhances cell infiltration, vascularization and immunomodulation following in vivo implantation. As demonstrated by a rat model for subtotal uterine reconstruction, the ECM-SPS could promote endometrial regeneration at the initial stage, which was evidenced by thicker endometrium, higher proportion of glands and smaller area of fibrosis, in addition with regeneration of more mature smooth muscles. Furthermore, the reconstructed uterus could sustain normal pregnancy and has supported fetal development to full term.

Conclusion: The ECM-SPS therefore provide a potential treatment for women with uterine-factor infertility.

Key words: Uterus reconstruction, Biomimetic scaffold, Extracellular matrix environment

ID 219

多酚生物材料的探索

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目的：受植物界和动物界的多酚化学启发，利用多酚介导功能化生物材料，希望能够有效应对因老龄化引起的多种病理环境下组织修复难的共性问题。

方法：以多酚化学为中心，围绕生物活性与组织修复材料的体系变量多和服役环境复杂的难点，结合材料、化学、生命多学科交叉，提出了多酚 - 金属双催化体系、电子转移介导酚醌平衡等策略，同时，开发了高通量表面处理设备、高通量生物材料微量制备平台、高通量材料筛选平台和电化学驱动的层层自组装表面修饰新技术，用过构建和

评价多酚生物材料的性能。

结果：系统性研究了力学性能、导电性、表面拓扑结构、化学基团等材料学因素影响组织再生机理，实现从微观功能分子到宏观多尺度结构的协同调控，揭示了关键材料学因素与组织微环境相互作用的分子机制。

结论：基于材料服役行为的高通量多尺度计算和制备与表征，提出了基于电子转移的多酚介导生物功能化新策略，结合材料基因组学和生物多组学的多维网络信息，解码了多酚基生物材料“分子 - 结构 - 生物学”之间的构效关系，赋予了生物材料在多种慢性疾病环境下的组织再生与调控能力。

关键字：多酚化学；仿贻贝；水凝胶；组织修复

ID 381

电针大椎穴协同多酚介导载中药导电水凝胶微针促进糖尿病皮肤创面修复

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目的：观察电针大椎穴结合微针对糖尿病大鼠皮肤创面修复的协同效应。

方法：将大鼠分为 2 组，非电针组：（a）Blank，（b）GelMA-PCNP，（c）GelMA-PCNP-PP，（d）GelMA-PP-LBP，（e）GelMA-PCNP-PP-LBP。电针组：分别在 a,b,c,d,e 组基础上给予大椎穴电针 (ES) 刺激。操作：微针：负载 PP 和 LBP 的微针（GelMA、PCNP 构成）贴片用绷带固定于创面上。电针：针刺大椎穴、第六颈椎后凹陷处，电流 1mA，每日 1 次，每次 20min，连续干预 3d。皮肤造模后 4d、14d 检测创面。并进行免疫荧光染色，检测 IL6、TNF-α。

结果：3d 后，IL-6、TNF-α：与非电针对应组别比较：电针组相对荧光面积都更低；GelMA-PCNP-PP-LBP（ES）相对荧光面积低于 GelMA-PP-LBP（ES）；GelMA-PCNP 的相对荧光面积高于 GelMA-PCNP-PP；14 天后，微针 - 电针干预伤口愈合程度显著优于其它组。

结论：微针生物相容性良好，PCNP 微针有导电性，PP 和 LBP 协同降低糖尿病创面炎症，辅以大椎穴电刺激，可进一步降低创面炎症及促进愈合。

关键字：关键词：电针 -ES；双键化明胶 -GelMA；多酚介导导电纳米颗粒 -PCNP），多酚 -PP-，枸杞多糖 -LBP

ID 383

First Clinical Application of the Novel Large-diameter Composite Polycarbonate Polyurethane Artificial Blood Vessel

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Objective: The Objective of this study was to explore the perioperative performance of the novel large-diameter composite polycarbonate polyurethane artificial blood vessel in the first clinical application.

Methods: In this study, we retrospectively analyzed 14 patients with thoracic aortic prosthesis replacement (7 patients had polyurethane prostheses and 7 patients had coated polyester prostheses) from 2016 to 2021. The preoperative, intra-

operative and postoperative data of the two groups of patients were assessed in detail

Results: We defined the patients with polyester artificial blood vessels as the control group and the patients with hybrid polycarbonate polyurethane /polyester artificial blood grafts as the experimental group. The total operation time of the experimental group was significantly shorter than that of the control group, which were 159.29 ± 38.13 min and 252.57 ± 64.40 min, respectively (P <. 001). There was no significant difference between the two groups in the length of time from the beginning of the operation to aortic opening. The length of time from aortic opening to the end of operation in the experimental group was significantly shorter than that in the control group, which were 70.43 ± 8.08 min and 124.71 ± 37.59 min, respectively (P <. 001). None of the patients experienced any serious complications, such as death, stroke, myocardial infarction, etc. The mean total drainage of pleural fluid was lower in the experimental group than in the control group (383.43±139.68 mL vs. 828.00±457.27 mL; p<0.05). The mean postoperative in-hospital time was shorter in the experimental group than in the control group (6.71±0.75 days vs. 9.43±2.82 days; p<0.05).

Conclusion: The novel graft is the first type of three-layered large-diameter artificial blood vessel that combines polyester and polycarbonate polyurethane in the world. The novel artificial blood vessel has good mechanical properties, histocompatibility, hemocompatibility and anti-seepage function in the human body.

Key words: Artificial blood graft; Polycarbonate polyurethane artificial blood vessel; polyester graft

ID 444

近红外响应性 3D 打印形状记忆聚氨酯 / 镁复合支架促进骨再生

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目的：由骨折、创伤等引起的大范围骨缺损的修复是骨科临床面临的重大挑战，研发新型骨修复材料是骨科临床医学重点领域。形状记忆聚氨酯（SMPU）是一类新型的刺激响应材料，基于 SMPU 开发新型智能响应生物活性骨修复材料将具有重要的研究意义和临床应用价值。

方法：聚氨酯 / 镁复合支架（SMPU/Mg）由形状记忆聚氨酯（SMPU）作为热响应基质，镁（Mg）作为光热剂和生物活性成分，通过 3D 打印技术制备复合多孔支架。重点研究了支架在近红外光照射下的智能响应形状记忆及恢复性能。利用大鼠颅骨临界骨缺损模型研究支架植入后在体近红外响应恢复及缺损部位紧密填充性，以及支架对骨缺损的修复能力。

结果：SMPU/Mg 复合支架具有相互连通的多级孔结构，良好的力学性能，在近红外光照射下具有良好的光热性能，实现快速升温调控支架形状记忆功能，具有优异的形状固定率和回复率（均大于 90%）。同时可持续释放镁离子，具有促成骨功能。动物实验证明，通过近红外调控支架形状恢复可紧密填充在缺损部位，同时促进骨缺损修复。植入 12 周后相比于对照组实现了更加有效的骨缺损修复。

结论：近红外响应形状记忆聚氨酯 / 镁 3D 打印复合支架可为临床骨缺损治疗提供一种有效的策略。

关键字：骨缺损，形状记忆聚氨酯，近红外响应，3D 打印

ID 452

Evaluation of Polycaprolactone Vascular Grafts Implanted into an Intimal Hyperplasia Rat Model

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Objective: Small diameter vascular graft implanted into disease animal models has rarely been studied. The present study was performed to evaluate the performance of polycaprolactone (PCL) vascular grafts (length: 1 cm; inner diameter: 2 mm) implanted into disease animal models.

Methods: An intimal hyperplasia (IH) rat model was established by outflow ligation of the left common carotid artery and followed by a 45-day high cholesterol diet exposure. Ultrasound and histology staining were used to verify the IH rat model. Thereafter, PCL grafts were implanted into rats. Serum biochemical analysis after surgery was performed and the explanted graft was examined by scanning electron microscopy (SEM).

Results: Data showed that IH rats had thickened intima of left carotid artery compared with the normal rat. IH rats have an extremely low survival rate (1/14) after surgery. Furtherly, biochemical analysis of the blood showed that the concentration of substances related to liver, heart and kidney function existed significant differences. Ischemia during implantation surgery induced severe injury and inflammation, which may be the main cause of the low survival rate.

Conclusion: These findings suggested that the IH rat model may not be suitable for graft implantation study. It also indicates the importance of disease animal models in artificial graft development, especially for pre-clinical evaluation.

Key words: PCL graft, implantation, intimal hyperplasia rat, carotid artery, ischemia

ID 541

戊二醛聚合牛 HBOC 对心脏移植供心保护作用的研究

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目的：探究戊二醛聚合牛血红蛋白氧载体（HBOC）对延长供心有效保存时限、减轻缺血缺氧和缺血再灌注损伤的有效性。

方法：12 只巴马小型猪随机平均分为两组，实验组含 1.2 g/dL HBOC 的 HTK 液，对照组不含 HBOC 的 HTK 液，分别灌停心脏并体外冷保存 8h 后连接 ECMO 用猪自体血复灌 1h，取供心进行组织病理分析。以心脏复跳率、血浆丙二醛（MDA）浓度、心肌含水量（MWC）、心肌 ATP 含量和心肌酶谱（乳酸脱氢酶（LDH）、磷酸肌酸激酶（CK）、磷酸肌酸激酶同工酶（CKMB））作为评价指标。

结果：实验组心脏复跳率显著高于对照组（100% vs 33.33%，P ＜ 0.05）；低温保存至缺血再灌注阶段，对照组 MDA 恢复率显著高于实验组（P=0.03）；供心保存 8h 及缺血再灌注后，对照组 MWC 显著高于实验组（P=0.02），ATP 含量显著低于实验组（P=0.00），心肌酶谱均显著高于实验组（P 均＜ 0.05）；组织病理学结果显示，实验组心肌组织学损伤积分、心肌细胞凋亡指数和心肌超微结构损伤平均分级均显著高于对照组。

结论：戊二醛聚合牛 HBOC 可显著减轻心脏移植供心保存缺血缺氧损伤和缺血再灌注损伤，有望延长供心有效保存时限。

关键字：心脏移植；供心保护；HBOC ； 复跳率

ID 676

明胶 / 细胞外基质复合电纺丝水凝胶对皮肤创口修复的影响研究

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目的：通过静电纺丝工艺制备一种明胶 / 细胞外基质复合水凝胶，探讨其理化性能、生物相容性以及对皮肤创口修复的影响。

方法：培养小鼠成纤维细胞获得大量细胞群后 , 冻干获取其细胞群产生的细胞外基质，将提取到的细胞外基质与明胶混合于有机溶剂中，通过静电纺丝工艺法纺织出电纺水凝胶。对水凝胶的理化性能、细胞相容性和皮肤修复性能进行表征。

结果：扫描电镜 (ECM) 显示水凝胶具有丰富的多孔结构。体外实验证实该水凝胶具有很好的保水率和可控的降解性能。力学测试显示水凝胶的力学性能随着明胶含量的增高逐渐增强。在水凝胶表面滴水后，接触角实验显示该水凝胶亲水性高，能够良好贴敷伤口。CCK8 试验和细胞活死染色实验显示水凝胶具有很好的细胞相容性。动物皮下植入实验后未引起皮肤炎症及排斥反应，水凝胶满足安全性要求。在鼠皮肤上进行创口建模后并贴敷水凝胶，染色结果显示水凝胶有良好的皮肤创口修复性能，抑制疤痕生成性能，并能促进创口后的血管生长和毛孔生成。

结论：明胶 / 细胞外基质复合电纺水凝胶有好的力学性能、细胞相容性、亲水性和保水性能，且对细胞无毒，安全性高，促伤口修复性能好。这种水凝胶能够促进创口愈合。因此，这种水凝胶具有很好的修复皮肤创口的应用前景。

关键字：明胶，细胞外基质，静电纺丝，水凝胶

ID 686

Self-adaptive Dual-inducible Nanofibers Scaffolds for Tendon-to-Bone Interface Synchronous Regeneration

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Objective: It has been established that one major cause of retear following rotator cuff repair is the failure of regeneration of the native tendon-to-bone interface. Therefore, identification of noval strategies to promote the synchronous regeneration of different tissues at the inhomogeneous tendon-to-bone interface is a critical challenge for tendon-bone healing after rotator cuff repair. Both chondrogenic and osteogenic induction microenvironment can coexist in the tendon-to-bone interface, however, it is inadequate to support the fibrocartilage and bone regeneration during tendon-bone healing. Thus, inspired by intrinsic induction microenvironments present at the tendon-to-bone interface, self-adaptive dual-inducible nanofibers scaffolds (SDNS) were designed to improve bone and fibrocartilage synchronous regeneration

in response to local induction microenvironments during tendon-bone healing.

Methods: Strontium-doped mesoporous bioglass nanoparticles (Sr-MBG) were synthesized by modulated sol-gel method and loaded into nanofibers of SDNS through electrospining. The cytocompatibility of nanofibers scaffolds was examined by CCK-8 and AM/PI staining. The extract induction medium of nanofibers scaffolds was employed to assess the osteogenic and chondrogenic effect on BMSCs. Rats rotator cuff tears model was established to estimate the effect of SDNS on promoting tendon-bone healing.

Results: SDNS were capable of releasing strontium ions continuously and thereby improving osteogenic and chondrogenic differentiation of the mesenchymal stem cells in response to specific induction microenvironments. SDNS stimulated synchronous regeneration of the fibrocartilage and bone layers at the tendon-to-bone interface after implantation in the torn rotator cuff, improving the biomechanical strength of the supraspinatus tendon–humerus complexes significantly.

Conclusion: Taken together, our study provided a novel perspective on the utilization of electrospining scaffolds for the in situ regeneration of inhomogeneous interface tissue by regulating microenvironments through metal ions.

Key words: rotator cuff tear, tendon-to-bone interface, strontium, meso-porous bioglass nanoparticles, nanofibers scaffolds

ID 873

温敏、pH 响应的可注射自愈水凝胶用于慢性创伤修复的研究

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目的：慢性创伤，如糖尿病足等修复过程十分困难，其病理过程常伴有局部温度升高，pH 值降低等现象的产生。水凝胶作为一种具备三维网状结构的材料，常用于慢性创面修复。

本研究首先制备出接枝普郎尼克 F127 的壳寡糖 (CS) 以及高碘酸钠氧化的氧化透明质酸 (A-HA) 制备自愈合水凝胶，并通过体外体内实验评价其促进再生的功能及其机制。

方法：通过物理化学实验，证明水凝胶的成功合成、通过细胞相容性测试证明水凝胶的生物相容性和最适药物浓度、通过成管化和细胞迁移实验，证明负载药物的水凝胶的促成管化和迁移能力、通过动物实验、HE、Masson、免疫组化染色证明水凝胶的促创面修复能力。

结果：本课题制备的水凝胶具备可注射性，表现出水凝胶的自愈合性。

具备良好的生物相容性，具备促血管化和促细胞迁移的能力。

体内实验表明，水凝胶促进了糖尿病创面的愈合，证明其具备促进糖尿病足创面愈合的效果。

结论：本课题制备的响应性水凝胶，具备温敏和 pH 响应特性，自愈合效果，通过对 DFO 的缓释作用，对糖尿病大鼠创面修复起到了较为理想的效果，为响应性水凝胶用于糖尿病创面修复提供了思路。

关键字：壳寡糖；透明质酸；普郎尼克 F127 ； 去铁胺；糖尿病足

ID 911

Biomimetic Tri-layered Vascular Grafts Constructed from Electrospun Poly (L-lactide-co-caprolactone) (PLCL) Fibers Incorporating Decellularized Extracellular Matrix (dECM) Promote Anti-thrombotic and Pro-regenerative Functions

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Objective: Small-diameter vascular grafts (SDVGs) are urgently required for clinical applications. To realize biofunctional SDVGs, anti-thrombotic and pro-regenerative activities are necessities. Here, we constructed a tri-layered vascular graft with a native artery decellularized extracellular matrix (dECM) mimicking the component of arteries.

Methods: Natural blood vessels dECM maintain bioactive factor contents, which are conducive to vascular tissue regeneration. Porcine thoracic aorta was decellularized, frozen, and milled to retrieve dECM powders from the differential arterial layers. The intima and media dECM powders were blending with PLCL and utilized as the inner and middle layers of electrospun vascular grafts, respectively. Pure PLCL was electrospun and used as a strengthening sheath for the outer layer. Salidroside (Sal), an antithrombotic agent derived from Rhodiola rosea plants, was loaded into inner layer of vascular grafts to inhibit thrombus formation.

Results: The incorporation of dECM significantly promoted human umbilical vein endothelial cell (HUVEC) extension adhesion, proliferation, migration, and tube-forming *in vitro*. *In vivo* studies demonstrated that PLCL-dECM-Sal SDVGs improved extracellular matrix formation, lumen endothelialization and smooth muscle layer regeneration, compared to PLCL SDVGs lacking dECM. Incorporation of Sal promoted macrophage polarization to the M2 phenotype and attenuated calcification, thereby promoting tissue regeneration.

Conclusion: The addition of dECM and Sal successfully inhibited thrombosis and promoted vascular tissue regeneration, providing a promising rationale for their implementation in the construction of SDVGs.

Key words: small-diameter vascular graft, biomimetic, decellularized extracellular matrix, antithrombosis, tissue regeneration

ID 979

Irradiation of Near Infrared to Multifunctional NAC-loaded HA/PDA/SF Hydrogels Enhances Drug Delivery from the Nasal Route to Brain Tissues in a Rat Study

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Objective: The nasal administration of mucoadhesive hydrogels can be used to bypass the blood-brain-barrier (BBB) and may increase the efficacy of drug delivery to the brain. We investigated that Irradiation of near infrared (NIR) to multifunc-

tional NAC-loaded HA/PDA/SF hydrogels may enhance drug delivery from the nasal route to brain tissues in a rat study.

Methods: Herein, the development of N-acetyl-L-cysteine (NAC)-loaded hyaluronic acid/ polydopamine/silk fibroin (HA/PDA/SF) or HDS/NAC hydrogels with highly adhesive forces, near infrared (NIR) photothermal responses, and anti-oxidative effects had been done although those properyies were dependent on PDA contents. *In vitro* and *in vivo* studies with or without NIR irradiations to the hydrogels were also carried out to examine the efficacies of the objectives.

Results: *In-vitro* studies demonstrated the HDS/NAC hydrogels could open tight junctions in the RPMI 2650 cell line, a model cell of the nasal mucosa. The utility of HDS/NAC hydrogels as nasal drug delivery vehicle was investigated *in-vitro* and *in-vivo*. HDS/NAC hydrogels were able to open tight junctions in RPMI 2650 cells, as demonstrated by decreased trans-epithelial electrical resistance (TEER) and ZO-1 staining. This effect was markedly enhanced by NIR irradiation (HDS/NAC-NIR hydrogels). An *in-vivo* imaging study (IVIS) in rats demonstrated a 9-fold increase in the amount of NAC delivered to the brain over two hours with the use of HDS/NAC-NIR hydrogels compared to solutions containing NAC.

Conclusion: Our study demonstrated that highly adhesive with NIR irradiation of HDS/NAC-NIR hydrogels represented a novel strategy for enhancing the delivery of NAC to brain tissues using the nasal route of administration.

Key words: HA/PDA/SF hydrogels, Drug delivery, Nasal to Brain, NIR irradiation, Tight junctions, IVIS image.

ID 1000

改善损伤微环境的多功能复合水凝胶促进骨质疏松性骨缺损的修复

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目的：骨质疏松患者骨损伤部位高水平的炎症和活性氧（ROS）会打破骨形成和骨吸收的平衡，因而骨修复难度较大。在本研究中，我们制备了具有调控骨损伤部位 ROS 微环境、调控免疫响应等多重作用的复合水凝胶，探讨其在促进骨质疏松性骨缺损修复中的作用。

方法：将负载有成纤维细胞活化蛋白抑制剂的具有二氧化锰涂层的多孔磷酸钙微球（MMS）掺入到甲基丙烯酰化聚谷氨酸 / 甲基丙烯酰化明胶（m-PGA/GelMA）水凝胶中，制得复合水凝胶。采用 SEM、体外降解测试等手段对复合水凝胶的形貌、降解性能等进行表征。随后，利用骨质疏松大鼠模型，检测了 ROS 和 FAP 的表达、巨噬细胞的极化、破骨细胞的数量，并通过 Micro-CT、组织形态学染色评价骨修复效果。

结果：复合水凝胶通过下调体内 ROS、促进巨噬细胞 M2 型极化、促成骨和抑制破骨细胞分化改善骨质疏松性骨损伤微环境从而促进骨修复。

结论：开发了一种基于 ROS 微环境和免疫调节以促进骨修复的多功能复合水凝胶，为骨质疏松性骨缺损的修复提供了一种有前途的方法。

关键字：ROS 调控；免疫调节；骨质疏松；骨修复

ID 1004

生物材料产业化及临床应用

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目的：在于提供一种生物陶瓷材料人工骨，生物性和理化性能稳定，对组织无刺激，生物相容性好，使用时间长，还具有较好的抗拉和抗弯强度。可以显著减少更换频率，延长其使用寿命更加经济实惠。

方法：采用硅溶胶和六水合硝酸镁为主要原料，配以骨胶原蛋白、骨形态发生蛋白和抑制骨吸收药物进而降低破骨细胞活性，防止人工关节部位发生骨溶解；同时还可以补充骨胶原，增强骨矿化，使骨的抗压缩抗折弯能力增强，脆性降低，韧性增强，促进骨骼修复和再生。

结果：采用多功能力学测试机进行检测。抗弯强度达到 203MPa，断裂韧性达到 2.4MPam½。

采用成骨细胞种植在硅镁玉生物陶瓷材料人工骨片上，采用 MTT 比色法检测细胞的增殖能力，经过 7 天的培养，成骨细胞在硅镁玉生物陶瓷材料人工骨表面的增殖率明显高于空白对照组（P ＜ 0.05）。说明其具有很好的细胞相容性。

结论：硅溶胶分散液有大量的羟基和硅离子，硅离子能够诱导成骨细胞增殖，分化和相关蛋白表达。六水合硝酸镁做为镁源，镁离子是人体必须的微量元素之一，适量的镁能促进成骨细胞的繁殖，并直接调控骨代谢。

配以骨胶原蛋白可以促进钙、磷等无机质在骨骼上的沉积，起到修复骨组织，有利于维持健康骨组织的正常生理活动。

关键字：生物材料；降解；生物相容性

ID 1103

Supercritical Antisolvent Technology Assisted Fabrication of ICG-based Composite Nanoparticles and their Biomedical Applications

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Objective: Indocyanine green (ICG) is a commonly near infrared (NIR) imaging agent in clinical, with outstanding photo-therapy performance for tumor diagnosis treatment and therapy, as well as bacterial infection. However, ICG suffers from multiple shortcomings of poor aqueous instability in the physiological environment, short half-life and rapid body clearance, which often hinder its clinical biomedical application. Although impressive progresses in nanocarrier were made toward a joint goal that improved outcomes of ICG, the low drug loading efficacy and sophisticated construction process remain significant challenges in the production of nanoplatform.

Methods: According to the unique advantages of supercritical antisolvent process (SAS) and solution casting method, we firstly developed a novel approach to obtain ICG-loaded nanoparticles (ICG-PLO NPs), which was fabricated via coating of SAS produced-ICG nanoparticles (ICG NPs) by polypeptide poly-L-ornithine (PLO). Morover, a versatile nanoplatform based on chitosan coated ICG and luteolin (ICG/LUT-CS) was also developed for the chemotherapy-photothermal treatment of S. aureus-infected skin wounds.

Results: This unique nanoplatform (ICG-PLO NPs) with ultra-high drug encapsulation efficiency exhibited remarkably improved aqueous and photothermal stability of ICG. Notably, the coating of PLO could improve the internalization level

in cells and anticancer effect in vivo, which has comprehensively augmented the cancer phototherapy effect of ICG. In another case, ICG/LUT-CS performed excellent hyperthermia activity for damaging cell integrity and reducing drug tolerance of bacterial biofilms. Moreover, the photothermal effect significantly accelerated LUT release, damaging the intercellular protection system of bacteria and facilitating LUT delivery into biofilms. This synergistic chemotherapy-photothermal eradication of bacterial and biofilm strategy displayed outstanding potential in reinforcing the therapeutic efficacy in vivo and in vitro and diminishing the side effects.

Conclusion: Overall, this novel particle formation integrated strategy broadened the applications of SAS technology, which enlighten the design of nano-formulations containing ICG for clinical translation.

Key words: Supercritical antisolvent; Indocyanine green ; anticancer; antibactrial

ID 1127

甲壳素 /MXene 复合气凝胶球的制备及其对胆红素特异性吸附性能的研究

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目的：目前血液灌流中应用的胆红素吸附剂存在生物相容性差、吸附效率较低、无特异性吸附能力等不足，因此开发一种安全高效、特异性吸附的胆红素吸附剂有重要研究意义。

方法：选用两种对胆红素有吸附作用的原料：甲壳素（Ch）和 MXene（MX）。Ch 有良好生物相容性，二维纳米材料 MX 表面有大量含氧基团（活性位点）。将 Ch 作为基底，MX 为纳米填料，以碱 / 脲体系为溶剂，低温反复冻融 Ch 和 MX 混合物，滴落成球固化，经超临界二氧化碳干燥制备 Ch/MX 复合气凝胶球。此外，引入能特导性结合胆红素的聚 -L- 精氨酸（PLA），制备 Ch/MX/PLA 复合气凝胶球。

结果：Ch/MX 气凝胶球：能承受自身重量的 25000 倍；对胆红素有高吸附量（521.95 mg/g）；吸附过程符合准二级动力学模型和 Langmuir 等温吸附模型。Ch/MX/PLA 气凝胶球：与 Ch/MX 相比，对胆红素吸附量提高了 15.38%，在带相同电荷及相似相对分子量的竞争分子（胆固醇）存在的情况下，仍有较高吸附量（257.62 mg/g），抗干扰能力强。

结论：两种复合气凝胶球能有效吸附胆红素，Ch/MX/PLA 气凝胶球有特异性吸附胆红素能力，有望应用于临床上高胆红素血症的治疗。

关键字：甲壳素；MXene ；聚 -L- 精氨酸；复合气凝胶球；胆红素

ID 1353

羧基化丝蛋白的高效制备与生物医学应用

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目的：蛋白基天然生物材料具有良好的生物相容性与生物可吸收性，被广泛应用于组织修复、再生医学、药物缓释等生物医学工程领域。但相比于合成生物材料，已发展的针对蛋白基材料的化学改性方法十分有限，并难以对修饰

度的精确控制，极大地制约着其实际应用和未来发展。丝蛋白是一种重要的生物材料，近年来受到研究者的广泛关注。在本工作中，我们希望对丝蛋白进行高效化学改性，并能够精准调控丝蛋白分子的化学结构及材料性质。

方法：通过控制丝蛋白与丁二酸酐的反应条件等方式，实现丝蛋白的可控羧基化修饰。将羧基化丝蛋白加工为薄膜、水凝胶、多孔海绵及蛋白块材并表征其物理化学性质。通过体外实验与体内实验验证其生物相容性与生物可吸收性。

结果：经化学改性后，丝蛋白分子中羧基占比高达 12%，同时羧基化程度能够被精确调控。羧基化丝蛋白材料具备良好的加工性能，并由于羧基官能团的引入，大大增强了其亲水性与酶降解性能。生物学实验显示羧基化丝蛋白具有较低的生物毒性与良好的组织相容性，并能够在植入三个月内得到完全降解。

结论：丝蛋白的化学改性条件温和，经济高效，能够实现大批量制备，具有产业转化前景。羧基化丝蛋白材料性质优良，预期将在生物医学工程领域中发挥重要的作用。

关键字：丝蛋白；功能化；可控化学改性；生物降解；生物相容性

ID 1388

基于神经肽的肌腱 - 骨界面愈合治疗策略及其临床转化前景

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目的：前交叉韧带（ACL）损伤属于常见运动型损伤。手术重建后肌腱 - 骨界面（TBI）因高度异质性，致使复原生理性梯度结构的 TBI 存在挑战。已知调控 TBI 愈合的关键是促进新骨长入，故本人课题组长期关注采取激活内源性或补充外源性细胞或生化因子以介导 TBI 愈合。

方法：因降钙素基因相关肽（CGRP）诱骨生成特性和骨膜作为干细胞池的属性，课题组尝试利用富集 CGRP 的骨膜包裹肌腱移植物开展 ACL 重建。此外，因 CGRP 半衰期短，采用基因调控方式增强骨隧道内 CGRP 受体表达也是激活 CGRP 介导信号轴的可能方向。进一步，因镁离子可调控 CGRP 分泌，可降解镁界面螺钉被尝试用于固定肌腱移植物。研究中分别建立了小鼠、兔和羊等 ACL 重建模型，通过组织学、步态行为学、micro-CT 影像学和生物力学等评估干预方案的有效性。

结果：相比较各自空白对照组，富集 CGRP 骨膜、基因调控引起的 CGRP 受体上调以及可降解镁界面螺钉替代植入方式，均显著增强了 TBI 新骨长入量。

结论：可降解镁界面螺钉有望作为新一代肌腱固定器械通过调控神经肽水平改善 TBI 愈合。

关键字：ACL 重建；神经肽；腱骨界面；镁界面螺钉；降钙素基因相关肽

ID 1395

治疗骨感染性缺损的骨再生修复支架研究

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目的：为了减少全身的用药量，降低毒副作用的同时提高治疗效果，需要将药物引入到骨修复材料中，以达到骨重建和局部药物治疗的双重目标。因此，本项目创新性地应用天冬氨酸六肽（Asp6）靶向羟基磷灰石（HA）的作用，

制备了 Asp6 改性环糊精（β-CD）载体和胆碱磷酸分子（MCP），并将其引入到 HA 的三维多孔支架上，包载疏水的诺氟沙星（NFX）和骨髓间充质干细胞来源的外泌体，以达到重建骨缺损的同时预防和治疗骨缺损合并的感染，诱导骨相关细胞的粘附促进骨组织的再生，为骨再生修复支架的设计提供了新思路。

方法：合成可与 HA 特异性结合的 Asp6-MCP 和 Asp6-β-CD，将两种分子结合到三维多孔的 HA 支架上，包载 NFX 与外泌体，将多功能支架植入到兔子股骨远端进行骨缺损及骨感染的治疗。

结果：药物载体系统 Asp6-β-CD 和 Asp6-MCP 已经成功合成，并成功结合到 HA 多孔支架上，包载 NFX 以及结合外泌体后，能够发挥其抗菌性，诱导细胞粘附，改善材料与细胞的相互作用，同时能够促进骨缺损部位的组织再生。

结论：该支架能够在治疗骨缺损的同时治疗骨感染并诱导骨组织的再生，有望成为新一代的骨再生修复材料 .

关键字：羟基磷灰石；天冬氨酸六肽；抗菌；胆碱磷酸；外泌体

ID 1429

纳米金与人皮肤成纤维细胞作用的转录组学和代谢组学联合分析

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目的：纳米金在体外具有尺寸依赖性细胞毒性。为了探究纳米金与细胞作用机理，高通量组学技术被引入此领域，而多组学整合是功能基因组学时代研究的必然趋势。本论文的目的是联合采用两种组学技术分析纳米金对人皮肤成纤维细胞的影响机制。

方法：首先采用转录组测序技术筛选 20nm 纳米金诱导的差异表达基因并对其进行生物学通路分析。然后通过与前期获得的代谢物参与的代谢通路的对比及基因、代谢物上下游关系分析，构建基因 - 代谢物 - 代谢通路网络，最后对重要网络中代谢通路、基因和代谢物功能进行分析和验证。

结果：纳米金作用细胞 4、8、24h 后分别使 1904、1216 和 489 个基因差异表达，这些基因分别参与了 270、235 和 163 条生物学通路。构建了基因 - 代谢物 - 代谢通路网络，获得 4 条重要代谢通路和包含的 9 个基因、7 种代谢物。功能分析与验证实验发现，纳米金通过通路中的上游基因调控了下游代谢物的合成，抑制了氧化应激因而未诱导明显的细胞凋亡，但已对细胞功能产生了影响：阻滞了细胞周期，并影响了细胞骨架和细胞粘附。

结论：本论文除了获得与前期研究一致的结果外，还发现了纳米金对细胞骨架和细胞粘附能力的影响。

关键字：纳米金，人皮肤成纤维细胞，转录组学，代谢组学，生物信息学

ID 1578

Development of Photothermal-Triggered Dendrimer Nanovaccines to Boost Systemic Antitumor Immunity

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Objective: Tumor vaccine that can effectively activate or strengthen the body's antitumor immune response to kill and eliminate tumor cells has attracted widespread attention. Currently developed tumor vaccines have severe shortcom-

ings such as low bioavailability and lack of dual or multiple functions, resulting in poor antitumor efficacy.

Methods: Herein, we report the development of an advanced nanosystem integrated with phenylboronic acid (PBA)-functionalized poly(amidoamine) dendrimers of generation 5 (G5), copper sulfide nanoparticles, and cyclic GMP-AMPP (cGAMP), an immune adjuvant (for short, G5-PBA@CuS/cGAMP) to act as a photothermal-triggered nanovaccine.

Results: We show that the prepared functional nanosystem possesses an average CuS core size of 3.6 nm, prominent near-infrared absorption feature to have an excellent photothermal conversion efficiency of 44.0%, and good protein adsorption characteristics due to the PBA modification. With these features, the developed nanosystem can be adopted for photothermal therapy of primary melanoma tumors and simultaneously absorb the released tumor antigens, thus creating photothermal-triggered dendrimeric nanovaccine of G5-PBA@CuS/cGAMP/antigen in situ to induce antitumor immune response to inhibit the distal tumors as well. Meanwhile, melanoma cells treated with the G5-PBA@CuS in vitro under laser irradiation allowed the creation of G5-PBA@CuS/antigen complexes that could be further integrated with cGAMP to form preformed nanovaccine for effective primary tumor inhibition and tumor occurrence prevention.

Conclusion: The designed photothermal-triggered dendrimeric nanovaccine may represent an advanced nanomedicine formulation to effectively inhibit the growth of primary and distal tumors, and prevent tumor occurrence through the stimulated systemic antitumor immunity.

Key words: dendrimers; copper sulfide nanoparticles; nanovaccines; tumor therapy

ID 1734

3D 打印具有抗菌潜力的 Se/Sr/ zn 掺杂羟基磷灰石 / 聚己内酯复合支架用于骨肉瘤治疗和骨再生

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目的：消除骨肉瘤并修复骨缺损的同时避免细菌感染。

方法：将硒 / 锶 / 锌掺杂的羟基磷灰石浸提液分别与金黄色葡萄球菌和大肠杆菌共培养并铺板，记录和观察上述两种细菌的增殖和菌落的生长情况。将硒 / 锶 / 锌掺杂羟基磷灰石混合生理盐水（50mg/ml）注射到荷瘤小鼠的实体瘤内，每 3 天注射 1 次（100ul/ 次 ），8 天后取出肿瘤表征并记录相关结果。将硒 / 锶 / 锌掺杂羟基磷灰石 / 聚己内酯复合支架植入大鼠股骨缺损部位，在 4 周和 12 周观察并记录缺损处骨组织修复情况。

结果：结果表明，相对于对照组和羟基磷灰石组，硒 / 锶 / 锌掺杂羟基磷灰石粉末的浸提液能有效抑制金黄色葡萄球菌和大肠杆菌的增殖及菌落的生长。给药 8 天后，硒 / 锶 / 锌掺杂的羟基磷灰石能有效消除肿瘤，且呈现良好的体内生物安全性，而对照组和羟基磷灰石组的肿瘤体积较大。硒 / 锶 / 锌掺杂羟基磷灰石 / 聚己内酯复合支架能有效修复股骨缺损，相对于对照组和羟基磷灰石 / 聚己内酯组其成骨面积较大。

结论：硒 / 锶 / 锌掺杂羟基磷灰石能有效消除骨肉瘤并抑制黄色葡萄球菌和大肠杆菌的增殖，硒 / 锶 / 锌掺杂羟基磷灰石 / 聚己内酯复合支架能有效修复股骨缺损。

关键字：骨肉瘤，3D 打印，羟基磷灰石，成骨，抗菌

ID 1752

布拉氏酵母菌生物活性材料作为气管插管涂层拮抗白念珠菌

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目的：气管插管所建立的人工气道对 ICU 重症患者极其重要，但是插管的留置会导致白念珠菌等病原真菌的繁殖和生物被膜的形成，带来一系列真菌感染问题，其中白念珠菌引起的念珠菌血症具有极高的致死率，严重危及重症及免疫缺陷患者的生命安全。如何预防气管插管引起的念珠菌感染成为临床中亟需解决的问题。

方法：布拉氏酵母菌是一种常见的益生菌，能够拮抗白念珠菌的黏附。我们基于一步光交联反应构建了新型布拉氏酵母菌生物活性材料，实现了益生菌在水凝胶孔洞内的集聚生长，提高了布拉氏酵母菌应对高盐、氧化压力等外界环境的能力。

结果：生物活性材料作为气管插管涂层，显著抑制了白念珠菌在气管插管表面的黏附，降低了其侵袭小鼠组织的能力。

结论：这种限域生长模式提高了益生菌的抗逆性，为气管插管等医疗器械真菌感染的防治提供过了新途径，为益生菌的应用提供了新思路。

关键字：气管插管；抗真菌涂层；布拉氏酵母菌；限域生长；白念珠菌

ID 2047

原位 3D 打印液态金属 - 水凝胶多功能柔性生物电子器件

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目的：水凝胶生物电子因其优异的生物相容性、对组织的机械顺应性和多功能可修饰性受到广泛关注。然而，目前的困难，如与金属界面的互连问题，制造策略的缺乏，仍然是开发功能集成水凝胶生物电子的巨大挑战。

方法：本文开发了一种简便的原位 3D 打印方法来制备液态金属 (LM)- 水凝胶杂化体，该杂化体不仅能够对软组织具有优异的机械顺应性 (~1-10 kPa)，且具有可用于电流注入的离子界面 (1.21-2.43 S m-1)。更重要的是，本文使用的水凝胶中含有明胶、海藻酸钠和氯化钾 (以下简称 GSP)，不仅在 LM 打印中起到支撑基质和电解质的作用，而且经 Ca2+ 一步交联后可直接作为水凝胶生物电子或器件的生物界面。

结果：由于 GSP 水凝胶对软组织具有良好的机械顺应性、低热导率、生物相容性、载药能力以及离子导电性，我们实现了基于水凝胶的生物电子器件或植入式生物电子器件的快速制造，包括具有可移动电气连接的 LM- 水凝胶混合电路，多模式压力传感器，用于刺激细胞和组织的软体电刺激器，以及离子辅助抗菌伤口敷料。

结论：通过这种简便、自动式原位 3D 打印方法制备的 LM- 水凝胶杂化体，为水凝胶生物电子器件的开发提供了一个通用的、多功能的平台。

关键字：液态金属 - 水凝胶杂化结构；原位 3D 打印；液态金属；水凝胶生物电子学；水凝胶器件

ID 2097

The Feasibility Study of HOC-Ti for Dental Implant *in vitro* and *in vivo*

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Objective: This study was aim to investigate a suitable surface treatment method for high oxygen concentration titanium (HOC-Ti) and to evaluate its biocompatibility as dental implant material in vitro and in vivo.

Methods: HOC-Ti was produced by titanium powders and rutile powders using powder metallurgy method. Then, its surface was modified by anodic oxidation (HOC-NT). After detected the electrochemical characteristic of HOC-Ti, the surface properties of HOC-NT were investigated. MC3T3 and MLO-Y4 cells were attached to evaluate the biocompatibility of HOC-NT in vitro, following a co-culture system to observe the osteogenisis effects induced by HOC-NT on osteoblastic functional cells. In addition, the osseointegration formation around HOC-NT implant was evaluate through in vivo experiment.

Results: The electrochemical properties of HOC-Ti was changed and lead to a unique micro-nano composite structure after anodic oxidation on HOC-Ti, which exhibited excellent hydrophilicity and suitable surface roughness. Unique morphology significantly promoted biocompatibility in vitro. Notably, studies confirmed the regulation effect of HOC-NT in functional osteogenisis cell. Following in vivo study also indicated an accelerated formation rate of new bone and a more stable osseointegration around HOC-NT implant.

Conclusion: The unique morphology of HOC-NT has been created by anodic oxidation method and exhibited enhanced physicochemical and biological properties. The promotion of bone formation around implants indicated the feasibility of HOC-NT for oral implants applications.

Key words: titanium,anodic oxidation,biocompatibility,high oxygen concentration

ID 2108

Antibacterial Hydrogel Dressing with Ca^{2+}-dependent Hyaluronidase Responsiveness Accelerates Wound Healing via On-demand Release of AIE Photosensitizer

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Objective: The combination of hydrogel (as dressing) and AIE photosensitizers (PSs, ROS-generator for bacteria killing) brings new paradigm for infected wounds healing since growing risk of antibiotic abuse. Current research concentrates mainly on the continuous production of ROS, while the side effects of its overproduction were often neglected. The on-demand system having a "shutting down" mechanism of ROS release is desiderated to improve the current status of wound management.

Methods: The novel antibacterial hydrogel dressing with Ca^{2+}-dependent hyaluronidase (HAase) responsiveness and on-demand release of AIE PSs (TTpy-$NH_{2,}$ generating ROS under visible light irradiation.) has been prepared by hyaluronic acid (HA) and sodium alginate (SA). HA, as the skeleton of the hydrogel dressing, could undergo degradation by HAase, produced by extensive pathogenic bacteria. SA, as the tendon of the dressing, not only directly mediates the gelation of hydrogel under the action of $Ca^{2+,}$ but also manages the release process of Ca^{2+}. Ca^{2+} was for the first time demonstrated to be able to promote the activity of HAase at low concentration and deactivate HAase at high concentration.

Results: The "ON" mechanism of bacteria-killing was regulated by the level of infection that more seriously infected wounds produced more HAase, which degraded more hydrogel dressing and released more TTpy-NH_2 that produced more ROS. The low Ca^{2+} concentration released by the hydrogel dressing helped in this process. Once the bacteria were killed efficiently, the "OFF" mechanism was demonstrated along with the accumulation of released Ca2+, HAase was deactivated, thus, shutting down the outflow of TTpy-NH_2 and minimize the damage caused by ROS overproduction.

Conclusion: This on-demand system having a "shutting down" mechanism in the healing process exhibit great superiorities (smarter, safer and more precise) compared with the mediocre model, in which TTpy-NH2 are continuously released through the whole process of wound healing.

Key words: antibacterial hydrogel, AIE photosensitizer, enzyme responsiveness, on-demand release, wound healing

ID 2319

DC 外泌体工程化用于三阴性乳腺癌治疗

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目的：利用成熟的树突状细胞来源的外泌体（Dex），利用化学修饰的方法进行改造，使其具备独特的靶向能力，从而聚集于三阴性乳腺肿瘤部位；同时在外泌体内部装载化疗药物阿霉素，进行高效的药物递送，从而构建工程化生物治疗外泌体，将免疫治疗与靶向化疗有机结合，应用于三阴性乳腺癌的治疗中。

方法：通过超速离心法获得了 Dex，基于无铜点击化学的原理对其修饰荧光与靶向肽，定量研究其与肿瘤细胞、免疫 T 细胞等的相互作用。

结果：工程化修饰后的外泌体（Dex-c(RGD)/Cy5/DOX）在体外靶向杀伤 4T1 肿瘤细胞。同时，Dex 利用其天然具备的免疫 T 细胞刺激作用，成功激活 CD4+/CD8+T 细胞。

结论：本课题基于成熟树突状细胞分泌的外泌体（Dex），成功构建了一种具备肿瘤细胞靶向性、免疫激活、以及化疗药物精准输送等多功能的工程化纳米药物（Dex-c(RGD)/Cy5/DOX），可用于三阴性乳腺癌的治疗，具有潜在的临床应用价值。

关键字：乳腺癌，外泌体，肿瘤靶向，化疗

ID 2326

Photothermal Ferrotherapy – Induced Immunogenic Cell Death via Iron-based Ternary Chalcogenide Nanoparticles against Triple Negative Breast Cancer

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Objective: Photothermal therapy that allows rapid and minimally invasive ablation of cancer has received considerable attentions in the past decade. Still, there is an unmet need to have a multifunctional nanodrug system with more potent efficacy for highly aggressive cancers or those with limited therapeutic options, e.g., triple negative breast cancers (TNBC).

Methods: We reported iron-based ternary metal chalcogenide nanoparticles (NPs), namely, AgFeS2, which enabled synergistic therapy of TNBC via apoptosis, ferroptosis, and tumor antigen-induced ICD.

Results: The designed AgFeS2 NPs have strong absorption in the NIR region and can convert NIR light into heat under laser irradiation. After the NPs were uptaken by tumor cells, the silver and iron ions were released in the lysosomes, and accelerated via the laser-induced heat can accelerate this process. Subsequently, the Fe3+was converted to Fe2+ by glutathione (GSH) reduction, which resulted in the production of highly toxic .OH via a Fe2+-driven Fenton reaction and further initiated the ferroptosis of tumor cells. The in vitro and in vivo antitumor studies exhibited a remarkable suppression of tumor growth. We also demonstrated that AgFeS2 NPs-mediated PTT/ferroptosis could induce ICD and promote innate/adaptive immunity by enhancing the CD4+/CD8+ T cell infiltration in the tumor area.

Conclusion: This presented study demonstrated the great potential of iron-based ternary chalcogenide nanoparticles as a new therapeutic platform for combining photothermal therapy, ferrotherapy, and immunotherapy for the suppression of TNBC.

Key words: Iron-based ternary chalcogenide nanoparticles; tumor; apoptosis; ferroptosis; immunogenic cell death

ID 2378

Construction of Up-regulated ROS Bifunctional Protein-Copper Ion Nanoflower and its Application in Biofilm Removal

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Objective: Chronic infection caused by bacterial biofilms is a major threat to human health. Facing the issues of increased multi-drug resistant strains from antibiotic misuse， the limited large-scale application of bacteriophages and antimicrobial peptides， people are more urgent for novel antimicrobial technologies. In this study, organic-inorganic hybrid protein nanoflowers (SNFs) were prepared to introduce a dual mode of photo-dynamic/chemo-dynamic therapies, paving the way for the treatment of complex bacterial infectious diseases.

Methods: We prepared BSA-Ce6, a novel photosensitizer, by using bovine serum albumin (BSA) as a "co-solvent" to carry chlorin e6 (Ce6). Then we prepared organic-inorganic hybrid protein nanoflowers (SNFs), in which BSA-Ce6 acted as an organic component with photodynamic properties and copper ions as an inorganic component. SNFs introduced copper ion-mediated Fenton reaction in addition to photodynamic therapy. The disruptive effects of SNFs on bacterial biofilms in vitro and in vivo were explored using live/dead bacteria fluorescence staining and a rabbit dorsal Staphylococcus aureus abscess infection model.

Results: The Results showed that compared with the unmodified Ce6 and free BSA-Ce6, SNFs were superior in storage stability, $^1O_2$/•OH production efficiency, and affinity with bacteria. Benefitted from the flower-like hierarchical structure and micrometer size, SNFs could effectively remove the biofilm formed by Gram-negative/positive bacteria, and exhibited better wound healing effects.

Conclusion: The bifunctional protein nanoflowers prepared based on the ROS upregulation strategy have higher stability and catalytic activity, simple and novel structures, mild and harmless preparation methods. SNFs can be developed into novel antibacterial materials to deal with complex bacterial infectious diseases.

duced toxic treatment, Protein nanoflower, Bacterial biofilm removal, Photo-dynamics, Chemo-dynamics

ID 2561

抗伤口动态撕裂的梯度模量粘性凝胶复合材料

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目的：潮湿、动态环境下，缝合 / 吻合的伤口容易产生应力集中和动态撕裂；现有的组织粘性凝胶，弹性模量低，在动态载荷下容易产生大变形，无法保持伤口的紧密贴合。针对潮湿环境下伤口动态闭合的难题，本研究提出了梯度弹性模量粘性凝胶复合材料的设计及制备方法。

方法：该研究提出了角度溶液吹纺方法，制备了模量范围可控的梯度弹性模量纤维网络；以梯度模量纤维网络为骨架，结合粘性凝胶基体，制备了梯度弹性模量粘性凝胶复合材料（GmTAC）。

结果：GmTAC 贴片在干式状态下（100μm 厚）可粘附在湿润的组织表面，实现伤口密封；由于其独特的梯度弹性模量特性，GmTAC 通过优化应力传导和应变抑制，在不限制伤口周围正常组织变形的同时，能够避免伤口的动态撕裂；优化设计的 GmTAC 贴片能够让伤口组织像正常组织一样变形，即便在大拉伸和大内压的情况下，也没有明显的撕裂或应力集中；由于采用可降解的材料组分，GmTAC 可在体内安全降解。相关特性在体外和体内实验中得到了系统的验证；相关技术已获中国发明专利授权。

结论：该研究提出的结构功能一体化梯度弹性模量粘性凝胶复合材料，将为体内伤口的动态闭合提供了一种有效的解决方案。

关键字：伤口闭合、粘性凝胶、组织凝胶复合材料、伤口撕裂、梯度模量

ID 2784

Multifunctional Microcapsules with Programmable Precise Photorelease Manufactured by Microfluidic Aerodynamic Printing

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Objective: Microfluidic-engineered microcapsules capable of protecting, delivering, and tuning the trans-shell behavior of encapsulated payloads are considered advanced controlled-release materials and have attracted a lot of attention in biomedical engineering. In particular, microfluidic-engineered microcapsules are promising as novel embolic agents for transarterial chemoembolization (TACE), a widely recommended interventional therapy designed to block tumor supply vasculature with drug-laden embolic agents, thereby cutting off tumor tissue of oxygen and nutrients and administering local chemotherapy. It is because the current TACE is limited by the weak theranostic integration of available embolic agents, especially the deficient controllability of the therapeutic window. Therefore, there is an urgent need to develop a multifunctional embolic microcapsule capable of precise controlled-release.

Methods: Based on the photoisomerization material spiro-pyran (SP), a substance capable of multiple property alterations upon UV/Visible light irradiation, we manufactured photo-responsive embolic microcapsules (PEMCs) with dynamic shells of reversible permeability-switching capability by programmable pulsed aerodynamic printing (PPAP), a novel in-air microfluid-

ic drop-on-demand technique. Specifically, PPAP allows rapid on-demand customization of PEMCs by utilizing a high-speed pulsed airflow as the driving sheath flow to eject the double emulsion droplet consisting of a SP-modified PLGA oily shell and a therapeutic aqueous core containing magnetic nanoparticles and drugs into the aqueous receiving fluid without surfactants, shaking until the solidification.

Results: Benefiting from the high spatiotemporal resolution and high sensitivity of the photo-stimulus-responsive systems, the PEMCs are capable of precise on-demand controlled drug release and incorporate multifunctional features such as imageable, magnetically actuatable, and biodegradable. Furthermore, after the mechanism analysis and experimental validation, the process parameter domains of the PPAP technique and drug controlled-release models of the PEMCs have been presented.

Conclusion: By combining with functional optical devices, PPAP-manufactured PEMCs are promising to be the novel smart embolic agents for vascular interventional therapies and other various advanced controlled-release applications.

Key words: Embolic Microcapsules, Droplet Microfluidics, Photo-responsive, Transarterial Chemoembolization (TACE)

ID 2831

A Synthetic Dynamic Photoresin for Fast Volumetric Bioprinting of Functional Hydrogel Constructs

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Objective: Volumetric bioprinting (VBP) has emerged as a powerful tool for fast 3D bioprinting of living cellular constructs in one step. However, existing bioresins that meet the physicochemical requirements of VBP are limited to thermo-responsive photosensitive gelatin derivatives of high polymer concentrations.

Methods: For this project, a series of bioresins were formulated with varying amounts of norbornene-functionalized PVA (nPVA), sacrificial gelatin, PEG dithiol crosslinker, LAP photoinitiator and human mesenchymal stem cells (hMSC). Photo-rheology and unconfined compression tests were applied to assess printability and mechanics. The incorporation of 5% gelatin as a temporary network enabled the printability of nPVA resins with low polymer concentrations down to 1.5%.

Results: After 24 h incubation at 37°C, ~85% gelatin was released out of the fabricated constructs. Resins containing 1.5% and 3% nPVA were used to print soft and stiff hydrogel constructs with a compressive modulus of 2.7±0.1 kPa and 25.1±1.7 kPa, respectively. After bioprinting, cells appeared highly viable (>90%), indicating good cell-compatibility. However, the morphology of embedded cells showed a remarkable difference in soft and stiff matrices. After 7 days, cells embedded in soft matrix showed longer protrusions compared to cells in stiff matrix. Additionally, complex cell-laden constructs such as trabecular bone were printed using nPVA resins within 7-15 s. Interestingly, single hMSCs self-organized into multicellular aggregates in alignment with the orientation of the printed channels.

Conclusion: In conclusion, we developed a synthetic bioresin by introducing a thermo-releasable gelatin network into a photo-clickable PVA hydrogel for fast VBP of 3D tissue models. The incorporation of gelatin as a temporary network enabled us to decouple the physicochemical properties of resins from the fabrication process, providing a dynamic environment for fast spreading and growth of embedded hMSC. Our PVA resin represents a versatile biomaterial for fast photofabrication of 3D living environments with well-defined biophysical and biochemical properties.

Key words: volumetric bioprinting, hydrogels, biofabrication, thiol-ene reaction, tissue engineering

ID 2835

Mn-Single-Atom Nanozyme Functionalized BCP Scaffolds for Cascade Reaction-Enhanced Antibacterial Activity and Bone Regeneration

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Objective: The bone defects caused by open trauma, osteosarcoma, infection or congenital diseases, has always been a challenging work in orthopedics. Especially the infective bone defect, which involves bone defect and bone infection simultaneously, is increasingly threatening human health. Conventional therapeutic strategies have several drawbacks. The unsatisfactory efficacy has been ascribed to factors such as secondary trauma of autologous grafts, immune response of allogeneic grafts, and second surgery for non-degradability of bone cement. Thus, it is of great scientific and clinical significance to develop a biomaterial which not only has good osteogenic differentiation capacity to repair the bone defect, but also owns the ability to kill the bacteria.

Methods: The morphological images, EDS and corresponding elemental mapping of Mn/HSAE@BCP scaffolds were obtained from SEM. The pore structure and compressive strength of scaffolds were also evaluated. The CAT, OXD and POD-like activity were evaluated. The In vitro antibacterial activities and osteogenic differentiation (alizarin red S and ALP staining) were also performed. Finally, the In vivo osteoinduction and antibacterial activities were evaluated by micro-CT, MRI, X-ray, the tibia sections were stained with H&E, Masson trichrome and Giemsa solutions.

Results: The integrated Mn/HSAE@BCP scaffolds could catalyzes the conversion of H2O2 to produce ·OH and ·O2- through cascade reaction. Besides, the prominent thermal conversion efficiency of Mn/HSAE@BCP scaffolds can be utilized for sonodynamic therapy (SDT). The synergetic strategy of CDT/SDT enable the sufficient generation of reactive oxygen species (ROS) to kill S aureus or E. coli. Also, the Mn/HSAE@BCP scaffolds has the excellent ability to promote the proliferation and osteogenic differentiation of rabbit bone.

Conclusion: Our Results demonstrate the good potential of Mn/HSAE@BCP scaffolds for the enhanced antibacterial activity and bone regeneration, which provide an effective method for the treatment of clinical infective bone defect.

Key words: Infectious bone defect, Mn-single-atom nanozyme, BCP scaffolds, Cascade reaction, Osteogenesis

ID 2877

细菌纤维素基可食用片状载体在细胞培养肉中的应用研究

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目的：细胞培养肉可改善传统畜牧养殖肉生产中存在的污染排放大、能量转换效率低、动物痛苦等问题，作为新型替代蛋白备受瞩目。细胞培养肉的规模化生产需要高密度培养技术，其中载体至关重要，它可为贴壁细胞提供必需的锚定位点和生长空间，保护细胞免受机械损伤。然而，现有用于高密度培养的载体难以在可食用性、制备成本、使用成本各方面兼顾。因此，需要面向细胞培养肉生产需求有针对性地开发载体。

方法：本研究通过简易、可规模化的方法制备了细菌纤维素（BC）基可食用片状载体，采用活死染测试了成肌细胞在一系列 BC 基载体上的 7 天生长情况，并对载体进行循环利用测试和多重条件下的酶解测试。

结果：BC 基载体厚度约为 20μm。由细胞培养测试发现，BC- 蘑菇壳聚糖（MC）载体中活细胞面积比可达 90% 以上，成肌细胞培养效果优于聚赖氨酸、明胶改性的 BC 基载体。由循环利用测试发现，BCMC 载体在二次培养中仍能使细胞良好增殖。由酶解测试发现，BCMC 载体在接种细胞前后均可良好降解。

结论：本研究制备的 BCMC 载体简易、经济、可食用、可循环、可降解，为细胞培养肉规模化生产提供支持。

关键字：生物材料；多糖；纤维素；蘑菇壳聚糖；细胞农业

ID 2905

近红外响应的具有协同抗菌和促进骨整合的牙科种植体

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目的：减少抗生素的使用，使得种植体术后感染的治疗越来越有挑战性，特别是针对植入早期组织与种植体整合不足而引发的细菌入侵问题。通过协同作用开发多种方式减少细菌感染将优于单一模式的抗菌手段

方法：在这项工作中，磷酸钛 / 纳米羟基磷灰石（TiP-Ca）与氧化铜纳米粒子（n-CuO）构成的复合涂层（TiP-ua）结合近红外（NIR）光照射被证明可以通过光热、光动力来杀灭金黄色葡萄球菌和大肠杆菌

结果：复合涂层具有高效的光热转换能力，并能产生少量活性氧（ROS）。在体外试验证明只需照射 10 分钟就使种植体具有优异的抗菌能力。除此之外，复合涂层 TiP-ua 还能加快种植体与周围骨组织的整合速率，改善新骨的形成，加速抵御细菌的入侵。在该方案中，复合涂层表现出优异的生物相容性，NIR 光照射下也不会对正常细胞造成致命的结构破坏。

结论：我们的研究揭示一种协同抗菌的方法，具有高生物安全性，并对骨组织的修复产生积极作用，将在骨科和牙科应用中具有巨大的临床潜力。

关键字：近红外、协同抗菌、骨整合、牙种植体

ID 3007

Boosted Near-infrared II Photoimmunotherapy via a Multifunctional Biomimetic Gold Nanorods for Solid Tumor

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Objective: Efficient immunotherapy for solid tumor faces many challenges, e.g. selective delivery of therapeutics into the deep center, low immunogenicity, the complex immunosuppressive tumor microenvironment. Phototherapy triggered by the second region of near-infrared laser (e. g. NIR-II, 900-1700 nm) is very beneficial for deep tumor killing and immuno activation because of that NIR-II laser owns higher tissue penetration depth and immunogenetic cell death effect. On the other hand, NO emerges as a potent candidate to promote angiogenesis, alleviate tumor hypoxia and reprogram the tumor immunosuppressive microenvironment. Based on the above, a kind of multifunctional biomimicry gold nanorod (denoted as GS@MMT) was developed with the aim to realize deep tumor targeting & penetrating, NIR-II phtothermal ab-

lation of tumor cells, photothermally controlled releasing NO to reprogram tumor immunosuppressive microenvironment and enhancing the efficiency of photoimmunotherapy.

Methods: GS@MMT was constructed by camouflaging the S-nitrosothiol grafted gold nanorods with macrophage membrane and further modified with the tumor-penetrating peptide tLyp-1.

Results: GS@MMT had excellent efficiency of photothermal conversion and NO releasing under irradiation (1064 nm),. The data of 3D tumor sphere and in vivo 4T1 mammary tumor model verified its targeted penetration and accumulation into deep tumor layers and thus effectively suppressed the tumor growth. Moreover, GS@MMT could effectively reprogram the tumor immunosuppressive microenvironment (e. g. decreasing programmed death ligand 1, repolarizing tumor associated macrophages) by relieving tumor hypoxia and enhancing the blood perfusion. GS@MMT was relatively biosafe by the analysis of the liver function, kidney function and organ H&E staining.

Conclusion: In summary, our study demonstrated an engineered biomimetic nanosystem for efficient photoimmunotherapy against solid tumors with the external NIR-II laser activation and the internal interfere of tumor microenvironment.

Key words: NIR-II phototherapy; NO; macrophage membrane; cancer immunotherapy; tumor suppressive microenviroment

ID 3019

The study of the Construction of PLGA-PEG Nanoparticles Conjugated with IL1Ra and sTNFRI and their Efficacy in Experimental Treatment of Rheumatoid Arthritis

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Objective: Rheumatoid arthritis (RA) is an autoimmune disease dominated by joint disease. Clinically, drug therapy is mainly used to relieve the condition of patients, but the short blood circulation time and poor curative effect of some drugs have promoted the research and application of drug delivery systems based on nanomaterials in the treatment of RA. Therefore, we prepared nanoparticles loaded with IL1Ra and sTNFRI and explored their therapeutic effects on collagen-induced rheumatoid arthritis(CIA), providing some research experience for the clinical treatment of RA disease.

Methods: We purified the proteins IL1Ra and sTNFRI respectively and conjugated them to the nanomaterial PLGA-PEG. The experimental Methods mainly include morphology and functional verification of IL1Ra+sTNFRI nanoparticles, verification the existing time and efficiency of IL1Ra+sTNFRI nanoparticles at the site of inflammation , and exploring the therapeutic effect of IL1Ra+sTNFRI nanoparticles in CIA mice.

Results: We successfully conjugated the proteins IL1Ra and sTNFRI to the surface of nanoparticles (PLGA-PEG), and cellular experiments showed that NHS modification did not affect the biological activities of proteins. The Results of the imaging system further showed that IL1Ra+sTNFRI nanoparticles could significantly prolong the existing time of the proteins in the joint cavity of mice. The ZIA model demonstrated the ability of IL1Ra+sTNFRI nanoparticles to passively target sites of inflammation. The Results of treatment experiments showed that the levels of inflammatory factors were significantly reduced. Moreover, clinical arthritis scores and histological sections also indicated that the CIA symptoms were significantly relieved in mice treated with IL1Ra+sTNFRI nanoparticles.

Conclusion: The nanoparticles loaded with proteins IL1Ra and sTNFRI can not only increase the residence time of protein drugs in the joint cavity, but also rapidly target inflammatory sites in the ZIA model of mice, and also achieve good therapeutic effect in CIA mice, which provides a potential method and strategy for the treatment of RA.

Key words: Rheumatoid arthritis; IL1Ra; sTNFRI; nanoparticles; PLGA-PEG

ID 3027

考虑空间多向腐蚀和非均匀腐蚀耦合效应的生物可降解金属血管支架降解模型

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目的：生物可降解金属血管支架被誉为介入医疗领域的第四次革命，其降解行为是制约其临床应用推广的主要原因。本研究通过自主建立的降解模型研究生物可降解金属血管支架降解过程中力学性能演化规律。

方法：根据连续介质损伤力学理论，建立考虑空间多向腐蚀效应的非均匀降解模型，同时提出了基于质量损失、拉伸断裂和多暴露面腐蚀实验的校准方法，并对模型及校准方法的通用性和准确性进行了验证。对比研究了所提出模型与现有模型的模拟结果，验证了模型的先进性。利用自主开发的降解模拟计算程序对复杂的血管支架结构进行了降解过程数值模拟，获得了支架力学性能的演化规律。

结果：研究结果表明：所建立的降解模型具有空间和时间双重属性，校准后的模型能够准确地模拟实验中腐蚀对试件质量损失和结构完整性的影响规律；与现有降解模型相比，所提出的模型能够更真实地反映腐蚀过程中试件表面形貌的变化过程；在支架降解模拟过程中，因腐蚀的非均匀特性，其力学性能随着降解时间的增加呈非线性下降趋势。

结论：降解实验和数值模拟表明，相较于现有降解模型，该模型能够更真实地反映降解过程中试件表面形貌和力学性能的演化。

关键字：生物可降解金属；血管支架；降解模型；降解实验

ID 3279

基于毛细血管效应的壳聚糖止血海绵的研究

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目的：战争和平民事故等创伤引起的不可控制的出血是士兵和平民死亡的主要原因，其中由于失血过多死亡占全球创伤失血死亡的 30%，其中大多数死亡是发生在紧急治疗之前。止血材料紧急救援是十分必要的，在这过程有效和快速的止血可以挽救生命。其中止血海绵被广泛被应用。海绵的液体吸收能力影响着止血性能。因此寻找具有高吸收性和快速吸收性的止血材料是重要的。先前的研究主要是通过形成互通网络的 3D 结构的海绵来提高液体吸收性能，而这个吸水速率往往比较缓慢，并没有达到理想的状态。有文献报道，与非定向孔结构相比定向排列孔结构的海绵低的曲折效应和毛细管力使得定向孔的海绵具有更快的液体吸收速率。因此通过制备定向有序结构多孔海绵可以更好的加速止血效果。

方法：制备了非定向孔结构和定向排列有序孔结构的 CS 海绵，通过液体的吸收速率实验来测试多孔结构的 CS 海绵吸液能力，并通过体外和体内初步研究多孔结构的 CS 海绵止血性能的好坏。

结果：定向孔结构的 CS 海绵由于毛细管效应吸液能力和止血性显著的优于非定向孔结构的 CS 海绵，且结论具有定向排列孔结构的止血海绵通过毛细管效应其加速血液的吸收促进血细胞和凝血因子的聚集，加速了伤口止血过程。

关键字：毛细管效应 止血海绵

ID 3498

Low-dose EDB-Fibronectin Gd-DOTA Specific Contrast Agent for Pancreatic Cancer Targeting Magnetic-optical Dual-modality Imaging *in vivo*

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Objective: PDAC is a lethal and hypovascular tumor surrounded by dense stroma. Precise detection and accurate monitoring chemotherapy are important to improve patient survivals. Molecular imaging is a promising method for accurate detection of the disease. Extradomain-B fibronectin (EDB-FN), a high-expression onco-protein in the tumor stroma, can realize targeted and effective molecular imaging. Albumin-bound paclitaxel and gemcitabine (AG) chemotherapy caused histological changes seriously affect the accuracy of conventional imaging techniques for assessment. Therefore, we prepared EDB-FN targeted Gd-based contrast agent (EDB-Gd-DOTA-Cy7) to perform fluorescence molecular imaging (FMI) and MRI for accurate therapeutic monitoring of PDAC.

Methods: For FMI/MRI, subcutaneous and orthotopic models were established. Mice were intravenously injected with EDB-Gd-DOTA-Cy7 and free Cy7 or Gd-DOTA at the Gd concentration of 0.05 mmol/kg, merely a half of clinical dose. The TBR (Tumor background ratio) of fluorescence intensity and the ratio of T1 value reduction (T1d%) were compared quantitatively. For chemotherapy monitoring, mice were treated with or without AG chemotherapy. FMI/MRI were performed before and after treatments. Histological analyses were used as references for validation.

Results: The optimal imaging time point was 30min after injection of EDB-Gd-DOTA-Cy7 with 0.05 mmol/kg, only a half of clinic dosage, in both FMI and MRI, except FMI of orthotopic model due to limit imaging depth. In addition, the targeted probe generated 1.4-fold and 1.9-fold robust contrast-enhanced and longer retention compared to Cy7 or Gd-DOTA ($p < 0.05$). For chemotherapy montoring, AG chemotherapy reduced tumor volume. T1d% and TBR were significantly increased 2.3-fold and 1.3-fold in Vehicle group in fibrotic tumor areas compared to AG group ($p < 0.05$). Histological analyses were used for validation.

Conclusion: Integration of FMI/MRI with low-dose EDB-Gd-DOTA-Cy7 could complement its advantages and visualize PDAC precisely. Moreover, EDB-Gd-DOTA-Cy7 monitor chemotherapy accurately, which means the targeted probe possesses clinical applications in precise diagnosis, post-treatment monitoring and disease management.

Key words: Pancreatic cancer; Dual-modality imaging; Fibronectin; Targeted imaging

ID 3518

Light-triggered Nanohybrid Liposomes as *in situ* ultrafast CuET Generators for Precise Cancer Therapy

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Objective: Recently, the strategy of co-delivering copper ions and disulfiram for in situ generation of cytotoxic CuET has been extensively investigated in cancer management. However, how to rapidly and massively generate CuET at tumor sites remains to be resolved. Enhancing the reaction rate at the maximum copper ions/DSF concentration to quickly produce large amounts of CuET is crucial for therapeutic effects, but has not been achieved so far.

Methods: Herein, we designed a burst-release cascade reactor consisting of Cu2−xSe QDs and DSF, which triggered by the second near-infrared (NIR-II) light irradiation to rapidly and massively generate Cu2-xSe-ET complexes for enhanced in situ chemotherapy.

Results: This work breaks the spatial-temporal limits, and achieves simultaneous delivery and precisely controlled release of DSF and copper sources at relatively high doses, which successfully increases the efficiency and quantity of Cu2-xSe-ET generated in situ inside tumors. Furthermore, by taking advantage of the features of small-size Cu2-xSe QDs with multiple defects and high surface reactivity, DSF can be directly reduced and chelated at the surface defect sites of Cu2-xSe to form Cu2-xSe-ET complexes. Meanwhile, Cu2-xSe-ET was conformed to have the same anti-tumor mechanism as CuET, namely inducing cell tumor death via increased autophagy.

Conclusion: A light-triggered cascade of interlocking reactions, combined with in situ explosive generation of tumor-suppressive substances, provides a promising paradigm for the design of novel nanoplatforms in tumor therapy.

Key words: Copper selenide, Phase change materials, Autophagy, Precise cancer therapy

3570

A Novel GSH-responsive Host-guest Polymer-based Nanoparticles as Carrier of a Hexokinase Inhibitor for Inducing Cancer Immune Cell Death and GSH Probing

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Objective: Tumor proliferation and metastasis rely on energy provided by mitochondria. Moreover, the produced energy participates in an Adenosine triphosphate (ATP)-dependent multidrug resistance (MDR), resulting in deficiency of anti-tumor drugs. Therefore, inhibition against function of mitochondria in cancer cells is on demand. As a kind of hexokinase inhibitor, lonidamine (LND) would induce damage of mitochondria thus suppress tumor growth. However, effect of LND was limited by its poor water-solubility and the relative excess of glutathione (GSH) in cancer cells. In addition, an accurate and simple method for GSH probing is crucial for LND-related therapies.

Methods: Therefore, a nanocarrier based on supramolecular host-guest self-assembly was synthesized for the delivery of LND, resulting in enhanced anti-cancer effect as well as ability of GSH probing. The carrier consists of β-cyclodextrin-poly(ethylenimine) (β-CD-PEI) as host polymer and dextrin-SS-thio-bis-(2-nitrobenzoic acid (Dextran-SS-TNB) as guest polymer. The prepared nanoparticles named ST was used for LND delivery.

Results: The LND-loaded ST (LST) nanoparticles exhibited nano-size and optimized LND loading ability in aqueous solutions. Compared with free LND, the improved cellular uptake rate of LND in CT26 cells in LST could be justified due to better water dispersion. In addition, the abundant disulfide bonds of Dextran-SS-TNB in LST caused significant more GSH degradation, which was monitored by the absorbance of the GSH-triggered released TNB2- ions at 410 nm. Due to down-regulation of GSH, LND released from LST effectively inhibited critical function of mitochondria, resulted in enhanced tumor cell death compared with control groups. Moreover, CT26 cells treated with LST were demonstrated induce immune cell death (ICD) and maturation of dendritic cells (DCs).

Conclusion: Thus, this work may pave the way for a nanosystem for GSH probing and complete cancer immune cell death.

Key words: Lonidamine, mitochondria dysfunction, host-guest assem-bling, GSH depletion and probing, immune cell death.

ID 3571

Cationic Micelles Based on Amphiphilic Triblock Copolymer Forming Stable Drug and Gene Codelivery System

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Objective: Codelivery of anticancer drugs and genes is a popular strategy to achieve synergistic or combined effects in cancer therapy. However, ensuring the stability of the codelivery system remains a significant challenge. The system must be able to protect both drug and gene from degradation or loss of potency before they reach the target. If the codelivery system is unstable, it can reduce the efficacy of the treatment, and increase side effects.

Methods: Herein, a stable codelivery system for the anticancer drug doxorubicin (Dox) and plasmids DNA (pDNA) was developed for potential cancer therapy. We synthesized and characterized a triblock copolymer composed of cationic poly(N,N-dimethylaminoethyl methacrylate) (PDMAEMA) and poly(ε-caprolactone) (PCL), denoted as PDMAEMA-PCL-PDMAEMA. The amphiphilic triblock copolymer self-assembles into micelles with a PDMAEMA hydrophilic shell and a PCL hydrophobic core in aqueous environment. The core-shell structure of the micelles facilitated codelivery, with the hydrophobic Dox encapsulated in the core and the positively charged shell responsible for gene binding.

Results: Empty PDMAEMA-PCL-PDMAEMA micelles had a small size of approximately 25 nm, while Dox- and gene-loaded micelles showed sizes of were around 80 nm in size. The micelle exhibited a drug loading content of 6% and drug loading efficiency of 68%. Gel retardation assays demonstrated that the Dox-loaded micelles effectively bound with luciferase-encoded pDNA at and above an N/P ratio of 1.5. Importantly, the PDMAEMA-PCL-PDMAEMA micelle was found to significantly enhance gene stability for a long period as compared to the particles formed by branched polyethyelnimine 25k and pDNA. It was shown that micelle could maintain its stability in vitro for three weeks and exhibit excellent gene transfection ability in B16-F10 cell even after eight days storage.

Conclusion: These Results indicated that cationic PDMAEMA-PCL-PDMAEMA micelles has great potential as carriers for the codelivery of hydrophobic anticancer drugs and genes, especially in providing excellent stability for genes.

Key words: micelle, amphiphilic triblock copolymer, drug delivery, gene delivery, cancer therapy

S12
数智融合创新，赋能智慧医院发展
Integration and innovation of Big Data and Artificial Intelligence Empowers the Development of Smart Hospital

ID 588

An Imputation Approach to Electronic Medical Records Based on Time Series and Feature Association

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Objective: Due to the interruption of network transmission, the collected electronic medical records are usually incomplete data. Therefore, the imputation of missing values is of great significance, whose main challenge is to accurately predict the missing data. Current state-of-the-art Methods often employ time relationships to predict the missing data, while ignoring the correlation of similar features. This motivates us to explore the association relationships of similar features, and fuse them with time series data mining.

Methods: In this paper, we propose a novel time series and feature association approach, GRU-RMF, which can effectively improve the accuracy of missing value imputation in electronic medical records. In our GRU-RMF, we utilize the matrix factorization principle to decompose electronic medical records into time feature matrix and spatial feature matrix; we design a nonlinear regularized GRU deep neural network, which can learn the time relationship in the time feature matrix; we design a time-space feature fusion method with alternate solving to organically fuse the feature correlation and time correlation, which can improve the comprehensive accuracy of missing value imputation.

Results: The experimental Results on several public datasets show that the proposed GRU-RMF outperforms the current state-of-the-art methods.

Conclusion: The proposed GRU-RMF has the advantages of higher imputation accuracy and better scalability.

Key words: Deep learning, electronic medical, GRU, missing value imputa-tion, time series data

ID 912

3D Simulation Model for Urine Detection in Human Bladder by UWB Technology

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Objective: Develop a 3D simulation model for non-contact detection of urine volume in human bladder by Ultra-wide-band (UWB) imaging technology.

Methods: A 3D simulation model for urine detection was established, which consists of an elliptical cylindrical fat layer and a spherical urine layer, and the dielectric permittivity of tissues is considered. The UWB Vivaldi antenna is used in the simulation and sweeps the model in a linear form. By mimicking the action of a UWB radar system, the reflected signals at each aperture position are obtained from the boundary of fat and urine. To generate the imaging results, the synthetic aperture (SA)-based imaging algorithm is applied to the calibrated signal.

Results: The estimated radius of bladder agrees with theoretical data with an accuracy of 90%.

Conclusion: It is shown that the possibility of detecting the volume of urine in the human bladder and UWB imaging technique has a huge application prospect in medical diagnosis.

Key words: UWB, model simulation, urine detection, SAR imaging

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第五届医工韶光创新分会场
The 5th Medical Engineering Shaoguang Innovation Session

ID 453

Artificial Intelligence Diagnosis of Respiratory Diseases Based on Electronic Health Record

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Objective: To improve the prevention and early diagnosis of respiratory diseases, we developed an intelligent diagnosis model based on deep phenotyping of respiratory department EHRs.

Methods: We conducted a retrospective study and obtained EHRs from 61,199 respiratory patients from the First Affiliated Hospital of Guangzhou Medical University, including 10 respiratory diseases. We use the algorithm based on deep learning to identify the clinical features in the medical record, and then use the PIAT algorithm to identify the attributes of these clinical features to build a fine-grained clinical phenotype representation. To select the best intelligent diagnosis model, we use AUROC and AUPRC to evaluate and compare the four machine learning algorithms. For the machine learning model with the best diagnosis performance, the accuracy of the Top 1 and Top 3 diagnoses was calculated, respectively.

Results: We developed a machine-learning model for the intelligent diagnosis of 10 respiratory diseases. By comparison and evaluation, other 3 machine learning (Naïve Bayes, Logistic regression, Random Forest), the LightGBM model performs best in disease diagnosis, with an AUROC of 0.952 (95% CI, 0.951-0.953) and an AUPRC of 0.768 (95% CI, 0.763-0.773). The macro average precision, recall and f1 score of our model in the disease diagnosis performance of the top 1 were 0.76, 0.67 and 0.70, respectively. The diagnosis performance for TOP 3 is much better than that of TOP1, with precision, recall and f1 score were 0.87, 0.81 and 0.84, respectively. Especially in chronic obstructive pulmonary disease and interstitial pulmonary disease, the f1 score can reach 0.92 and 0.89 respectively.

Conclusion: We used a machine learning model to develop an intelligent diagnosis system for respiratory diseases and achieved satisfied performance. This study may help physicians deal with a large number of inpatients record and could potentially provide clinical decision support in diagnostic uncertain cases.

Key words: Artificial intelligence; Auxiliary diagnosis; Natural language processing; High-fidelity phenotyping; Electronic Health Record

ID 472

The Spatial and Multi-Task Attention Network for the Radiotherapy Treatment Response Prediction in Locally Advanced Cervical Cancer

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Objective: Cervical cancer is a common gynecological tumor. Clinically, radiotherapy is the main treatment for locally advanced cervical cancer (LACC). However, within 18 months after treatment, nearly one third of patients have a recurrence. This makes it extremely important to predict the treatment response of patients before treatment, which is the primary factor for clinicians to consider in the selection of treatment plans. The current research uses manually segmentation of radiotherapy clinical target volume (CTV) in MRI images to predict treatment response. However, manual segmentation is extremely time-consuming, and the prediction Results are not ideal due to the separation of two related tasks of CTV segmentation and treatment response prediction. We propose a multi-task architecture to simultaneously evaluate the treatment response and segment radiotherapy CTV.

Methods: A spatial and multitask attention network is proposed to predict the treatment response of radiotherapy. Specifically, we devise a spatial attention module to enable the network to focus on CTV areas. Then, a multi-task attention module is constructed to improve the prediction accuracy of treatment response by using the correlation between CTV segmentation and treatment response prediction.

Results: We retrospectively collected MRI images of 138 cases of LACC before radiotherapy. The experimental Results of the 5-fold cross-validation also show that our proposed method is competitive. The TPR, TNR, Accuracy and AUC of treatment response prediction are 0.926±0.094, 0.884±0.065, 0.835±0.085, and 0.857±0.064, respectively. The dice score of segmentation also achieves 0.768±0.046.

Conclusion: We propose a multi-task architecture to simultaneously evaluate the treatment response before radiotherapy, and segment the CTV. Additional task can not only improve the accuracy of treatment prediction, but also greatly reduce the manual cost of CTV delineation in radiotherapy implementation, which is of great clinical significance.

Key words: radiotherapy, locally advanced cervical cancer, treatment response prediction, radiotherapy clinical target volume segmentation

ID 515

Quantitative Evaluation of Vitiligo Treatment Efficacy Based on Deep Learning

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Objective: Vitiligo will seriously affect patient's appearance and causes psychological stress to them. Evaluation of vitiligo treatment efficacy is prerequisite for adjusting the treatment plans. Clinically, the methods of evaluating treatment efficacy rely on dermatologists' clinical experience, which are troublesome and laborious. This study aims to provide an **Objective:** and convenient method for quantitative evaluation of vitiligo treatment efficacy.

Methods: A dataset containing 2500 vitiligo images was collected for segmentation study. Besides, a validation subset containing 13 pairs of pre- and post-treatment vitiligo images was collected from the test set of the dataset for evaluation studies. In the segmentation study, four convolutional neural networks (PSPNet, UNet, HR-Net and DeeplabV3+) were performed to segment lesions and evaluated according to mean Intersection over Union (mIoU). In the evaluation study, a comprehensive indicator ($Indicator_v$) was proposed to quantitatively evaluate vitiligo treatment efficacy on the validation subset, and lesion area change and color change were incorporated with weight calculated by the entropy weight method. Eventually, concordance analysis between the *Indicator*v and the dermatologist evaluation based on the Vitiligo Area Scoring Index (VASI) was performed by kappa test on the validation subset.

Results: The HR-Net architecture achieved the highest mIoU of 0.8421 and was selected as segmentation model. According to the kappa test, no differences were observed between the and the dermatologists' evaluation based on the VASI with moderate agreement (K=0.576, P<0.05).

Conclusion: This study proposed a deep learning-based method for quantitative evaluation of vitiligo treatment efficacy, which can objectively and conveniently reflect the changes of lesions after treatment.

Key words: deep learning; vitiligo; efficacy evaluation; convolutional neural networks

ID 744

诊疗一体的光动力胶囊微机器人及在消化道肿瘤的应用

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目的：光动力疗法是一种无创的肿瘤诊疗方法，随着微电子、LED 和人工智能的发展，消化道光学诊疗微设备的开发将成为消化道肿瘤早诊早治的重要手段之一。

方法：本研究开发了一种智能光动力诊疗内镜胶囊微机器人系统，集成了人工智能图像识别、胶囊内镜、光动力诊断和治疗、磁场控制等技术。

结果：实现了胶囊微机器人对早期胃癌在白光和光敏剂荧光的图像采集和肿瘤识别，以及 630nm 的光动力治疗的序贯工作，在控制上，研发的胶囊微机器人可完成胃内 5 个维度的运动控制，精度 0.5mm，同时建立了数据管理云平台，存储和分析所有胶囊的图像数据、治疗数据和人工智能识别结果，实现了医疗物联网的临床应用。

结论：智能光动力诊疗内镜胶囊微机器人系统实现全过程智能化，在早期胃癌的筛查和早诊早治方面具有潜力。

关键字：光动力疗法；胶囊机器人；人工智能；诊疗一体；消化道肿瘤

ID 1125

基于 VAT 模型的小鼠背部伤口自动识别和面积测量系统

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目的：小鼠是生物、医学领域的重要实验材料，其体貌特征（如伤口、肿瘤等）测量是研究的重要环节，目前的手动测量方式需投入大量人力，且易引入主观偏差，结果可重复性低。本研究基于人工智能语义识别模型和计算机视

觉测量技术提出了一种小鼠体征测量自动化的解决方案。

方法：研究采集了 675 张小鼠背部造模伤口处于不同愈合阶段的照片，选出 15 张包含不同尺度背部伤口的照片作为指导样本，手动绘制小鼠周身轮廓及其背部伤口轮廓作为指导标签。测量系统包括：小鼠躯干识别模块，可缩小背部伤口搜索范围；小鼠背部伤口识别模块，从小鼠躯干区域中识别背部伤口；面积测量模块，识别出刻度板的标准尺寸并估测小鼠背部伤口面积。

结果：在 660 张测试图像中，系统分割结果与人类测试者 1 的分割结果吻合度（IOU）大于 80% 的占 79.7%；系统分割结果与人类测试者 2 的 IOU 大于 80% 的占 67.0%。作为参考，人类测试者间的 IOU 大于 80% 的占 72.0%。

结论：该系统仅依靠少量指导样本即可达到接近人类测试者的语义分割效果，显著缩短测量时间，减少主观偏差，有望成为动物水平研究中一种快速检测的手段，此外，由于不需要额外训练人工智能模型，该方法可快速部署大规模测量的定制化系统。

关键字：小鼠体征自动测量；少样本语义分割；深度学习；人工智能；自动化

ID 1183

基于切比雪夫参数模型的人工神经网络骨科植入式医疗器械的 MRI 射频安全评估

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目的：由于 MRI 复杂的电磁环境，骨科植入物的存在给接受 MRI 的患者带来了一些潜在的风险，其中射频磁场引起的发热问题是最严重的安全问题之一。最常用的评估方法是通过体外（假体）和动物实验进行，从而需要昂贵的测试与时间成本。本文的目的是通过设计一种基于切比雪夫参数模型的神经网络来实现骨科植入物在 MRI 中射频安全的快速有效评估。

方法：我们将骨科植入物的物理特性和周围的组织电磁特性表征为切比雪夫参数模型，并通过设计一个三层人工神经网络进行优化训练，从而实现了骨科植入物周围组织射频诱导功率沉积和温升的快速评估。在本文中，该方法用各种几何尺寸的 300 个螺钉和 300 个钢板植入物实现并通过实验和计算机仿真对评估结果进行了验证。

结果：通过本文提出的基于切比雪夫参数模型，骨科植入物的主要特征可以被准确识别并建模，并通过神经网络实现骨科植入物周围组织的功率沉积与温升的快速预测。螺钉和钢板植入物的预测值与目标值的相关系数分别为 0.9989 和 0.9985，均方误差都小于 0.03。

结论：结果表明，该方法可以实现骨科植入式医疗器械在 1.5T 和 3.0T MRI 中射频诱导加热的高效准确预测。

关键字：人工神经网络；射频 (RF) 致热；骨科植入物；磁共振成像 (MRI)

ID 1192

基于可学习加权特征融合的膝关节图像三维分割及自动量化分析

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目的：根据患者自身 MRI 数据为基础，手工建立三维模型常费时费力，医生对膝关节数据序列进行逐张二维量化分析，缺乏准确性和客观性，鉴于此，本文开发一套三维自动分割量化系统，实现从二维断层图像到三维模型的转化，及各部分体积的自动计算。

方法：通过采集人体 MRI 图像，创新了一个基于可学习加权深度监督的特征融合网络结构，自动分割生成股骨、胫骨、软骨、半月板三维模型；设计了一种加权损失函数调整不同类别的重要性；设计了一种基于可适应加权操作融合特征方式；自动量化阶段采用对各部分微小切片层自动识别并建立数学微分方程，通过积分运算求解各部分总体积。

结果：实现了从二维图像自动到三维模型的过程，其中分割衡量评价指标 Dice 系数均达到 96% 以上。在 128 名临床测试对象中，男性股骨 (P<0.001)、股骨软骨 (P<0.001)、胫骨 (P<0.001)、胫骨软骨 (P<0.01)、内侧半月板 (P<0.01)、外侧半月板 (P<0.01) 体积比女性大。健康人股骨软骨 (P<0.01)、胫骨软骨 (P<0.01) 体积比骨性关节炎患者大。

结论：本研究实现了膝关节自动三维建模及量化分析，为临床医生提供辅助诊断信息和临床数据，为患者定制个性化假体提供依据。

关键字：可适应加权、深度监督、加权损失函数、微分方程

ID 1278

基于数据增广和复合神经网络的血糖水平精准预测

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目的：血糖管理是糖尿病治疗过程中的关键环节，但长时间准确的在体测量往往不易实现。随着深度学习技术的快速发展，基于小样本数据预测血糖水平已然实现，但现有模型往往预测准确率不高且训练耗时过长。基于此，本文提出一种基于数据增广策略和复合神经网络的血糖预测模型，可以快速准确地预测未来 15、30 和 45min 的血糖水平。

方法：首先，采用变分模态分解（VMD）等三种信号分解方式对血糖数据进行平稳化和数据增广，在串行增广基础上发展了并行增广策略；其次，发展基于麻雀搜索算法（SSA）的 TCN-LSTM, CNN-LSTM 等多个复合神经网络，在 OhioT1DM 数据集上利用单个患者数据学习 + 预测来验证模型的可行性和准确性；最后，利用多个患者数据学习 + 预测其他患者来验证模型的泛化性。

结果：所提出的并行增广 + 复合神经网络模型对未来 15、30 和 45 min 血糖预测结果的 MAPE 值均低于 5%，在克拉克误差网格中 99% 落于临床可接受区域，训练时长均低于 120s，泛化性要远远优于串行增广。

结论：所提出的并行增广 + 复合神经网络模型可以在保证血糖水平预测准确率的同时极大降低训练时长，对智能

人工胰腺的轻量化部署具有重要的参考价值。

关键字： 血糖预测，数据增广，复合神经网络，信号分解

ID 1283

基于 AI 的医疗器械安全危机值管理体系研究

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目的： 借鉴医疗危急值体系及原理，研究基于 5G 物联网和 AI 技术的危急值管理体系，实现具备人工智能的医疗器械危急值管理体系，保证医疗质量和安全。

方法： 建立基于 5G 物联网构建的危急值信息采集系统，将分散于医院各处的需管控医疗器械危急值进行实时、智能化的集中监测和采集，同时建立相关高风险医疗器械危急值项目和界限值，制定危急值采集、应答标准，在完成危急值数据采集后，应用 AI 技术对海量危机值进行分析和处理，实现智能化的全方位医疗器械危急值预警管控体系。

结果： 该研究的管理体系将替代原有的医疗器械安全使用管理模式，将人工风险评估转换成人工智能代替的安全风险评估，建立了“高效”、“动态”、“规范”的智能化医疗器械安全使用管控体系。

结论： 本研究依托具备人工智能化的危急值预警管理体系，实现了对高风险医疗器械安全使用的人工智能化管控，极大提升医疗器械的安全运行效能。

关键字： 基于 AI 的危急值；医疗设备；安全管理体系

ID 1420

人工智能使能的可穿戴电子技术及智慧健康诊疗模式展望

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目的： 针对个性化智慧医疗发展存在的问题，本文主要分析人工智能技术与医疗诊断结合发展现状，并期望发展一种可配合柔性可穿戴电子的个性化诊疗 AI 模型。

方法： 本文分析了人工智能技术与医疗诊断结合发展现状，包括医学影像的人工智能分析、智能医疗机器人、全面评估监测个人健康状态的可穿戴柔性电子及智慧健康管理，基于支持向量机诊断模型、贝叶斯深度学习模型等人工智能技术提出了一种可配合柔性电子器件的个性化诊疗 AI 模型思路。同时，需要从政策、法规、机制等多方面着手，进一步推进医疗大数据有序开放和利用。

结果： 针对个体化治疗而言，智慧医学诊疗模式能有效地解决现今健康需求不断扩大与医疗保健费用不断增加等矛盾。

结合人工智能与健康诊疗的应用现状，对我国目前人工智能在医疗领域中全面落地所面临的挑战与需要的措施进行了展望。

结论： 医疗数据的泄露事关患者的生命健康，在线医疗系统对可靠隐私保护的需求尤为迫切。在保护隐私的基础上，所提出的基于贝叶斯深度学习模型的辅助医疗诊断技术，其模型和数据的不稳定都将影响诊断结果。若将其应用

更多的医疗数据，可能将产生更大的作用。

关键字：人工智能，贝叶斯深度学习模型，智慧医学诊疗，精准医疗，个性化诊疗

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基于心电图与卷积神经网络的肥厚型心肌病诊断模型

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目的：肥厚型心肌病（HCM）是青少年猝死的常见原因，临床亟需寻找简便、智能化的方法对 HCM 患者进行广泛筛查。本研究基于卷积神经网络（CNN）识别 12 导联心电图，构建肥厚型心肌病诊断模型。

方法：选取 2013 年 -2021 年中国医科大学附属第一医院经超声心动图确诊为 HCM 的患者 2591 例，年龄、性别相匹配的 25910 例非 HCM 患者为对照组，获得心电图 - 超声心动图数据集。本研究设计了一种多重 HCM 的诊断效能。

结果：经过训练和验证，模型通过 12 导联心电图诊断 HCM 的敏感度为 87.5%，特异度为 94.7%，接受者操作特性曲线下面积（AUC）为 0.96，在单导联心电图上 AUC 仍能达到 0.94。亚组分析，模型在超声提示为左心室肥厚和主动脉瓣狭窄的患者中诊断准确性为 0.69 和 0.92，模型在年轻、女性患者中表现更好（AUC 分别为 1.00 与 0.97）。随机抽取 100 份心电图数据与 2 位心电专家比较，模型拥有更高的诊断敏感度（敏感度分别为 0.58、0.54 和 0.88）和更短的诊断用时（诊断时间分别为 6 分 21 秒，11 分 20 秒和 30 秒）。

结论：人工智能识别心电图可以快速、有效的筛查 HCM 患者。

关键字：心电图、超声心动图、肥厚型心肌病、卷积神经网络

ID 1647

药师对重性精神病居家患者开展远程药学服务管理的效果分析

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目的：探讨药师借助“互联网 + 重性精神病居家患者”模式（微信或微信群），开展优质药学服务管理的实践效果。

方法：随机选取长期居家服药的重性精神病患者，计 116 例，在 2022 年 1 月 -2022 年 12 月间，药师对对照组 58 例，采取常规指导；观察组的 58 例，采取常规指导后，再开展远程药学服务，指导、监测、比较患者不良反应发生后的处置率、对医嘱药物治疗方案知晓率、对药师满意度等，同时患者不合理用药发生率、病情加重复发率对比效果差异。

结果：观察组患者不良反应发生后的处置率、对医嘱药物治疗方案知晓率、对药师满意度明显高于对照组；而患者不合理用药发生率、病情加重复发率明显低于对照组，且 $P < 0.05$，具有统计学意义。

结论：药师借助“互联网 +”模式，开展远程优质药学服务管理，可减少不合理用药，提高不良反应处置率，提升患者满意度，促进用药依从性、减少病情加重复发率等，值得推广开展。

关键字： 互联网 + 患者　重性精神病　精准服务　居家服药　家庭药师

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Lightweight Arrhythmia Detection Network based on Multi-Channel ECG using Residual CNN and Cascaded Transformers

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Objective: The rapid development of remote monitoring has brought the era of big ECG data, making the need for automatic analysis more pressing. As the layers of the network increased, Methods based on deep learning have been widely studied in recent years to reach cardiologist-level performance. However, the accompanying high complexity and unexplainability of the deep neural networks limit their application in clinical auxiliary diagnosis. Accordingly, a lightweight network with interpretability is urgently needed.

Methods: In this paper, we propose a lightweight hybrid network by combining residual convolutional neural networks (CNN) and cascaded transformers. To achieve lower algorithm complexity, the basic idea of the proposed network is to utilize the characteristic of ECG signals instead of numerous layers to extract the spatio-temporal features. Specifically, a 4-layer residual CNN network is applied to extract the spatial features from multi-channel ECG. Then, the cascaded transformers (only encoders) are used to extract the local and global temporal features of ECG successively. Meanwhile, the multi-head attention mechanism inside the transformers brings the possibility of model interpretability.

Results: Experiments result on the China Physiological Signal Challenge 2018 shows that our method can obtain a comparative average F1 score of 0.86 with lower complexity. Furthermore, the attention mechanism can effectively locate where the abnormal ECG occurred, making the model explainable.

Conclusion: The proposed network provides a promising solution for automatic arrhythmia detection, and can be generalized to other physiological signal analyses.

Key words: ECG, Arrhythmia detection, Lightweight, Residual CNN, Cascaded Transformers.

ID 2067

基于近场相干耦合和机器学习的心源性脑血流搏动水平评估方法研究

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目的： 心源性脑血流搏动水平的实时连续评估是脑血管疾病救治的关键，但目前已有手段存在有创与无创、连续与间歇、局部与全局等矛盾。

方法： 基于近场相干耦合系统获取的不同生理状态下 n 名健康志愿者心拍、脑血流同步监测数据，采用 TSFEL 对信号进行时、频、统计域的特征提取；训练 5 颗决策树模型后计算特征重要度均值，并按照阈值为 0.1 完成特征筛选；基于决策树、随机森林、SVM 分别构建脑血流搏动状态分类模型，并采用网格搜索法获取最优超参数；通过交叉验证、

留一法、重复留出验证法评估分类模型的性能。

结果：基于近场相干耦合检测信号共提取 320 个特征，经特征重要度筛选后得到 13 个反映不同脑血流搏动水平的特征。三个分类模型 5 折交叉验证结果的准确率均大于 0.96。留一法评估准确率、F1 分数、召回率、AUC 面积均大于 0.95。使用重复留出验证法计算的准确率结果显示，决策树为 0.95，随机森林与 SVM 均在 0.97 附近。

结论：基于近场相干耦合检测获取的心源性脑血流搏动信号构建的机器学习分类模型能够对不同水平心源性脑血流搏动取得较好的分类结果，具有准确度高、泛化性能好、模型稳定等优点，有望为心源性脑血流搏动的快速、安全、准确评估提供新的解决方案。

关键字：心源性脑血流搏动信号；特征筛选；机器学习分类

ID 2159

L-G Perception Unet: A Local- Global Perception for 2D Medical Image Segmentation

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Objective: The convolutional neural network (CNN)-based Unet has demonstrated excellent performance in medical image analysis. However, due to the inductive bias and insufficient receptive field of convolutional operations, its ability to capture long-range dependencies is limited. Recently, transformer-based Methods have been widely adopted due to their ability to capture global correlations of hierarchical multi-scale features. However, when down-sampling is applied, the combination of features from different scales leads to the loss of many local details.

Methods: To address these issues, we propose a multi-scale Local-Global Perception Unet (L-G Perception Unet), which adopts a symmetric pure transformer block as its encoder and decoder. To compensate for the loss of spatial information due to down-sampling, the skip connection after down-sampling consists of two modules with different functions, the local perceptor and the global perceptor. The former uses a cross-attention to establish local correlations between multi-scale features. The latter perceptor models its global dependence by unfolding and connecting multiscale feature vectors in the spatial dimension and then applying an attention. In addition, to solve the segmentation problem caused by the different sizes of lesions or organs in medical images, we propose a progressive double-branch structure. The main branch is used to accurately identify coarse semantic pixels with high confidence, while the fine branch is used to segment finer semantic pixels with complex features. Meanwhile, a progressive regularization loss is designed to gradually shift the focus of network training from the entire image to the segmentation of finer semantic pixels.

Results: We achieved the highest dice of 85.04 on the Synapse dataset and 91.14 on the ACDC dataset, and the best f1 score of 83.21 on the DRIVE dataset.

Conclusion: We believe that our design will inspire the development of medical image segmentation while taking into account local and global information.

Key words: Transformer, Multi-scale, Local, Global

ID 2170

多任务深度学习从 CT 图像预测卵巢癌的新辅助化疗反应和高级别浆液性卵巢癌：一项多中心研究

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目的：开发预测 NACT 反应和 HGSOC 的深度学习模型，确定可能 NACT 收益的患者。

方法：本研究包括三家医院的卵巢癌患者，所有患者 NACT 治疗前接受了 CECT 检查。本研究开发了基于多时期 CT 图像多任务深度学习模型，并与临床特征融合预测 NACT 反应和 HGSOC。

结果：共有 587 名妇女的 1761 张图像（平均年龄，55 岁 ±8.8[SD]）被纳入训练和验证集，67 名妇女的 201 张图像被纳入前瞻集，103 名妇女的 309 张图像被纳入外部集。多因素分析显示，腹膜侵犯和腹股沟 LN 转移是 NACT 反应的独立预测因素。对于预测 NACT 反应，使用多期 CT 图像结合临床危险因素的多任务深度学习模型在训练、验证、前瞻和外部集中分别获得了 0.87（0.83-0.90）、0.88（0.86-0.91）、0.86（0.82-0.89）和 0.79（0.75-0.82）。在 HGSOC 分类中，训练、验证、前瞻和外部集的 AUC 分别为 0.91（0.87-0.94）、0.89（0.86-0.91）、0.80（0.76-0.84）和 0.80（0.75-0.85）。

结论：利用多期 CT 图像开发的多任务深度学习算法可预测卵巢癌的 NACT 反应和 HGSOC。

关键字：卵巢癌，深度学习，多任务，NACT，HGSOC

ID 2172

Deep Learning Enhanced Effective Portable Skin Disease Diagnosis Instrument with Low Cost

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Objective: Skin diseases are one of the most common health problems in the world, affecting patients' quality of life, causing a significant socioeconomic burden to society and even leading to increased mortality. Early detection and prompt treatment of these lesions, especially malignant ones, can significantly improve patients' quality of life and reduce mortality. However, the visual differences between malignant and benign skin lesions can be subtle, and accurate differentiation often requires expert level experience. Advances in graphics card capabilities and machine learning techniques have greatly promote the development of deep-learning based Methods for skin disease diagnosis. The innovative lesion classification techniques have achieved encouraging diagnostic accuracies of better than 90%, comparable or even superior to those of dermatologists, which also promotes the development of intelligent diagnostic expert systems in hospital or online. However, due to the huge requirements for computing resources required, they are either expensive to

build or need a network, which seriously hinders their application in remote areas.

Methods: To promote the improvement of healthcare in these areas, we build a portable diagnostic device capable of working independently that combines Regnet, Raspberry pi, Intel® Compute Stick, and dermoscopy. We first trained different Regnets combing with different data enhancement policies on the ham10000 database, and the best official test of balanced accuracy arrive 0.860 ranking first in the channel of single-model-no-external-database.

Results: Taking into account the inference speed and diagnostic accuracy, we finally deployed trained RegnetY800M in the portable diagnostic device, capable of diagnosing a lesion image within 2 seconds, and outputting the scores of seven diseases.

Conclusion: The Results show that the portable device can help to diagnose the seven pigmented skin lesions without the need for human expertise, which will be of great significance in the pre-screening of skin diseases.

Key words: Deep learning, portable, skin disease, diagnosis, low cost

ID 2315

脑机接口中的通道筛选方法

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目的：随着脑机接口技术的发展，多通道、多模态的脑机接口设备已经被开发出来并且进入临床使用。但是脑机接口包含了大量时间、空间上重复的信息，因此如此大量的通道实际上阻碍了其在实际中的应用并且影响了性能。因此脑机接口领域亟待能够高效、高性能地筛选通道且尽可能保留更多信息的方法。总结并分析脑机接口中不同的通道筛选方法，并探讨各自的特点。

方法：搜集并筛选包含脑机接口通道筛选方法的文章，对其中的方法进行分类，分析该领域技术发展的趋势。并对不同方法进行筛选性能开销、数据节省量和剩余通道性能的对比。

结果：目前使用脑机接口通道筛选主流是卷积神经网络等深度学习方法。而且与其他方法相比，深度学习的精度和未来发展潜力都跟高。

结论：脑机接口通道筛选可以在轻微影响性能的前提下显著减少所适用的数据量，既减少了数据传输所需要占用的带宽，也降低了后续数据处理所需的性能。

关键字：脑机接口；人工智能；通道优化；

ID 2383

一种家用式缺血预适应训练仪的设计与实现

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目的：设计一款用于脑卒中康复治疗及卒中预防的家用式上肢缺血预适应训练仪，并分析本装置压力控制的稳定性及测量的准确性，同时研究在本装置缺血预适应训练状态下的血氧饱和度变化。

方法：基于单片机、气泵、袖带等组件，搭建了电控的袖带式肢体加压阻断装置作为臂带机；编写了在安卓平台

下运行的缺血预适应训练管理软件，通过蓝牙控制臂带机进行缺血训练和血压、心率的测量，并对训练数据进行显示和存储。使用血氧指尖仪（超思 MD300CN310）监测在本装置训练状态下的血氧饱和度变化，并绘制相关参数曲线。

结果：制作了家用式缺血预适应训练仪原理样机，并对关键参数进行了测试，经压力控制稳定度测试，本装置对于压力控制的稳定度良好；经血压、心率测量准确度测试，本装置与测量血压、心率较为准确的欧姆龙电子血压计所测结果无明显统计学差异（各项 P 值均大于 0.05），故本装置对于血压、心率的测量较为准确。在训练时组织的血氧饱和度的发生变化，与训练时间、训练过程中的压力控制有关。

结论：本装置为缺血预适应训练仪的开发、设计和缺血训练状态下其他生理参数的监测提供了一种新的思路。

关键字：缺血预适应训练仪；脑卒中；血氧饱和度

ID 2555

Data-limited and Imbalanced Bladder Wall Segmentation with Confidence Map-guided Residual Networks via Transfer Learning

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Objective: To develop an algorithm using a residual base network guided by the confidence map, combined with transfer learning for limited dataset size and imbalanced bladder wall segmentation.

Methods: 1088 magnetic resonance imaging (MRI) T2 images containing the bladder wall were used for training and testing, of which 900 images were used for training, 100 for validation, and 88 for testing. Considering the small amount of data, the geometric transformation was made to the training data for data augmentation, and a pre-trained Resnet50 model on ImageNet was also adopted for transfer learning. Three loss functions were put into the pre-trained resnet50 network, the cross-entropy loss function (CELF), the generalized Dice loss function (GDLF) and the Tversky loss function (TLF). Three models were obtained through training, and three corresponding confidence maps were output after inputting a new image. By selecting the point with the largest confidence value, the three images were merged into one image, threshold filtering was performed to avoid external anomalies, and finally, the segmentation result was obtained.

Results: The average Jaccard similarity coefficient of model training based on the CELF, GDLF and TLF is 0.9173, 0.8355, 0.8757, respectively, and the average Jaccard similarity coefficient of 0.9282 can be achieved with our algorithm in contrast to 0.518 for the classical U-net algorithm. Qualitative Grad-CAM map analysis was also conducted for interpretability analysis.

Conclusion: Our study demonstrates that the confidence map-assisted residual base network can accurately segment bladder walls on a limited-size data set. Compared with the segmentation Results of each model alone, our method dramatically improves the accuracy of the segmentation by combining confidence map guidance with threshold filtering. Qualitative Grad-CAM map analysis also opens up the black box effect of neural network models and explains the reasons behind the improvement of the accuracy of our method.

Key words: Bladder wall， Segmentation, Confidence map, Transfer learning, Grad-CAM map

ID 2665

基于 OpenPose 的心肺复苏培训算法研究

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目的：针对传统心肺复苏培训系统只能实现监测按压深度、频率等指标，对学员现场操作姿势等只能凭人工主观判断，且存在智能化程度低，交互程度低等问题，本文设计了一套基于计算机视觉技术的智能心肺复苏培训系统。

方法：首先，通过摄像头采集学员操作视频，制作心肺复苏动作数据集。对视频进行预处理，提取视频帧，使用 OpenPose 获取学员身体关键点坐标数据。利用 K 近邻算法和人体关节间的角度变化规律识别学员动作，与标准动作进行对比，对错误动作进行局部标注处理。最后，向学员反馈指导意见。

结果：利用该算法对视频心肺复苏动作进行判别，算法识别的准确率为 87.80%，召回率为 93.87%，F 值和精度都达到了较高水平。采用传统心肺复苏培训和智能心肺复苏培训系统辅助的方式分别培训 10 名志愿者，考核志愿者心肺复苏掌握程度，经过智能心肺复苏培训的志愿者达标率为 83.33%，远高于经过传统方式培训的志愿者。

结论：基于 OpenPose 的智能心肺复苏培训系统可准确识别学员动作并反馈学员改进意见，能有效提高学生对心肺复苏的掌握程度，提高教学满意度，对于公众急救知识和技能的科普推广具有重要意义。

关键字：机器视觉；姿态识别；OpenPose ； 心肺复苏培训；K 近邻算法；

ID 2799

基于深度学习的左心室舒张功能智能评价方法研究

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目的：LV 舒张功能评价指南推荐采用二维和多普勒超声参数基于标准流程综合评价。然而，尚存在多图像采集、多参数测量、多指标计算、多截点值应用及多条件判断等问题，导致诊断流程复杂，费时、费力。临床亟待实现 LV 舒张功能的自动化、快速评价。

本研究旨在基于深度学习方法进行左心室舒张功能智能评价的方法研究，为临床评价 LV 舒张功能提供快捷方法。

方法：基于超声心尖 4 腔心切面，首先构建左心房 (LA) 及 LV 心腔分割模型构建；其次，采用凸包算法提取 LA/LV 轮廓信息；最后，基于轮廓信息构建一维 ResNet-18 模型实现 LV 舒张功能分类。

结果：1. LA/LV 心腔分割模型可准确分割 A4C 切面的 LA/LV 心腔，具有良好的分割效能，LA 分割的平均 Dice 系数为 0.95，LV 分割的平均 Dice 为 0.94。

2. 采用凸包算法实现了 LA/LV 轮廓信息提取。

3. LV 舒张功能分类模型具有良好的诊断效能，5 折交叉验证的平均 AUC 为 0.89，精确度为 0.91，灵敏度为 0.91，特异度为 0.85。

结论：基于二维超声心尖切面图像的深度网络模型，可智能评价 LV 舒张功能，从而为临床快速、全面评价 LV 功能提供新方法。

关键字：深度学习 ; 左心室 ; 舒张功能

ID 2820

“数字化赋能精准医疗”—3D 导板在小儿先天性脊柱侧弯临床应用与研究

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湖南医药学院

目的：本研究旨在结合医学数字建模与 3D 医学影像技术，探讨 3D 数字导板在辅助小儿先天性脊柱侧弯椎弓根螺钉内固定的治疗效果

方法：回顾性分析 2020 年 6 月至 2022 年 6 月在院治疗的 25 例小儿先天性脊柱侧弯患者资料，其中 2020 年 6 月至 2021 年 6 月中有 14 例采用传统徒手操作进行螺钉内固定（传统组），2021 年 7 月 -2022 年 6 月中有 11 例采用个性化 3D 数字导板辅助螺钉内固定（数字导板组）。比较两组在围手术期、术后恢复效果（随访）以及影像数据等资料，分析结果。

结果：1. 两组患者均完成手术，术中神经电生理监测均无神经损伤，数字导板组的手术损伤、手术时间、术中出血量等指标均显著优于传统组，差异具有统计学意义（P<0.05）；

2. 术后随访数字导板组 Cobb 角显著小于传统组，具有统计学意义（P<0.05），有效矫正率优于传统组；

3. 影像复查显示 : 数字导板组螺钉内固定无失效、无松动，而传统组出现 2 例置钉失败。

结论：3D 数字导板能有效的辅助小儿先天性脊柱侧弯的治疗，实现椎弓根螺钉的精准植入，同时为小儿先天性脊柱侧弯治疗提供数字医学的新思路与新方法。

关键字：数字化；3D 导板；先天性小儿脊柱侧弯；精准医疗

ID 2840

基于扩散模型的 PPG 生成 ECG 算法研究

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目的：移动监护设备（如可穿戴手环）通常能够采集短程 ECG 和长程 PPG。然而，ECG 的采集需要使用者双手握持设备并保持静止，难以实现长程监测；PPG 从皮肤表面测量皮下血容量变化，可实现单手测量，更容易实现长程监测。与 ECG 相比，PPG 难以直接反应心脏电活动。有研究表明，PPG 与 ECG 之间存在转换的可能。因此，本研究基于扩散模型，一种新型的生成式深度学习算法，研究由 PPG 生成 ECG 的人工智能算法。

方法：首先，我们将包含同步 PPG 和 ECG 的公开数据集以 9:1 划分为训练和测试数据。接着，我们构建了一个 U-Net 模型作为基础网络，使用 SSIM 损失作为损失函数。然后，我们将扩散模型的训练机制引入生成过程中，将 ECG 与随机噪音相加，再与 PPG 拼接后输入 U-Net 模型，并把 PPG 作为约束条件嵌入到 U-Net 模型特征提取的过程。在模型训练完毕后，我们将算法部署为云服务，通过便携式设备实现了 ECG 的实时生成。

结果：本研究提出方法在测试集上生成 ECG 的 RMSE 为 0.293mV，优于 GAN 等方法。

结论：该方法能够结合 PPG 和 ECG 的优点，实现在未改造传感器的情况下生成长程 ECG 信号，从而提高阵发性疾病（如阵发性房颤）的识别效果。

关键字：扩散模型；PPG；ECG；U-Net

ID 2850

面向脑性瘫痪的电子病历标注及实体识别

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目的：在脑性瘫痪康复图谱构建中，电子病历标注及实体识别、特别是嵌套实体识别仍难以满足现实需求。因此建立了面向脑性瘫痪的电子病历实体语料库，并提出了基于 GlobalPointer 的嵌套实体识别方法。

方法：首先，在医学专家指导下制定了脑性瘫痪的命名实体标注规范；对 74 万字的脑性瘫痪电子病历进行人工标注及校对，构建了面向脑性瘫痪的医学实体语料库。然后构建命名实体识别模型：先引入 GlobalPointer 的全局归一化方法来实现嵌套实体和非嵌套实体的无差别识别；同时通过旋转式位置编码引入相对位置来提升对实体边界的识别；再用“Softmax+ 交叉熵”解决多标签分类不平衡问题。

结果：自建语料库共包含疾病、症状、检查、治疗和身体部位 5 类实体，实体共 114178 个，其中嵌套实体 30535 个，占 26.74%。实验结果显示：脑性瘫痪电子病历的实体多轮标注一致性为 86.06%、86.80%、92.22%，命名实体识别模型的总体 F 值为 85.98%。

结论：GlobalPointer 对医学嵌套实体具有较好的识别性能，面向脑性瘫痪的电子病历标注及实体识别可为后续构建脑性瘫痪知识图谱提供资料和技术支持。

关键字：脑性瘫痪、电子病历、命名实体识别、自建语料库

ID 2884

Sception-net: An Inception Architecture Based Network for Chinese Sign Language Recognition Based on Surface Electromyography

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Objective: Due to the large number of deaf and hearing-impaired people, the development of sign language recognition is becoming increasingly crucial. Surface electromyography (sEMG) signals directly reflect the degree of muscle contraction during performing sign languages. By decoding the sEMG, specific sign languages can be recognized. This work aims to construct a deep learning model that fuse feature maps with different receptive fields to recognize the sign languages.

Methods: This paper proposed an Inception architecture-based model with residual module and dilated convolution (Sception-net) to recognize ten Chinese sign languages. The Sception-net not only enlarged the receptive field but enriched the feature map of the classification model. Since the sEMG signal has the property of non-stationary, the physiological characteristic contains in the sEMG signal is unobvious. In order to extract more information about the non-stationary sEMG signal, the Discrete Fourier Transform (DFT) was applied to transform the time domain sEMG signal into time-frequency domain to obtain the frequency domain information of the sEMG. Then the recognition Results between the time domain and time-frequency domain dataset was compared to investigate the classification performance under the two domains. Moreover, a public dataset Ninapro DB1 was used for verifying the effectiveness of the proposed Sception-net.

Results: showed that after transforming the time domain sEMG signal into time-frequency domain, the classification ac-

curacy increased from 84.29% to 91.70% by using the Sception-net on our sign language dataset. For the time-frequency information of the Ninapro DB1 dataset, the classification accuracy reached 89.82% which was higher than the studies studied on the Ninapro DB1 in recent years.

Conclusion: This study applied the sEMG as a medium to construct the human-computer interaction to help the hearing-impaired people better integrate into the society. The Sception-net also showed high generalization performance on both our dataset and Ninapro DB1.

Key words: Sign language recognition, Surface electromyogram, Inception network, Residual module, Dilated convolution

ID 3116

结合机器学习和理论仿真实现聚焦超声消融浅表组织的损伤预测

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目的： 聚焦超声 (FU) 具有治疗浅表组织疾病的潜力，然而涉及浅表组织 FU 消融的量效关系仍不明确。本文旨在通过机器学习和理论仿真实现 FU 消融浅表组织的损伤预测。

方法： 本研究在不同辐照深度、辐照时间和声强（1745W/cm2、3490W/cm2）条件下消融离体猪皮肤组织，同时结合组织中的声传播和生物传热理论预测 FU 消融组织损伤，基于随机森林（RF）回归、K 近邻算法和梯度提升回归实现不同条件下的组织损伤预测。

结果： 低声强下组织损伤面积分别为 0.1±0.01-3.3±0.34mm^2 和 0.2±0.01-2.5±0.31mm^2，对应理论结果为 0-2.20mm^2 和 0-1.83mm^2；高声强下组织损伤面积分别为 0.1±0.01 -3.7±0.31 mm^2 和 0.2±0.04 -3.0±0.29 mm^2，理论结果为 0-3.14mm^2 和 0.3-3.65mm^2。相同辐照深度下实现相同组织损伤所需声能量关系为 $E_{猪肌肉}<E_{猪皮肤}$。RF 回归模型在验证组 R^2 为 0.871，具有最佳预测结果。

结论： FU 消融浅表皮肤组织具有安全有效的量效关系且受组织特性、辐照深度、声强等因素的影响，FU 消融的损伤面积可以经理论仿真和机器学习进行预测。

关键字： 聚焦超声；浅表组织；量效关系；机器学习

ID 3161

基于大尺度脑网络分析的脑卒中功能连接异常模式研究

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目的： 人脑是由多个脑区复杂地连接在一起的，大脑中的信息处理需经过成千上万个神经元间的复杂互动完成，跨越多个尺度，识别人脑大尺度网络组织结构是探究大脑功能和机制的重要手段之一。本研究旨在通过构建大尺度脑网络模型，分析卒中患者大脑功能连接的异常模式。

方法：招募 10 名健康被试和 40 名卒中患者，采集特定运动任务下的脑电数据。基于图卷积网络理论构建大尺度脑网络模型，计算节点之间的拓扑结构和时序信号特征，将大脑皮层划分为多个功能模块，确定每个模块中的核心节点，并计算各个功能模块之间的连接情况。

结果：卒中患者和健康人之间存在显著的大脑连接模式的差异。相比健康对照组，卒中患者的大脑活动呈现出更弱的全局和局部连接，尤其在前额叶、颞叶和枕叶等区域。此外，卒中患者的大脑连接呈现出更高的随机性，即网络的连接模式更不规则。

结论：卒中患者大脑连接的缺失会导致大脑整体网络结构的变化，进而影响患者的认知和神经功能。探究大脑功能连接的异常模式有助于理解卒中后神经可塑性的变化，为卒中康复治疗提供理论基础。

关键字：脑卒中；图卷积网络；功能连接模式差异；高随机性；神经可塑性

ID 3270

Simultaneous Pelvic Floor MRI Super-resolution and Artifact Removal Using Deep Learning

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Objective: High-quality, high-resolution MRI is crucial for accurate diagnosis of pelvic floor disorders (PFD). However, acquiring such images is expensive and time-consuming, and they are often plagued by artifacts due to hardware limitations. To address these challenges, we aimed to propose a deep learning method to simultaneously enhance the resolution and quality of pelvic floor MRI.

Methods: A residual-in-residual dense block network was used as a backbone for through-plane super-resolution of 3D MR data. An enhanced deep super-resolution network was added to the pipeline for further in-plane super-resolution based on through-plane super-resolution results. To remove artifacts caused by hardware limitations, we built a synthetic dataset to train a deep residual learning network with MR data from 94 patients and then transfer to real MR images with artifacts. Peak signal-to-noise ratio (PSNR) and structural similarity (SSIM) were used to evaluate the model's performance.

Results: The testing experiment using data from 11 patients shows that our pipeline effectively improved the quality of MR images. After through-plane super-resolution, the mean interval spacing of the pelvic floor MRI test set was reduced from 5 mm to 0.78 mm. After in-plane super-resolution and artifacts removal, the mean value of PSNR and SSIM were enhanced by 21.56 dB and 0.145, respectively.

Conclusion: Our proposed deep learning framework effectively achieves both in-plane and through-plane super-resolution MRI and artifacts removal. The method can improve the quality of pelvic MRI, which can be beneficial for high-precision diagnosis of PFD.

Key words: MRI, Super-resolution, Artifacts removal, Deep learning, Pelvic floor disorders

ID 3277

物理智能快速量化磁共振成像

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目的：医疗科研领域，许多科研人员致力于结合人工智能和医学成像技术，解决当前医学成像慢、图像质量差的问题。训练人工智能往往需要庞大的数据集才能做到满意的准确率和泛化性，对医学影像数据集的需求是巨大且迫切的。但在医学成像中，高质量数据采样难、有效数据少甚至无、数据私密性等问题严重阻碍了人工智能在医学成像应用中的进一步发展。

方法：所开发的磁共振智能云脑成像系统基于成像物理，可解决以上问题。用户仅需设置相应的生理组织、磁共振实验参数等，通过磁共振物理模型演化，即可快速在线生成大规模、高质量、配对的合成数据，为人工智能在磁共振成像中的研究提供了强大数据支持。

结果：本系统还集成了可解释、可信任、鲁棒的物理智能方法，可通过磁共振物理建模、正则化约束、元学习等方式来进行增强学习，实现了高效的域自适应，以有效处理真实场景数据，覆盖如快速成像、精准量化、数据分析、影像分割等广泛的应用场景。

结论：所开发的磁共振智能云脑成像系统立足成像物理，以数据为突破口，打造物理方程数据生成、神经网络训练与图像重建、智能量化与评估的产、学、医一体化在线云平台，快速实现智能磁共振成像新技术临床科研验证和诊疗装备应用，最终服务临床。

关键字：快速成像，量化成像，磁共振成像，物理智能，人工智能

ID 3335

基于高阶拓扑结构的阿尔茨海默症脑功能网络特征研究

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目的：阿尔兹海默症会带来大脑结构的改变以及功能的退化，同时大脑具有功能代偿机制，因此对脑功能网络进行研究可以深入了解神经退行性疾病对大脑功能的影响。

方法：本文基于 30 名阿尔兹海默症患者以及 30 名健康被试的 8 通道闭眼脑电信号进行研究。首先从预处理后的脑电数据中提取 δ、θ、α、β 四个特征频段数据，其次结合滑动窗口技术与互信息算法分别计算整个频带及四个特征频段脑电数据在各时间窗内的功能连接矩阵，然后计算各矩阵对应位置数据组成的序列间的皮尔逊相关性以构建高阶脑网络，最后计算其局部聚类系数。

结果：与健康对照组相比，患者组局部聚类系数显著下降，高阶脑网络的耦合度显著降低；全频段与特征频段间的局部聚类系数均呈现下降趋势，且与全频相比，θ、α 频段下降趋势更为明显。

结论：神经退行性疾病会使大脑的功能整合能力下降，且对低频节律信号的影响更为显著。

关键字：阿尔兹海默症；脑电；高阶脑网络；图论指标

ID 3466

复杂系统的共时性

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目的：人工智能的数学机理研究主要基于因果推断。荣格提出了区别于因果推断的共时性推断。 本文试图研究复杂系统参数之间的共时性关系。

方法：根据 Weber-Fechner 定律，引入定量差异和几何均值。

结果：1. 简单的共时性关系：两个客观参数的主观感觉差值或比值守恒，不但可以推出大量物理定律，而且可以推出两个客观参数的非因果关系。2. 时中守恒性：复杂系统横向 N 个参数的 M 次纵向测量构成数据流。横向 N 个参数的几何均值称为时中。时中满足 Arndt-Schulz 定律，可以分为守恒区、平台区和陡变区。守恒区对应于冯诺依曼的稳定过程，可以用于机器学习输入数据的检验。3. 健康标尺：守恒区的参数分为阴性参数和阳性参数，从疾病到健康，阴性参数下降，阳性参数上升。将所有阴性参数取到数，所得数据流称为阳性数据流。阳性数据流所有参数的几何均值称为健康标尺。4. 生物标志物：守恒区每个参数横向除以所有参数的时中，每个取值纵向除以所有取值的几何均值，所得数据流称为易流。如果易流一个数据与 1 的定量差异满足显著性或非常显著性，对应的参数称为亚健康或疾病的生物标志物。

结论：参数之间的共时性是复杂系统的重要特征。

关键字：定量差异；几何均值；共时性；Arndt-Schulz 定律；Weber-Fechner 定律

ID 3615

Longitudinally Evaluation of Locally Advanced Rectal Carcinoma Treated with Preoperative Chemotherapy Using Time-dependent Diffusion MRI

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Objective: The effectiveness of neoadjuvant Chemotherapy (NCT) is most commonly assessed by the change in tumor size based on conventional rectal cancer imaging. However, morphologic changes often occur later during treatment. Time-Dependent Diffusion MRI (TD MRI) is a novel MRI tool for depicting cellular microstructures. This study aimed to investigate the feasibility of time-dependent diffusion MRI–based microstructural mapping for noninvasively characterizing cellular properties of LARC during NCT.

Methods: TD MRI technique requires acquisition of diffusion MRI signals at varying diffusion times by using a combination of oscillating gradient spin-echo (OGSE) and pulsed gradient spin-echo sequences to measure diffusion within solid tumors over a broad range of diffusion times (2.5–46 ms). All scans were performed with a 3.0-T MRI scanner ((Ingenia Elition, Philips Healthcare, the Netherlands)

Results: The effectiveness of NCT is most commonly assessed by the change of tumor size based on conventional rectal T2 weighted MRI. However, morphologic changes often occur later during treatment. TD MRI not only provide conventional ADC value, but also cellular microstructural information, such as cell diameter (Dmean), intracellular volume frac-

tion (Vin), and extracellular diffusivity (Dex) through Imaging Microstructural Parameters Using Limited Spectrally Edited Diffusion (IMPULSED) approach. Although tumor size remained unchanged at the early stage, cellular microstructures make the response to the treatment .

Conclusion: Time-Dependent Diffusion MRI is a valuable tool in the non-invasive longitudinally evaluation of locally advanced rectal carcinoma treated with neoadjuvant Chemotherapy

Key words: diffusion MRI; OGSE

ID 3617

Deep Learning-based Acceleration of Compressed Sensing Non-contrast-enhanced Coronary MRA in Patients with Suspected Coronary Artery Disease

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Objective: This study aims to propose a novel non-contrast compressed sensing artificial intelligence (CSAI) coronary MRA methods and to evaluate its diagnostic performance for patients with suspected (coronary artery disease) CAD using the coronary CTA as a non-invasive clinical reference standard.

Methods: The MR examinations were performed on a 3T MR scanner (Ingenia Elition, Philips Healthcare) using a 16-channel body matrix coil combined with a 12-channel spine matrix coil. Fifty-six consecutive patients (60±10 years, 29 males) with suspected CAD were finally included in this study and underwent non-contrast CSAI coronary MRA. The details of CSAI coronary MRA using a free-breathing balanced SSFP sequence with a 3D non-selective pulse. Data acquisition was accelerated by employing a CSAI framework with a factor of 6.

The image quality of coronary segments was rated by two observers in consensus on a 5-point scale (1, non-diagnostic; 5, excellent). Images with a score ≥3 were considered to be satisfactory and acceptable for diagnosis. Significant coronary stenosis were defined as luminal diameter reduction of ≥50%. Sensitivity, specificity, positive (PPV) and negative predictive values (NPV) of CSAI coronary MRA for the detection of significant CAD were calculated. Curved planar reformation (CPR) and volume rendering (VR) images were used for image display.

Results: The mean image acquisition time was 8.3±2.5 min. Twenty-four (42.9%) had significant CAD on coronary CTA. Overall, 718/777 (92.4%) of coronary MRA segments were deemed diagnostic. The sensitivity, specificity, positive predictive value, negative predictive value and diagnostic accuracy were as follows: per patient (91.7%, 81.3%, 85.7%, 78.6% and 92.9%), per vessel (82.5%, 92.2%, 89.9%, 76.7% and 94.4%) and per segment (76.8%, 97.7%, 96.1 %, 74.1% and 98.0%) respectively.

Conclusion: The novel non-contrast, radiation-free, whole-heart coronary MRA framework with CSAI, could provide excellent image quality and diagnostic performance within clinical feasible time for patients with suspected CAD.

Key words: coronary artery disease; deep learning; artificial intelligence; compressed sensing; coronary MR angiography

ID 3633

Correlation of Brain N-acetylaspartylglutamate Level with Nicotine Dependence Score in Adult Cigarette Smokers

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Philips Healthcare

Objective: Long-term smoking can lead to both cardiovascular and respiratory diseases, as well as cognitive and neurological damage. Numerous studies have shown that nicotine addiction induces changes in brain structure and function, but only a few has been done on the changes in neurometabolism in smokers. Excitation/inhibition (E/I) balance of neurotransmitters is vital for maintaining normal brain functions, while the contributions of nicotinic signaling to homeostatic regulation and maintenance of the E/I ratio are only beginning to be understood. This study aims to explore the changes in brain neurotransmitters in the prefrontal cortex of patients with nicotine addiction (NA), which may help understand the underlying metabolic mechanism in nicotine addiction.

Methods: All subjects underwent conventional MRI and the editing 1H-MRS scans on a 3.0 T scanner (Ingenia Meta, Philips Healthcare). After excluding patients with underlying diseases, combined alcohol dependence or bad data quality, 18 NA patients and 22 age-and sex-matched HCs were included for analyses. Two independent samples t-test was used to analyze the differences in N-acetylaspartylglutamate (NAAG), gamma-aminobutyric acid (GABA) and Glx (glutamate + glutamine) levels between the two groups. Finally, the correlation analysis of GABA, Glx and NAAG levels with the clinical characteristic assessment scales (Including Daily smoking amounts, Age of smoking, FTND score, RRSQ score and BIS-11 score) was performed using the Spearman criteria.

Results: No significant difference was observed in the GABA, Glx and NAAG levels between the NA and HC groups. The NAAG level in mPFC shown a significant correlation with the score of Fagerstrom Test for Nicotine Dependence (FTND) in NA patients.

Conclusion: The correlation of NAAG level with nicotine dependence suggests that the metabolism of NAAG is changed in the pathogenesis of nicotine dependence patients, and the change of NAAG levels may be an important factor in the formation of addictive behaviors in nicotine addicts.

Key words: MR spectroscopy; NAAG; nicotine; neurotransmitter

ID 3636

Submillimeter mDixon Quant Sequence

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Objective: The scan resolution for the traditional mDixon Quant sequence is limited and cannot fulfill the imaging requirements of the animal experiments and the muscle-skeleton scanning. This study aims to develop a new submillimeter mDixon Quant sequence.

Methods: **T**raditional mDixon Quant utilizes a multi-echo acquisition scheme. Therefore, the lower limit of the echo spacing is limited by the acquisition window. For high-resolution scans, the acquisition window is prolonged, which may lead to a huge echo spacing. Fat leakage may occur in this case and the quantification results are not reliable anymore.

To resolve the above-mentioned problem, we propose a submillimeter mDixon Quant sequence with multi-acquisition

scheme. All 6 echoes are acquired in different repetition times, resulting in a shorter echo spacing (theoretically could be 0 ms), therefore no fat leakage anymore.

A mouse was scanned on a 3.0T scanner (Elition X, Philips Healthcare, Best, the Netherlands) with the traditional and the new submillimeter mDixon Quant sequences, using a dedicated animal coil.

Results: Compared with the traditional mDixon Quant (minimum 1.3*1.3 mm2 achievable in-plane acquisition voxel size), the new mDixon Quant sequence could achieve a higher in-plane resolution (in this experiment, acquisition voxel size of 0.4*0.4 mm2, could be even smaller with a longer scan time) and higher image quality. The images are sharper and the partial volume effect is reduced. The total scan time for the new sequence is 3 min 57 s, compared with 5.8 s for the traditional sequence.

Conclusion: A new submillimeter mDixon Quant sequence is proposed and implemented, which could be used for high-resolution fat quantification.

Key words: Submillimeter; mDixon Quant; Animal scan

ID 3641

Peri-coronary Adipose Tissue Attenuation Parameters Predict Coronary Atherosclerosis Heart Disease Based on Dual-layer Spectral Detector Computed Tomography: A Preliminary Exploration.

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Objective: Coronary atherosclerosis is a chronic inflammatory disease. Peri-coronary adipose tissue (PCAT) attenuation is closely related to coronary inflammation. This study aimed to investigate the relationship between PCAT attenuation parameters and coronary atherosclerotic heart disease (CAD) by dual-layer spectral detector computed tomography (SDCT).

Methods: This study included 45 non-CAD patients and 45 CAD patients. All patients underwent coronary computed tomography angiography (CCTA) with SDCT. FAI120kVp and FAIVMI were measured on conventional images (120kVp) and virtual monoenergetic images (VMI) by semi-automatic software respectively. The slope of the spectral attenuation curve (λ) was calculated. Logical regression models were established to evaluate the predictive value of PCAT attenuation parameters for CAD.

Results: FAI120kVp of CAD patients was significantly higher than non-CAD (− 72.64±5.94HU vs. − 77.19±3.68HU, P<0.001). FAIVMI and λ were also higher in CAD patients (P<0.05). FAI and λ of the vessels with or without plaques in CAD patients were higher than in vessels without a plaque in non-CAD (P<0.05). Furthermore, FAI and λ of vessels with plaques were slightly higher than that without plaque in CAD patients (P>0.05). According to ROC curve analysis, a combination model of FAIVMI, FAI120kVp, and λ obtained the maximum area under the curve (AUC) for discriminating between CAD and non-CAD patients.

Conclusion: Based on CCTA using SDCT, PCAT attenuation parameters can improve the ability to distinguish CAD patients from non-CAD patients. By detecting the Increase of PCAT attenuation parameters, it might be possible to predict the formation of atherosclerotic plaques before they appear.

Key words: Peri-coronary adipose tissue attenuation; Dual-layer spectral detector CT; Atherosclerotic plaque

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ID 72

Multimodal Collaborative Tumor Precision Therapy Based on Phototherapy

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Objective: Tumor has become the most important threaten of human health. Chemotherapy, radiotherapy and surgery are the main treatments in the field of tumor therapy, but they all have their own limitations, such as strong invassiveness and toxic side effects, which seriously damaged the life quality of patients. A more efficient and safer tumor treatment should be explores as soon as possible. In recent years, phototherapy has become one of the emerging straegy in the file of tumor therapy due to its' milder and high efficiency. Phototherapy, including photodynamic therapy (PDT) and photothermal therapy (PTT), which relies on the conversion of light energy into chemical and thermal energy by phototherapeutic moieties to kill tumors, has been widely used in clinic as a non-invasive oncologic therapeutic modality. Besides, the biological effects in vivo of phototherapy can be combined with other strategies to achieve the purpose of synergistic treatment.

Methods: In this study, we constructed a nanobiomaterial drug carrying system for multimodal combined precision treatment of solid tumor, which combined immunotherapy, gene therapy, chemotherapy and phototherapy to make each treatment cooperative and enhance tumor treatment including effective inhibition of tumor development, metastasis and recurrence. The synergistic anti-tumor effect of different treatment strategy combination was conducted at cellular and animal levels and the mechanism was studied by Western , q-PCR and other methods.

Results: In vitro and in vivo experiments have shown that these tactics may provide a promising and pragmatic platform for clinical applications.

Conclusion: Therefore, the multimodal collaborative tumor system based on phototherapy is of great significance for the precision therapy of tumor.

Key words: Phototherapy, nanobiomaterials, synergistic therapy, tumor targeting

ID 162

基于拉曼内窥镜的脑胶质瘤术中无创光学活检

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目的：脑胶质瘤是最常见的颅内原发肿瘤，根据 2021 年新版指南将 IDH、1p/19q、TERT、EGFR、7 号染色体、10 号染色体、CDKN2A 和 CNKN2B 相关的分子特征纳入高级别脑胶质瘤的分级分类标准，分子特征的检测对确定高级别脑胶质瘤的类型、级别和手术策略有着重要意义。目前，分子特征检测的金标准方法难以在术前或术中提供检测结果，无法指导手术切除策略。因此，临床上亟需一种无创、准确、快速的术中脑胶质瘤多分子特征检测方法。

方法：针对上述问题，本文建立了一种基于拉曼光谱的高级别脑胶质瘤多分子特征检测方法。首先，本文搭建了一套高灵敏度的拉曼光谱内窥镜系统；术中采集了 44 例高级别脑胶质瘤患者的 2358 条原始光谱；建立了基于深度学习的脑胶质瘤分子分型诊断模型。

结果：分子特征检测的 AUC 大于 0.95，且灵敏度、特异度、准确度均大于 90%，检测时间小于 1s。在模型的生物可解释性方面，本文发现脂质和胶原蛋白分子含量在分子分型诊断中的贡献度更为显著。

结论：综上所述，本文建立了一种基于拉曼光谱的快速准确的高级别脑胶质瘤多分子特征检测的新方法，有望推动脑胶质瘤术中分子特征检测方法的发展。

关键字：拉曼内窥镜；脑胶质瘤；分子分型；深度学习；

ID 170

In vivo Corneal Elastography: an Optical Coherence Tomography Method

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Objective: In vivo measurement of corneal biomechanical property is still a longstanding challenge, and there is no gold standard yet. We describe the use of dynamic optical coherence elastography (OCE) to characterize sub-micron amplitude mechanical wave propagation in the human cornea in-vivo, thus provide a method for clinical determination of corneal biomechanical properties, such as Young's modulus (YM) and natural frequency (NF).

Methods: High-resolution (0.24 nm) phase-sensitive optical coherence tomography imaging was combined with micro-liter-air pulse tissue stimulation to perform dynamic elasticity measurements in 18 eyes of 9 participants. Low-force (0.1 mm Hg), spatiotemporally discreet (150 μm; 800 μs) tissue stimulation produced submicron-scale (range: 0.005 to 0.5 μm) tissue deformations that were measured at multiple positions over a 1 mm^2 area. Surface wave velocity was measured and used to determine corneal YMs, while corneal NFs were quantified using a single degree of freedom model based on the corneal oscillations. Corneal YMs and NFs were compared with intraocular pressure (IOP) and central corneal thickness (CCT).

Results: The measured IOP varied from 11 mmHg to 20.7 mmHg, and CCT varied from 486 μm to 608 μm. Corneal elastic wave velocity ranged from 2.4 to 4.2 m/s (mean: 3.5 m/s, 95% CI: 3.2 – 3.8 m/s) and were correlated with CCT (r = 0.64, p = 0.03), and IOP (r = 0.52, p = 0.16). Young's modulus was estimated using a simplified group wave velocity equation (17 to 152 KPa). Corneal NFs ranged from 234 to 277 Hz (coefficient of variation: 3.2%), and were positively correlated with higher IOP (r = 0.72, p < 0.001). There was no correlation between NF values and CCT values.

Conclusion: These in vivo measurements of submicron surface wave velocity and NF enable clinical determinations of corneal tissue stiffness that will be important for disease detection and for monitoring clinical treatment.

Key words: Optical Coherence Elastography, Optical Coherence Tomography, Corneal Biomechanics, Young's Modulus, Natural Frequency

ID 233

基于差分相衬的定量相位显微成像研究

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目的：定量相位成像可以实现细胞无标记、高衬度成像，并具有检测干质量等功能。基于差分相衬的定量相位成像（qDPC）具有结构简单易实现的特点，但相位成像质量容易受到噪声影响。本研究探索如何实现了高保真、低噪声、无背景干扰的优质相位成像效果的算法。

方法：理论上采用 L0 范数和 L1 范数及组合约束探索其成像质量；实验上编码 LED 阵列实现定量差分相位成像装置，结合相位标定板，检测重构相位，并通过实验对比细胞相位成像效果。

结果：基于 qDPC 满足暗场稀疏先验特性，提出暗场先验 - 海森 -qDPC 模型，在原有解卷积模型的基础上组合提出的新的惩罚函数，运用半二次分分裂法等方法获得比传统 qDPC 重构算法更好的相位重构结果；探索并提出了基于 Retinex 理论的新型差分像衬相位重构算法，实现了高保真、低噪声、无背景干扰的优质相位成像效果；在迭代求解上，在细胞类样本下对比了 L2 范数和 L1 范数约束，L0 范数约束能获得免调参的快速反演相位，并具有良好的噪声水平，将提升实时成像速度。

结论：在相位反演算法中引入新的约束条件，能提升相位准确性和抗噪声干扰能力，降低了 qDPC 实验门槛，增强了该技术的泛用性与实用性，有望为临床细胞提供一种实用成像方法。

关键字：定量相位成像；差分相衬成像；细胞相位成像；范数；

ID 234

Label-free, Non-contact, Widefield, Quantitative Imaging of Oxy-hemoglobin, Deoxy-hemoglobin, Water, and Lipid in Tissue Using Spatial Frequency Domain Imaging (SFDI)

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Objective: Tissue chromophores, such as oxy-hemoglobin, deoxy-hemoglobin, water, and lipids, are important biomarkers for various diseases and physiological processes. Particularly, water and lipid are key participants of many biological processes such as inflammation and cardiovascular disease, but there are few label-free, non-contact optical Methods that can spatially map these components in vivo. Shortwave infrared meso-patterned imaging (SWIR-MPI) is an emerging technique that successfully addresses this need. However, it requires a dedicated SWIR camera to probe the 900-1300 nm wavelength region, which hinders practical translation of the technology. Compared with SWIR-MPI, we aim to develop a new technique that can dramatically reduce the cost in detector while maintaining high accuracy for the quantification of

tissue water and lipid content.

Methods: By utilizing water and lipid absorption features in the 900-1000 nm wavelength region as well as optimal wavelength and spatial frequency combinations, we develop a new imaging technique based on spatial frequency domain imaging (SFDI) to quantitatively map tissue water and lipid content using a regular silicon-based camera.

Results: The proposed method is validated with a phantom study, which shows average error of 0.9±1.2% for water content estimation, and -0.4±0.7% for lipid content estimation, respectively. The proposed method is also demonstrated for ex vivo porcine tissue lipid mapping as well as in vivo longitudinal water content monitoring. The proposed method is also able to simultaneously quantify oxy-hemoglobin, deoxy-hemoglobin, water, and lipid in tissue using 600-1000nm wavelength range. Additionally, compared to the state-of-the-art, the imaging speed of the proposed method is over 10x faster.

Conclusion: The proposed technique enables spatial mapping of tissue water and lipid content with the cost in detector reduced by two orders of magnitude compared with the state-of-the-art while maintaining high accuracy. The experimental Results highlight the potential of this technique for substantial impact in both scientific and industrial applications.

Key words: spatial frequency domain imaging, tissue optics, spectroscopy

ID 242

Microglia Modulation with 1070-nm Light Attenuates Aβ Burden and Cognitive Impairment in Alzheimer's disease

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Objective: Photobiomodulation, by utilizing low-power light in the visible or near-infrared spectrum to trigger biological responses in cells and tissues, has been considered as a possible therapeutic strategy for Alzheimer's disease (AD), while its specific mechanisms have remained elusive.

Methods: Here, we provide evidence that cognitive and memory impairment in an AD mouse model can be reduced by 1070-nm light via reducing cerebral β-amyloid (Aβ) burden, the hallmark of AD. The glial cells, including microglia and astrocytes, play important roles in Aβ clearance.

Results: Our Results have shown that 1070-nm light pulsed at 10 Hz triggers microglia rather than astrocyte responses in AD mice. The 1070-nm light-induced microglia responses with alteration in morphology and increased colocalization with Aβ are sufficient to reduce Aβ load in AD mice. Moreover, we have demonstrated that 1070-nm light pulsed at 10 Hz can reduce perivascular microglia and promote angiogenesis to further improve Aβ clearance.

Conclusion: Our study highlight the important roles of microglia and cerebral vessels in the use of 1070-nm light for the treatment of AD mice and provides a framework for developing a novel therapeutic approach for AD.

Key words: microglia modulation, 1070-nm light, Aβ, cognitive impairment, Alzheimer's disease

ID 325

双靶向磁性介孔二氧化硅纳米粒子通过解聚和肠道代谢减少脑淀粉样蛋白 -β 负担

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目的：主动去除多余的外周淀粉样蛋白 -β (Aβ) 是一种治疗阿尔茨海默病 (AD) 有前景的方法。 然而，使用抗 Aβ 单克隆抗体 (mAb) 的 Aβ 外周清除不能去除脑内 PET 可检测的 Aβ，这可能是由于 mAb 无法穿过血脑屏障来降解脑内不溶性 Aβ 斑块。

方法：我们筛选了低肝脏富集的非球形大粒径二氧化硅纳米颗粒，通过在其表面偶联的 Aβ42 靶向抗体和 CD44 靶向配体透明质酸 (HA) 开发了双靶向磁性介孔二氧化硅纳米粒子 (HA-MMSN-1F12)。

结果：HA-MMSN-1F12 对 Aβ42 寡聚体具有高结合亲和力。静脉注射三周后，10 月龄 APP/PS1 小鼠脑内不溶性 Aβ 数量显著减少。 此外，相比较 1F12，荧光标记的 HA-MMSN-1F12 在肝脏部位的富集显著降低，而在肠道部位的富集显著增加。这表明 HA-MMSN-1F12 降低肝脏对抗体的非特异性摄取，并通过肠道代谢将捕获的 Aβ 直接排出体外，从而降低脑内 Aβ 负担和神经炎症。

结论：这种基于 Aβ42/CD44 双靶向磁性介孔二氧化硅纳米粒子的独特 Aβ 去除策略可以避开 AD 肝功能障碍问题，为 AD 治疗开辟了一条新途径。

关键字：阿尔茨海默病 ; Aβ 清除 ; Aβ42 靶向抗体 ; 介孔二氧化硅纳米粒子。

ID 377

A Versatile 980 nm Absorbing Aggregation-Induced Emission Luminogen for NIR-II Imaging-Guided Synergistic Photo-Immunotherapy Against Advanced Pancreatic Cancer

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Objective: To address urgent tasks in the treatment of advanced deep-seated tumors, we developed a 980 nm absorbing agent with aggregation-induced emission (AIE) tendency, namely TPE-BT-BBTD, which simultaneously possesses the longest absorption wavelength among all the reported AIE molecules.

Methods: The functionality of deep near-infrared-II fluorescence imaging (NIR-II FLI) and outstanding photothermal performance was well tailored for advanced pancreatic cancer treatment.

Results: With the covalent attachment of αPD-L1 antibody, αPD-L1@TPE-BT-BBTD nanoparticles showed precise tumor targeting and excellent immunosuppression reversal ability. Following local photothermal therapy, immunogenic tumor vaccination was induced to trigger the infiltration of cytotoxic T lymphocytes (CTLs) in tumors. With the decreased FoxP3+ Treg cells and M2-like macrophages that reversed by αPD-L1, CTLs activity was further enhanced with more production of granzyme B (GrB), which much accurately led to tumor apoptosis and effectively suppressed spontaneous metastases.

Conclusion: Overall, αPD-L1@TPE-BT-BBTD nanoparticles based NIR-II FLI-mediated photo-immunotherapy was able to significantly improve the controlling of primary tumor and metastasis in the treatment of advanced deep-seated tumors.

Key words: aggregation-induced emission, photo-immunotherapy, NIR-II imaging, immunosuppression reversal, pancreatic cancer

ID 467

A Comprehensive OCT Technique for the Measurement of Cerebral Blood Vessel Structure, Blood Flow Velocity, and Blood Transit Time

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Objective: Accurate measurement of the microcirculation dynamics, including the blood vessel 3D structure, blood flow velocity and the blood flow transit time can not only improve our understanding of the pathology of microcirculation dysfunction-related disease, but also provide important parameters for disease diagnosis, prevention, and early treatment.

Methods: In this work, we introduce a comprehensive optical coherence tomography (OCT)-based functional imaging technology for the 3D measurement of the micro vessel networks' structure, blood flow velocity, and the blood flow transit time. The M-mode data acquisition (repeated Ascans) was employed in this technique. For blood vessel 3D structure imaging, we developed a first order field autocorrelation function (g1)-based adaptive analysis method to suppress the blood vessel tail artifacts and enhance the blood flow in small vessels. For blood flow velocity 3D imaging, we developed a set of quantitative dynamic analysis Methods to measure both the axial and total blood flow velocity of the complex vessel network. We further developed a graphing method to obtain the 3D topological parameters of the 3D vessel network, including the vessel skeleton, branching, vessel diameter, and the blood flow speed at each location.

Results: With those information, we are able to, to the best of our knowledge, obtain the 3D blood transit time in the complex vessel network for the first of time.

Conclusion: The proposed technique has the advantage of obtaining these three important blood flow biomarkers from a single data acquisition, which greatly simplifies the experiment procedure. The proposed OCT approach has a wide application in the field of microcirculation dysfunction-related disease studies.

Key words: optical coherence tomography, microcirculation dynamics, blood flow transit time, blood flow velocity, dynamic light scattering

ID 531

The Biomedical Applications of Light-responsive Chemistry

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Objective: Light-responsive chemistry provides an on-demand and non-destructive method to realize multiple biological applications. Here, we have developed and deployed two types of light-responsive chemistry in the applications of controlled drug release and surface functionalization.

Methods: We synthesized a series of photo-crosslinkable copolymers with different functional groups. In another application, we introduced a step-changing solution to uncontrolled drug release from porous silicon nanoparticles (pSiNPs). This approach involves the design, synthesis, and application of three different linker-drug conjugates comprising anticancer drug doxorubicin (DOX) and different stimulus-cleavable linkers (SCLs) including the photocleavable linker (ortho-nitrobenzyl), pH-cleavable linker (hydrazone), and enzyme-cleavable linker (????-glucuronide).

Results: By using a photo-crosslinkable copolymer that was prepared from monomers containing benzophenone and N-hydroxysuccinimide ester functional groups, we were able to evenly coat and functionalize microfluidic chip channels in situ, providing a covalently attached homogenous layer of extracellular matrix proteins (ACS Appl. Mater. Interfaces,

2020, 12, 56753-56766).

The SCL-DOX conjugates were covalently attached to the surface of pSiNP via copper (I)-catalyzed alkyne-azide cycloaddition (CuAAC, i.e., click reaction) to afford pSiNP-SCL-DOXs. The covalent conjugation between SCL-DOX and pSiNPs endows the pSiNPs with excellent stability and highly controlled release behavior (Adv. Healthc. Mater., 2022, 11, 2200076).

In addition to the abovementioned works, we have prepared photo-responsive fluorescent probes for disease diagnosis.

Conclusion: Photo-responsive chemistry is versatile for various biological applications. For device modification (surface chemistry), UV light is sufficient. However, short-wavelength light suffers from low tissue penetration for disease diagnosis and treatment. Our next step is to utilize different light sources to realize deeper tissue imaging and therapy.

Key words: Light-responsive chemistry; Organ-on-a-chip; Controlled drug release; Probes

ID 562

基于表面增强拉曼散射光谱的生物医学检测

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目的：体外诊断、检验检疫等对多元生物标志物的快速、准确、方便、定量化检测需求越来越凸显。针对这一需求，本研究主要基于表面增强拉曼散射原理，利用拉曼光谱的指纹光谱特性实现多元标志物的高灵敏度定量检测，提供一种新型的即时检验（POCT）技术。

方法：我们设计了一系列等离激元增强基底，包括平面和微球基底等，通过它们可以实现分子或者细胞等多种生物标志物的非标记或者标记高灵敏度检测。特别是在标记检测中，我们设计合成的具有核壳结构的 SERS 纳米标签可以有效提高拉曼染料的信号强度，同时还可以利用染料的分子指纹进行编码进行多重分析。

结果：通过非标记检测实现了细菌的快速鉴别以及气体的快速检测，多元 POCT 标记检测性能达到了实验室大型设备水平。

结论：基于表面增强拉曼散射光谱快速检测方法具有极高的灵敏度，在分子、细胞等生物医学检测领域具有广泛的应用前景。

关键字：表面增强拉曼散射，纳米标签，POCT，非标记检测

ID 627

基于 IVOCT 的动脉粥样硬化斑块光学特征参数表征方法研究

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目的：目前临床上通过血管内光学相干层析成像 (IVOCT) 判断动脉粥样硬化斑块类型存在一定的主观性，缺乏客观评价的量化标准。本研究探讨生物组织光学特征参数理论模型的计算方法，以期通过光学特征参数量化评估动脉粥样硬化斑块特性，为临床提供客观评价依据。

方法：本研究优化了已有的基于 OCT 检测信号计算生物组织光学特征参数的理论模型。在深度分辨模型中加入了恢复滤波器和加权水平总变异的去噪方式以提高最终计算衰减系数的准确性。在基于扩展的惠更斯菲涅尔原理模型中

先验地计算了模型拟合所需要的参数值，提高了最终散射系数计算结果的准确性。

结果：通过经典单次散射模型和蒙特卡洛模拟在光学仿体上对优化后的模型进行了测试，证实了其准确性。以家猪冠脉的血管壁和人动脉粥样硬化斑块组织为实验样本，确定了不同结构的光学特征参数，为进一步实现动脉粥样硬化斑块的光学特征参数定量表征奠定理论与实验基础。

结论：本研究通过光学仿体和生物组织样本验证了通过深度分辨模型和基于扩展的惠更斯菲涅尔原理模型计算基于 OCT 光学信号的动脉粥样硬化斑块特征参数的理论模型，为进一步建立斑块客观评价方法奠定了理论基础。

关键字：血管内光学相干层析成像；动脉粥样硬化斑块；光学特征参数；理论模型；样本测试

ID 665

Hyperscanning Real-world Interactions via Functional Near-infrared Spectroscopy

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Objective: A wearable functional near-infrared spectroscopy (fNIRS) system is implemented in this work for hyperscanning real-world interactions, enabling synchronous multi-subjects measurement, wireless master-slave connections and lower power consumption.

Methods: The proposed wearable fNIRS system is structured as a network of distributed fibreless optode modules, with each equipped with 10 dual-wavelength light emitting diodes and 4 monolithic silicon photodiodes with on-chip transimpedance amplifier. Software lock-in detection strategy is performed in each slave to separate the signals from the different source-detector combinations as well as the wavelengths.

Results: Phantom and in-vivo experiments are designed to evaluate the performances of the implemented fNIRS system, and validate the good raw signal quality with the static measurement fluctuation of < 2%, dynamic optical range of > 72dB, and variation coefficient of ~ 5.39%, as 10 channels work simultaneously, as well as the feasible sensitivity for detecting task-evoked activation.

Conclusion: The preliminary in-vivo experiment suggests that, the proposed system has a capability of distilling the inter-brain activation patterns with acceptable temporal resolution, and bears high potential toward fNIRS-based social neuroimaging in real-world.

Key words: functional near-infrared spectroscopy；hyperscanning；wearable multi-module system;

ID 666

Improved Non-Local Means Denoising Method for Photoacoustic Microscopy

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Objective: Photoacoustic microscopy (PAM) is a promising technique capable of label-free imaging of microvessels. Limited by the detection sensitivity of photoacoustic signals, many researches relying on PAM have been long suffered from poor image qualities. Non-local means filtering (NLM) was proved to be effective in the denoising of both natural and

medical images in recent years but has not been extensively investigated for PAM. Here, we present an improved non-local means denoising method named Depth-NLM for PAM which has a better performance than the state of the art.

Methods: In this study, features of 3-D datasets of PAM were illustrated and a theoretical analysis of both the standard NLM and Depth-NLM was given. Then, two types of data partitioning method from 3-D photoacoustic datasets were provided and compared; a fast computation mode for Depth-NLM was designed which could balance the processing time and the denoising performance. Finally, several in vivo imaging datasets by different PAMs were acquired and processed with NLM and Depth-NLM; Qualitative and quantitative analysis were conducted to demonstrate the superiority of Depth-NLM.

Results: Experiment Results verified that the proposed Depth-NLM could improve the image quality of PAM significantly. The signal-to-noise ratio (SNR) of images processed by Depth-NLM was 2 times higher than that of NLM. Moreover, thanks to the layer-by-layer processing method which incorporated 3-D information of vessels, Depth-NLM preserved more fine details of microvessels than NLM. In addition, under the fast computation mode, the computation speed of Depth-NLM could be improved by 5 times with a negligible reduction in SNR.

Conclusion: The proposed Depth-NLM is expected to facilitate PAMs using unfocused ultrasound transducers which are seriously affected by the background noise. It also has the potential to ensure high-speed PAMs which appeal a lower pulse energy to avoid damaging samples while at the expense of inferior SNR.

Key words: photoacoustic microscopy, image denoising, non-local means

ID 670

超高灵敏高特异性光子 Crispr 生物医学传感芯片研发

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目的： 解决 SPR 器件灵敏度较低的痛点；开发出高特异性高灵敏度高延展性的新型核酸传感平台。

方法： 利用锑烯二维材料独特表面等离激元（SPR）效应，通过设计 SPR 芯片实现对特定肿瘤标志物的光学响应。利用基于二维半导体的光学传感器高灵敏特性，将其与高特异性 CRISPR 技术联合。

结果： 研制出超高灵敏（10-18mol/L）SPR 传感芯片，为当时国际最高水平（Nature Communications 2019）。开发出新型核酸传感平台 MOPCS（(Methodologies of Photonic CRISPR Sensing)），实现了对杜氏肌萎缩症外显子缺失的基因片段极高灵敏度和超高特异性的检测（Advanced Science 2022）。

结论： MOPCS 光学传感优势包括：（一）高特异性。CRISPR/Cas12a 独特的酶切特性，有效避免了假阳性结果的产生。（二）高灵敏度。实现了 38 分钟内对 fM 级别病毒核酸的无需预扩增的有效检测，有效避免了假阴性结果的产生。（三）高延展性。可广泛应用于各类基因检测，对提高国家生物安全治理能力具有重要意义（National Science Review 2022 等）。

关键字： 生物传感器件，生物医学光子学，CRISPR

ID 685

异质 Au@AuAg 蛋黄 - 蛋壳纳米结构双等离子体模式转换的研究

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目的：由于具有独特的局部表面等离子体共振（LSPR）特性，贵金属纳米颗粒作为生物和化学传感器得到了深入研究。但是，大多数单金属纳米颗粒的 LSPR 特性过于简单，这限制了其应用潜力。与单金属纳米颗粒不同，双金属核壳结构的组成更加复杂，所以具有更加丰富多彩的光学特性。其中，Au@Ag 蛋黄 - 蛋壳结构在核心与壳层之间引入间隙，使其具有更为丰富的界面，从而呈现出更加多元化的 LSPR 特性。

方法：本文设计了一种新颖的具有非对称核体的 Au@AuAg 蛋黄 - 蛋壳纳米结构，该核体由一端的金纳米锥和另一端的银纳米棒组成，并可以与金银合金壳层耦合产生两种明显分离的等离子体模式。

结果：这两种不同等离子体模式均可以通过改变壳层厚度选择性地打开或关闭。当壳层多孔且薄时，其与内部银纳米棒的耦合占主导地位；当壳层密闭且厚时，其与内部金纳米锥的耦合占主导地位。

结论：通过改变银棒和金锥的尺寸调节核体形貌，从而灵活调控开关双等离子体模式时所需的壳层厚度，双等离子体模式的半峰宽以及双等离子体模式的距离和位置。此外，调整合金壳层的端面形态也可以调控双等离子体的间隔距离。这些发现在 LSPR 传感检测、表面增强光谱检测、双通道生物传感器等应用领域具有广阔的前景。

关键字：具有非对称核体的 Au@AuAg 蛋黄 - 蛋壳异质纳米结构，双等离子体模式，转换，耦合

ID 768

通过电化学置换法合成内部空隙可控的 Au@AgPt 蛋黄蛋壳纳米胶囊结构

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目的：铂基蛋黄蛋壳型纳米材料，由于其具有较高的比表面积，可调的内部间隙和中空外壳，在改善光学和催化性能方面具有良好的应用前景。本论文通过电化学置换反应合成了一种新的具有内部间隙可调的 Au@AgPt 蛋黄蛋壳纳米胶囊结构，并系统研究了其内部间隙、氯铂酸体积对纳米胶囊颗粒形貌和等离子体谱特性的协同作用，期望扩展铂基蛋黄蛋壳型纳米材料的形貌及其光学特性的研究。

方法：基于包裹在金纳米棒上的不规则 Ag 壳和 Pt4+ 离子之间的电化学置换反应。

结果：以不规则银层包裹的金纳米棒作为牺牲模板，通过改变银层包裹厚度和加入氯铂酸体积，对其形貌及等离子体光谱特性进行研究，发现随着 Pt4+ 离子的增加，Ag 壳总是优先从银层中间一点处开始出现“缺口”，再被逐渐“镂空”，最终形成具有内部间隙可调的 Au@AgPt 蛋黄蛋壳纳米胶囊。并且随着氯铂酸体积的增加会导致其局域表面等离子体共振（LSPR）吸收峰红移，峰宽变宽以及吸收强度下降。 同时，中间间隙厚度的增加，导致纵向和横纵 LSPR 吸收峰趋于融合。

结论：报告了一种新的具有内部间隙可调的 Au@AgPt 蛋黄蛋壳纳米胶囊结构，其形成过程可引起其吸收峰在 400 到 800 nm 范围内变化。

关键字：三元金属；电化学置换；Au@AgPt 蛋黄蛋壳结构；局域表面等离子体共振（LSPR）

ID 778

Label-free Structural and Functional Volumetric Imaging by Dual-modality Optical-Raman Projection Tomography

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Objective: Volumetric imaging by optical projection tomography (OPT) provides unprecedented structural details of specimens, but requires fluorescence label for chemical targeting. Label-free wide-field Raman imaging, combining with the projection tomographic strategy, can achieve high resolution volumetric imaging of large field-of-view sample, but lack tissue microstructure. Here, we demonstrate a dual-modality optical-Raman projection tomography (ORPT) technology, enabling label-free volumetric imaging of microstructures and chemical components of millimeter-scale samples with micron-level spatial resolution.

Methods: We built a dual-modality ORPT system, and validated its feasibility and the potential in biological applications.

Results: Our ORPT system is capable of resolving the 3D distribution of molecules and structural information in a volume with micron-level spatial resolution from the same system. The feasibility of the proposed ORPT system and the probability of the FBP algorithm for 3D reconstruction were first verified by detecting the single and multiple PS beads in a volume. We then demonstrated the applicability of this new methodology developed here by volumetric fusion imaging of zebrafish and Arabidopsis thaliana in a volume, respectively, showing that this technique could be used to visualize the microstructural and molecular information of biological samples. We finally showed that the ORPT system could be used as an imaging tool to monitor the process of lipid and protein metabolism of drosophila. We recorded the fat body changes of drosophila in microstructure and used the Raman imaging to identify morphology of lipid and protein distribution during the different developmental stages.

Conclusion: Collectively, our technology enables dual-modality of structural and functional volumetric imaging of multiple biomolecules in a large sample.

Key words: volumetric imaging, dual-modality imaging, label free imaging, projection tomography

ID 797

光声分子成像监测疫苗铝佐剂在小鼠淋巴系统内输运动态过程的研究

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目的：疫苗研发过程亟需能够高分辨、大深度、原位、可视化佐剂的技术，然而目前缺少能够满足以上要求的仪器。针对抗原—佐剂时、空检测难题，本项目拟基于光声成像装置，实现原位条件下佐剂跨生物屏障过程的快速可视化和定量评估。

方法：光声成像技术兼具光学高分辨率和声学大穿透深度的优点，还具有光谱解析能力，能够精准、定量、三维成像纳米佐剂的分布特征，高成像速度有利于开展动态评估。本项目将基于断层扫描模式并结合分子标记技术，在亚毫米分辨率下检测，吲哚菁绿（ICG）标记的铝佐剂在小鼠淋巴系统内输运情况。

结果：临床疫苗注射用的铝佐剂，可以被 ICG 分子高效的标记。通过设计合理的标记路线，铝佐剂的稳定性相对于标记前变化不大，电镜能谱检测进一步证实 ICG 分子标记的成功，透析 + 吸收光谱检测证实 ICG 标记分子可以稳定

的与铝佐剂结合到一起。进一步的光声断层成像实验结果表明，ICG 分子注射到小鼠后腿淋巴节后可以快速扩散到上肢的淋巴结种，ICG 标记的铝佐剂分子的扩撒过程相对较慢。

结论：光声分子成像可以三维动态可视化铝佐剂在小鼠淋巴系统的输运过程，更多细节还需进一步研究。

关键字：光声成像，铝佐剂，淋巴系统

ID 817

多参量弱脉冲光致压力的检测及参量特性分析

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目的：弱脉冲光可调控生物组织活动，其中有光热、光压力、光化学等多种效应。而光致机械压力（也称光致声）效应与光参量间有何特性，尚无系统探究。设计一种定量检测不同参量下弱脉冲光致压力的方法、获得实验数据，对光调控生命现象有参考价值。

方法：采用多波段可调参脉冲光源，固定光输出端口与特定压力传感器表面间距离、位置及光斑面积，采用固定变量法，在常温常压 (20℃、101KPa) 下，依次测量了 6 种波段脉冲光随光参量变化的光压，系统分析脉冲光致压力与光波段、脉宽及光强之间的响应特性。

结果：结果表明，6 波段光当脉宽从 100~500 μs 或峰值功率从 50~500mW 变化时，弱脉冲光致压力总体上均呈随脉冲光能量增大而变大，但升压趋势与参量关系各有差异，其中可见光 450、525、638 nm 的对应光压效应明显强于非可见光 810、980、1065 nm；且当峰值功率为 100~400mW 时 525nm 窄脉冲光对应光压最强，当峰值功率为 450~500mW 时 450nm 窄脉冲光压最强；在各参量变化中，980nm 和 810nm 的光压效应相对较弱。

结论：在光调控生物活动时，欲获得安全且高效的压力敏感通道调控效果，应对光参量做优选。

关键字：光致机械压力，弱脉冲激光，多波段，光与生物组织相互作用

ID 855

Engineering Synthetic Reporters for RNA Imaging and Functional Gene Regulation

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Objective: RNA processing plays a central role in accurately transmitting genetic information into functional RNA and protein regulators. To fully appreciate the RNA life-cycle, tools to observe RNA with high spatial and temporal resolution are critical. In the past years, our group has developed various genetically engineering reporter probes for visualizing the microRNA or pre-mRNA in living cells and animals. These tools have been successfully applied to monitor miRNA activity, screen miRNA-targeting natural products, evaluate pre-mRNA splicing, etc.

Methods: Here, we will present the recent progress from our group in the field of optical reporters for RNA imaging and its biomedical application. Specially, we described a miRNA-responsive CopT-CopA (miCop) genetic circuit system by engineered CopT-CopA into a optical reporter system.

Results: We demonstrated that miCop-Fluc and miCop-Gluc reporters realized the real-time monitoring the intracellular

expression of miRNA-124a during neurogenesis or miRNA-122 under the stimulation of extracellular drugs in living cells and animals. Furthermore, we evaluated the specific anti-tumor effect of this miCop reporter in tumor cells through activating a cytotoxic fragment A of diphtheria toxin (DTA).

Conclusion: Our Results provide a promising genetic strategy for miRNA detection and gene regulation, which may open up new diagnostic or therapeutic applications.

Key words: Reporter genes; CopT-CopA; miRNA; imaging; DTA

ID 864

Integrated Dose-effect Relationship of Near-infrared LED Light on Bone Regeneration in Disuse Osteoporosis Rats

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Objective: Low-intensity laser therapy has been shown to promote bone regeneration in osteoporosis (OP) rats. However, its integrated dose-effect relationship is not clear. In this paper, the integrated dose-effect relationship of near-infrared LED light therapy in promoting bone defect repair in the OP rat was investigated.

Methods: Twenty-weeks-old male Sprague-Dawley (SD) rats were randomly assigned to 11 groups: (i) no-treatment Control group (C group), (ii) Tail Suspension (TS)-induced disuse OP experimental group (TS-OP group), (iii) OP rats with LED light treatment at nine dosages (L1 - L9 groups). The tail of the rat was tied and suspended on the beam of the cage to suspend their hind limbs to induce bone loss for 4 or 7 weeks. The rats were then released and returned to their regular positions. A Near-infrared (NIR) LED at 810 nm was used on the bilateral hind limbs daily for 4 weeks. The C group rats were not given any treatment. The TS-OP group rats were subjected to identical procedures with LED groups, with the exception that the light power was not turned on. After the experiment, the dual-energy X-rays or the micro-CT scan analysis was performed to evaluate bone tissue status. Data analysis was done using health scale.

Results: NIR LED illumination promoted bone repair of TS-OP rats. In our dose levels, the greater the light intensity, usually the more effective the photobiomodulation.

Conclusion: NIR LED light therapy may promote bone repair in experimental rats with disuse-induced bone loss. Light intensity may influence photobiomodulation.

Key words: Photobiomodulation, Tail Suspension, micro-CT, Geometrical mean

ID 943

Developing a Real-Time Dual-modal Photoacoustic and Fluorescence Small Animal Imaging System

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Objective: By combining optical absorption contrast and acoustic resolution, Photoacoustic imaging (PAI) has enormous potential in biomedical imaging. Compared with traditional optical imaging, PAI provides high-resolution optical images

deep into the optical diffusive region. Meantime, Fluorescence imaging (FI), owing to its advantages of high sensitivity and high specificity, plays an important role in live animal study in the fields of life science and medical research. Based on different optical contrast mechanisms, PAI and FI can provide important complementary information to each other. However, imaging systems capable of providing real-time PAI-FI dual imaging in live animals are lacking.

Methods: In this work, we uniquely designed a PAI-FI imaging system that can provide real-time dual modality imaging. Our system employs a curved 256-element ultrasonic array that can provide high quality PA tomography of the small animal whole body. This system can provide 200 μm spatial resolution within the PAI imaging plane. To achieve real-time dual modality, there is a specially-designed optical window in the PAI part allowing whole-body illumination FI imaging simultaneously. Based on image reconstruction acceleration by GPU, the system can perform PAI reconstruction in real-time. The final frame rate depends on PA laser repetition rate and fluorescence exposure time.

Results: Based on the phantom study, this system can provide 200 μm spatial resolution within the PAI imaging plane. Besides phantom study, we also demonstrated the performance of PAI-FI system in animal study in vivo, especially we show the real-time monitoring of perfusion progress of the dye inside the animal body.

Conclusion: Both phantom and in vivo study have demonstrated the superior performance of the system, indicating the reported PAI-FI system has enormous potential to be a powerful platform for in vivo small animal study.

Key words: Fluorescence, Photoacoustic Computed Tomography, Small Animal Imaging, Real-Time

ID 950

基于频谱优化的高保真结构光照明超分辨显微图像重建

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目的：结构光照明显微镜（SIM）的超分辨图像中极易产生复杂重建伪影，限制了成像的保真度和可靠性。

方法：为克服线性 SIM 成像的典型伪影，提出高保真线性 SIM 算法 HiFi-SIM，通过将 SIM 成像的等效 PSF 优化为理想形式，从而校正重建频谱的异常特征，实现了线性 SIM 超分辨图像的高保真重建。

结果：针对非线性 SIM 中高阶级次信号弱、调制度低、更容易产生重建伪影的挑战，发展了基于“频 - 空域联合优化”的高保真非线性 SIM 重建算法 HiFi-NL-SIM，实现了优于传统算法的高质量非线性 SIM 超分辨重建。

结论：针对传统 Wiener-SIM 架构在许多成像场景无法确定准确条纹参数的难题，发展了无需估计结构光条纹参数的直接重建 SIM 算法 direct-SIM，在无需任何照明条纹先验知识的情况下，direct-SIM 绕过了伪影敏感的 Wiener 去卷积流程，实现了两倍空间分辨率增益。

关键字：超分辨成像，结构光照明显微，频谱优化，高保真图像重建

ID 967

反射式倾斜照明显微成像辅助光镊捕获小鼠肝脏微血管红细胞

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目的：在活体动物器官内，开展细胞层次的精准操控以及微血管力学参数的测量具有重要意义。但是，传统光镊系统基于透射光照明成像方式，限制了光镊在厚散射样品中的应用。本研究探索如何在活体体内深层的器官中实现光捕获。

方法：光镊结合反射式倾斜照明显微成像技术，用于活体小鼠体内微血管成像及细胞操作。光镊用于捕获和操控细胞，反射式成像系统用于可视化光镊进行细胞捕获。

结果：成功实现对小鼠体内肝脏中微血管中的红细胞进行捕获和操控。成像部分，将两个波长分别为 530nm，630nm 的 LED 照明光耦合到多模光纤提供反射式照明。彩色 CMOS 获得细胞及组织的显微图像经过成像通道分离后，进行差分相衬处理可以提高成像衬度。光镊部分，将 1064 nm 激光引入反射式成像系统，与显微系统共用 60X 水浸物镜。实验中，成功在小鼠肝脏的红细胞进行了操控，表明我们设计的系统具有应用于实时可视化光镊捕获小鼠肝脏微血管细胞的能力。

结论：光镊成功在小鼠活体肝脏内实现对红细胞的光学操纵。该结果进一步有望应于腹膜、肝脏以及颅内等器官中的微血管流体力学研究，为临床血液学的基础研究提供新技术及思路。

关键字：反射式显微成像，活体内光镊，倾斜照明，细胞捕获

ID 1001

光声分子成像在代谢疾病中的应用

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目的：光学成像具有高分辨率、活体动态、无损检测的特点。

方法：申请人围绕光学分子影像学的医工交叉领域，在优化光声成像技术、发展高分辨率结构、功能与代谢成像方法、揭示器官疾病演进过程等方面开展工作。

结果：本报告将介绍光声分子影像在代谢性疾病如肝纤维化、肾代谢性疾病中的应用进展。

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关键字：光学成像、高分辨率、代谢性疾病

ID 1009

用于检测模拟术中环境中尿路结石成分的自发荧光光谱分析

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目的：在过去的几十年中，随着尿石症的患病率和负担在全球范围内的大幅增加，腔内钬激光碎石成为了主要的治疗方法。然而，由于术中缺乏决定结石熔点的结石成分信息，不适当的激光能量设置会增加围手术期出现输尿管狭窄，瘢痕，甚至尿脓毒症等并发症的风险。但是，目前的检测手段，包括广泛应用的红外光谱检测，都必须在结石取出后进行体外分析。因此，迄今为止仍然缺乏一种实时和精确的术中结石成分分析技术。

方法：我们开发了一种基于光纤的实时的荧光光谱检测方法，对所收集的尿路结石进行干燥环境下以及利用 3D 打印的肾脏和生理盐水模拟的术中环境下的检测。支持向量机算法 (SVM) 用于结石类型的分类。

结果：尿路结石呈现自发荧光光谱“指纹”，应用 SVM，草酸钙结石与非草酸钙结石以及尿酸与鸟粪石的分类准确率分别达到了 90.28% 和 96.70%。在模拟的术中环境中，即使光纤的尖端和结石表面之间的工作距离（0-3mm）和角度（0-30°）发生改变，不同的类型结石同样可以被高精度和特异性的区分。

结论：我们的工作为设计一种临床设备奠定了方法学的基础，该设备可以实现术中尿路结石的实时、原位分类，以优化激光消融参数，从而减少围手术期并发症，实现精准治疗的目的。

关键字：尿石症，尿路结石荧光检测，自发荧光光谱，机器学习

ID 1011

积分散射显微镜：超越量子噪声极限的单分子检测研究

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目的：大分子，如蛋白质和复合体，在细胞生物学中发挥着重要作用。分子结构与动力学的多样性和异质性表明了发展单分子技术的紧迫性。由于单分子所固有的极低散射截面以及量子噪声极限的约束，导致微弱的消光信号比衍射极限点内的量子噪声波动低很多数量级，对单个未标记分子的光学检测依赖于增加光学强度，而导致光损伤、灵敏度和空间带宽方面的限制。

方法：现有基于散射的方法大多是平面外散射场的检测，散射场在入射平面外的焦点平面内被探测到。相比之下，我们研究了 SPP 的平面内散射，其中散射的 SPP 在入射面沿平面界面传播。我们发现，通过去卷积算法对平面内散射场的整体积分，可以在不增加光学强度的情况下产生高于量子噪声极限的可检测单分子信号。

结果：提出的积分散射显微镜可以对单个大分子进行质量成像（检出限低至 25kDa），量化单分子相互作用的结

合动力学，表征细胞分泌的“超微粒”（<30nm），和以免标签和多重方式检测生物标志物。

结论：积分散射显微镜对平面内 SPP 散射场的积分检测可以超过量子噪声极限，而无需增加光强度。可能使用暗场散射成像和各种等离子波导的其他积分散射形式来进一步提高性能。这些应用可以扩展到研究各种动态化学和生物过程中。

关键字：积分散射显微镜；表面等离子体激元；量子噪声；单分子检测

ID 1091

高速光声成像研究

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目的：大脑皮层血液动力学参数的动态波动是反映大脑功能的重要指标之一，全脑范围内各级血管间血液快速波动的潜在关联更是当前脑科学领域的研究重点。然而，尽管当前影像学技术可对脑皮层中微血管进行成像，但其成像速度往往难以突破 1 帧每秒，这在很大程度上限制了人们对高频大脑活动的深入理解。

方法：本研究采用光声成像作为技术基础，可对血液波动具有高敏感性，且信号可直接指示血红蛋白浓度这一关键参数；同时，采用新型血管随机采样技术，可在保证高性能成像的基础上，减少无血管区域的采样点数；此外，采用经过训练的 Swin-Transformer 网络进一步减少进行高分辨率成像的必要采样点数，并配合高重频激光器大幅提升系统成像速度。

结果：基于上述方法，本研究已完成对高速、大视场、高分辨光声显微镜的研制，通过对皮层微血管进行长时间稳定成像，验证了该成像技术可对大脑活动及全皮层功能连接进行研究。

结论：本研究通过结合新型扫描机制和深度学习技术，在保证视场、分辨率的基础上，提升成像速度，可为人们研究高频血液动力学波动、深入理解大脑功能提供一个独特的窗口。

关键字：光声成像，光声显微成像，高速显微成像、脑成像

ID 1106

基于波前整形实现高分辨率生物组织深层光学：近期研究进展和展望

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目的：由于生物组织的光学特性对于生物和病理变化响应灵敏，光学技术在现代生物医学中发挥着越来越重要的作用。然而，由于光在组织中固有的强散射特性，其高分辨率应用目前仅限于样品表面或者浅层。比如现有的显微成像技术的穿透深度通常都被限定在皮下 1 毫米左右。如何在生物组织深处实现散射光的无创聚焦和高分辨率成像是人们期盼已久但被认为是很有挑战性的目标，也是近年来生物医学光子学领域研究的热门和前沿。

方法：光学波前整形通过压缩或者补偿光在组织中传播时由于多次散射所引发的相位畸变，可以在散射介质内或透过散射介质实现聚焦或可控的光学传输和成像。

结果：本报告将介绍我们在领域的近年来在系统、算法以及应用等层面的努力和尝试，以实现稳健和优化的散射

光聚焦和操控，并将该能力尝试用于生物组织深层无创和微创的高分辨率成像和刺激等场景。我们还将简要讨论这些探索面临的挑战和未来可能的发展路线。

结论： 虽然还存在诸多不足，这些技术有望在不远的将来得到进一步的发展并为生物医学光子学带来全新的理念和机遇。

关键字： 波前整形，光学聚焦，光学成像，组织光学，光学散射

ID 1211

枝杈的粗糙化演变对金银合金纳米星光热性能的影响

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目的： 金、银纳米颗粒会吸收相同频率入射光能量，然后以热的形式释放，产生光热效应。此特性与颗粒的大小、形态和聚集程度密切相关，因此，精确调控纳米颗粒的形貌至关重要。星形纳米结构尖端处分布有强烈的局域电场，通过调控枝杈的数目和长度，可以将其吸收峰调至近红外区域，是优越的光热治疗材料。

方法： 本研究通过在金银合金纳米星生长的不同时刻添加抗坏血酸（AA）使其过度生长，制备了 2 种新颖的枝杈粗糙型纳米星。45 秒时，Ag+ 在 Au 表面沉积形成非对称生长位点的反应尚未完成，加入 AA 会促使形成更多的活性位点，Au 和 Ag 原子在活性位点处过度生长，形成具有更多刺状突起的海胆状纳米星；90 秒时，金银合金纳米星的主枝杈已形成，过量的 AA 可以促使 Au 和 Ag 原子克服表面活性剂在 {111} 晶面上的优先粘附，从而沉积在具有较大纵横比的主枝杈侧翼，形成锯齿状纳米星。

结果： 2 种粗糙型纳米星的光热性能均优于普通的金银合金纳米星，其中，海胆状纳米星因超多枝杈产生的大量局域电场以及在 1064 nm 附近的强吸光度而具有最强的光热转化效率，为 32.89%。

结论： 本研究成果为复杂双金属纳米结构的构建提供了指导，也为肿瘤诊疗多功能平台的构建提供了一种优越的材料。

关键字： 金、银纳米颗粒，光热性能，纳米星。

ID 1396

基于荧光聚合物点 pdots 的小尺寸管道的高分辨成像

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目的： 微循环是循环系统的中心环节，主要包括微动脉、微静脉和毛细血管间的微血管循环和淋巴循环。尽管微循环在调节生理机能方面和疾病发生发展方面有着十分重要的作用，但是目前对其仍然知之甚少。应用分子影像技术，可为微循环疾病的研究与诊治提供新的技术方法。而目前使用的探针存在局限性。例如，与管壁作用力弱，易从管道渗漏到周边组织，难以对小尺寸管道进行成像。因此，如何实现小尺寸管道的高分辨成像是一个关键科学问题。

方法： 选择电负性和亲脂性强的荧光共轭聚合物为主体，合成一系列高亮度荧光聚合物点 Pdots，并验证了 Pdots 在管壁滞留。

结果： 我们建立了基于 pdots 的淋巴管结构与功能成像新方法，并实现了对 4-9 μm 的毛细淋巴管的活体高分辨

成像，分辨率高达 3.3 μm，而且 Pdots 不渗漏，淋巴管显像时间窗口长达 35 天。进而，建立了基于 pdots 的组织微血管成像新方法。以眼部血管成像为例，Pdots 能成像直径仅有 1.6μm 的眼部脉络膜毛细血管。

结论： 我们构建了与管壁作用力强、不渗漏的 Pdots，实现了对小尺寸管道的高分辨成像。

关键字： 荧光聚合物点，小尺寸管道，高分辨成像，微循环

ID 1453

光声显微成像：技术发展与应用

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目的： 近年来，我们致力于光声显微成像（photoacoustic microscopy, PAM）的技术开发和应用探索。

方法： 对于技术开发，我们提出合成孔径聚焦技术和反卷积的新型定向算法，显着提高了 光声血管图像质量，且基于深度学习算法，我们能实现尺寸保真的反卷积、稀疏采样图像恢复、和图像去噪。通过调焦和图像融合技术，可实现大焦深的光声显微内窥成像。对于应用，我们利用光声血管图像的量化参数来研究脓毒症（sepsis）模型，以及光声血管成像来研究斑马鱼模型中的血液疾病。我们还研究了基于锗纳米粒子造影剂的近红外二区 PAM。除了生物医学应用，我们还探索了光声在锂金属电池成像和皮下微芯片可视化方面的应用。

结果： 如上所述，在技术方面，我们发展的算法能提高光声图像质量；可调焦光声内窥器件可用来拓展焦深。在应用方面，光声能用于监测脓毒症发生发展，也能更灵敏地识别斑马鱼血液疾病；我们发现锗纳米粒子具有很好的生物可降解性；此外，光声能用于观察锂枝晶和皮下芯片。

结论： 通过 PAM 技术研发，提高了光声图像质量，包括去噪、大焦深等。通过 PAM 应用探索，发现 PAM 在重症医学领域、血液疾病检测领域、以及工业检测领域都有很好的潜在应用。

关键字： 光声成像、光声显微、光声内窥、深度学习、无损检测

ID 1577

基于低对称性贵金属纳米结构的生物医学光谱检测

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目的： 重大疾病精准检测、食品安全检测、环境污染监测是人民健康领域的重大需求，依赖于检测方法与仪器的革命与创新。贵金属纳米结构以其光学可调性、良好的生物相容性以及易制备等特点成为光谱传感技术的核心平台，在生物医学分析、食品安全检测及环境监测等领域得到了广泛的应用。

方法： 贵金属纳米结构的光学特性及局域场增强与其形貌结构密切相关，结合当生物医学检测技术及应用的发展方向，本团队围绕开发高灵敏生物医学光谱检测技术与仪器，从贵金属纳米金结构形貌对称性调控出发，研究低对称性贵金属纳米结构光量子调控规律及光谱传感特性，开发了一系列高灵敏光谱检测方法，并将其应用于重大疾病标志物检测、食品安全检测、环境污染监测等领域。

结果： 借助低对称性贵金属纳米结构增强的光谱分析技术（紫外 - 可见吸收光谱、荧光光谱、拉曼散射光谱等），实现对肿瘤标志物、农药残留以及重金属离子的高灵敏检测，检测限低至皮摩尔量级（10-12）。

结论：本团队完成的上述工作，体现了生物医学光谱分析快速发展的趋势和良好的应用前景，为基于贵金属纳米结构的光谱检测技术的发展提供一些参考，进一步拓宽了生物医学光子学的应用领域。

关键字：光谱检测；局域表面等离子体共振；贵金属纳米结构；光量子调控；光学纳米材料

ID 1654

基于光学相干层析成像的凝血功能检测方法

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目的：凝血功能检测对于出血性疾病、血栓形成性疾病的诊断和治疗具有重要的临床意义。血液凝固过程中，从液态转变为固态，涉及多个级联的生化反应，并伴随着物理参量的改变。生化检测可以测定凝血因子的数量和活性，但预处理相对复杂繁琐，耗时较长，并且难以分析全血样品的凝血功能。物理检测通过测量血凝过程中物理参量的改变，可以评估全血的凝固属性，省去了样品预处理环节，更适合床旁即时检测。

方法：我们利用光学相干层析成像技术（Optical coherence tomography，OCT），研究了血凝过程中全血粘弹性和散射粒子扩散性的改变，提出了基于剪切模量测量、弹性波衰减测量、信号自相关测量、分形维数测量等凝血功能评估方法。

结果：通过对初始凝血时间、凝块形成时间等凝血特征指标的计算，定量分析了全血样品在促凝剂、血液稀释等作用下的凝血属性，验证了 OCT 技术用于凝血功能检测的可行性。

结论：OCT 凝血功能检测不仅可以克服生化检测操作复杂的困难，而且避免了其他物理检测方法中仪器测量参量与血液物理参量缺乏明确定量关系的问题，有望用于床旁即时检测、原位检测及流动血样的检测，具有较大的临床应用潜力。

关键字：光学相干层析成像，凝血功能，粘弹性，信号自相关

ID 1759

Deep Learning-based Stimulated Raman Molecular Cytology Enables Rapid and Precise Cancer Diagnosis

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Objective: Peritoneal metastasis (PM), the most common gastric cancer metastasis, is the leading cause of death in gastric cancer. Clinical guidelines recommend intraoperative peritoneal lavage cytology to detect PM for locally advanced gastric cancer. However, conventional peritoneal lavage cytology method has about 50% false negative rate. Moreover, the time-cost of current cytology hinders its intraoperative application.

Methods: Here we established deep learning-based stimulated Raman scattering molecular cytology (SRMC), a label-free, rapid, high-resolution, and chemical selective single cell optical imaging method for the PM diagnosis. We firstly segmented single cells by deep learning Stardist model (dice = 0.89) and quantitatively extracted various single-cell features about morphology, composition, and lipid droplets. Totally, 53951 peritoneal exfoliated cells collected from 80 advanced gastric cancer patients were quantitatively assessed. Cellular area, lipid protein ratio, and lipid area fraction were found to

be significantly different between samples from PM positive and negative patients. Then, we transformed raw features to feature matrix and used K-PCA algorithm to find significant marker cells, which could further differentiate the PM positive or negative into two populations.

Results: Compared with the histology under intraoperative laparoscopy as the gold standard, our deep-learning based SRMC method reached 81.5% sensitivity, 84.9% specificity, and area under receiver operating characteristic curve of 0.85, with the leave-one-out cross-validation. Furthermore, the SRMC method could give diagnostic result within 20 minutes for individual patient.

Conclusion: Together, our study demonstrates a novel peritoneal lavage cytology method that offers the great potential for rapid and precise PM detection.

Key words: stimulated Raman scattering, deep learning, cytology, cancer diagnosis

ID 1788

基于有机半导体聚合物的植入式光学传感系统的研究

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目的：面对目前迫切的医患临床需求以及植入式光学传感系统发展所遇到的关键科学和技术难题，以有机半导体聚合物点为基础，逐步构建新型植入式光学连续监测系统，用于生物标志物水平的实时光学检测及长期精准监测。

方法：我们以聚合物点氧敏感荧光探针（信号转换）和耗氧生物酶（分子识别）制备光学生物传感器，通过对酶催化作用下生物分子氧化耗氧过程的探测，实现生物标志物水平的实时光学检测。以此为底层基础，进而通过分子设计合成、光物理特性调控、生物多酶系统构建、校准系统构建、柔性植入体制备、小型光学检测装置开发、数据处理算法及终端应用程序开发等，提升传感系统光学特性、传感特性、生物相容性、长期稳定性、检测便携性等关键特性，并实现传感系统从分子识别、信号转换、信号采集、信号传输、信息处理、数据展现等全系列功能。

结果：基于有机半导体聚合物所具有优异光学特性的优势，我们所构建起的植入式光学传感系统，可实现体内生物标志物水平的精准、实时光学检测及长期精准监测。

结论：该光学传感系统的设计开发及不断深入研究，将为临床诊断提供新的有效途径，对疾病诊疗及健康护理意义重大，同时也对促进光学技术在临床检测和公共健康方面的创新发展奠定坚实基础。

关键字：半导体聚合物；光学传感器；光学检测；连续监测；葡萄糖

ID 1794

基于动态散射成像的细胞分类方法研究

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目的：细胞高通量分析与分选技术是医学研究及临床诊断热点，在疾病诊断，预后评估，药物评价等方面具有重要的研究意义和应用价值。流式细胞分析、激光共聚焦成像方法，对于仪器及检测条件要求较高，并需要对细胞进行

标记，检测成本较高，无法满足高通量、无损快速检测需要。本文基于动态光散射成像技术的无标记、速度快等优势，探究细胞高通量检测的方法。

方法：本文针对细胞分类检测要求，研究了基于动态散射成像的细胞分类方法，搭建了离轴数字全息显微成像系统，建立了细胞动态散射模型，提出了基于谱分解的细胞成像及散射特征提取算法。分析比较了不同细胞形态及散射结构特征，设计了基于卷积神经网络的细胞动态散射图像处理与分类方法。

结果：采用红细胞、EG7-OVA 肿瘤细胞、A549 肺癌肿瘤细胞进行实验验证，结果表明，本文提出的方法的针对三种细胞的分类准确率达 94.9%，二分类区分肿瘤细胞和红细胞的准确率达到 99.1%，卷积神经网络分类模型与机器学习算法相比，分类准确率提高了约 6%。

结论：本文的研究结果为高通量细胞检测与分类方法研究提供了一定的基础。

关键字：动态光散射；细胞散射成像；卷积神经网络；细胞分类

ID 1795

应用于术中前哨淋巴结定位的光声探笔

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目的：前哨淋巴结（Sentinel Lymph Node, SLN）对于癌症诊断和病情评估具有重要意义，对乳腺癌而言其在女性中发病率最高，治疗过程中需要对乳腺前哨淋巴结活检以确定治疗方案。目前，术中前哨淋巴结的查找定位主要是通过目视、荧光成像或者核素法实现的，但这些方法存都存在局限性。乳腺癌的外科手术中，通过前哨淋巴结活检确定是否需要进行腋窝淋巴结清扫和确定后续治疗方案，本项研究基于前哨淋巴结检测的临床问题，提出了一体式光声探头笔（Photoacoustic Pen, PAPen）用于辅助外科医生在术中快速准确地找到前哨淋巴结。

方法：提出了集成激光照射和超声探测的一体式 PAPen，通过单点超声探头检测 SLN 中造影剂的光声信号，从而实现对其探测和定位。在淋巴结产生光声信号到 PAPen 接收到这一过程符合声学传播特征，通过声波在组织中传播的速度和光声信号中的时间信息即可计算得出 PAPen 到淋巴结的物理距离。

结果：通过仿体实验、大鼠实验和临床验证三个方面展示了 PAPen 用于乳腺癌 SLN 探测的可行性且对仿体探测深度达 5 cm。

结论：PAPen 应用于临床探测淋巴结具有潜在可能。

关键字：光声探笔、前哨淋巴结探测、乳腺癌、术中导航

ID 1797

Full Optical Properties Estimation Method for Thin *ex vivo* Tissues

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Objective: Double integrating sphere (DIS) measurements obtained from thin *ex vivo* tissue, can provide more spectral information and hence theoretically allow estimation of full optical properties (OPs). However, the accuracy of OPs determination via traditional reconstruction strategies decreases sharply with the reduction in tissue thickness, due to the consequent rising ill-condition. Therefore, developing a full OPs estimation method for thin *ex vivo* tissues that is robust to noise is crucial.

Methods: In this paper, we present a deep learning solution to precisely extract full OPs of thin *ex vivo* tissues in real time. Based on the cascade forward neural network (CFNN), a dedicated network with single output is directly established for each OP using corrected CUDAMCML data sets. The extra input of the refractive index of the cuvette holder fitted by the Sellmeier equation was additionally introduced, thus enhancing the fitting ability of the CFNN model and eliminating the serious ill-conditioned bottleneck of OPs estimation.

Results: The Results show that the CFNN-based method enables the evaluation of full OPs approximately five orders of magnitude faster than the inverse adding-doubling method, as well as improved accuracy than the gold standard inverse Monte Carlo method. Moreover, the CFNN model achieves precise OPs determination within a wide spectral range by using only sparsely sampled data sets and robustness to noise, which proves the superior generalizability of the CFNN model.

Conclusion: Our proposed method provides a tool for real-time and accurate estimation of full OPs without any *a priori* information and is promising for the optical diagnosis of diseases and quantitative analysis of photodynamic therapy.

Key words: Optical property, Double integrating sphere, Cascade forward neural network, Ex vivo thin tissue

ID 1997

远红外疗法与有氧运动对睡眠障碍女大学生睡眠质量的定量整合影响

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目的：本研究用个体多导睡眠（PSG）参数定量整合的方法研究远红外疗法与有氧运动对睡眠障碍女大学生睡眠质量的影响。

方法：1. 将 28 名志愿者随机分为对照组（C 组）、远红外桑拿组（F 组）和有氧运动组（A 组）。C 组保持原有生活方式。F 组用新泓能光波房干预，40 min/ 次，3 次 / 周，共 8 周。A 组进行有氧慢跑，干预方案与 F 组相同。每个同学干预前后各测一次 PSG。2. 调整参数可以获得每个同学所有 PGS 参数守恒的几何均值，其中阴性参数的倒数和阳性参数联合计算的几何均值称为健康标尺（GCYY）。引入定量差异（QD）计算每同学前后测数据的 GCYY 的 QD，根据 QD 的显著性阈值 β（0.805）或 γ（1.22）判定干预效果。

结果： 结果：C 组 5 人变差（QD>1.22）；2 人无显著性差异（QD<0.805）；1 人变好（QD>0.805）。A 组和 F 组分别为 6 和 6 人非常显著变好（QD>1.22），3 和 2 人显著变好（QD>0.805），1 和 2 人无显著性差异（QD<0.805），各类占比的几何均值 0.266 和 0.288 的 QD 完全没有差异。

结论： 8 周的远红外疗法和有氧运动都可以改善睡眠障碍女大学生的睡眠质量。

关键字： 远红外疗法；有氧运动；睡眠；整合

ID 2003

Photobiomodulation Therapy: An Emerging Paradigm for Tissue Repair and Regeneration

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Objective: Photobiomodulation (PBM) therapy, which uses red and near-infrared light at 600–1,000 nm and fluences of 1–10 J/cm2, has been developed as a noninvasive, drug-free, and FDA-approved safe therapeutic approach. Therapy defect, whether intrinsic or acquired, is one of the biggest unmet medical needs. Based on decades of basic research, preclinical testing, and population-wide clinical trials, this review aims to investigate the phenotypic and mechanistic basis for applying and optimizing PBM therapy in the management of tissue repair and regeneration, discusses rational and effective treatment strategies for various injured or diseased tissue.

Methods: This review overviews the fundamentals of light-matter interactions, summarizes molecular mechanism and biological function of PBM therapy, and describes its proven clinical applications targeting various injured or diseased organs. Current clinical trials of PBM therapy for tissue repair and regeneration will be briefly highlighted. We conclude the paper with a discussion on challenges and promise of emerging PBM-based therapeutics.

Results: Investigation on the development and applications of PBM therapy holds great promise for human healthcare to offer an efficient, noninvasive, and economic adjunct to facilitate repair and regeneration. PBM therapy may aid tissue repair and regeneration by controlling energy homeostasis, facilitating angiogenesis and vascular repair, modulating immune response, mediating redox homeostasis, and regulating stem cell function. PBM therapy shows the potential to reduce healthcare costs since it is sustainable, safe, economical, can be developed as home-use devices, and it may be able to benefit many patients in the earlier stages of various injuries, even stalling or delaying the progression of some types of injury.

Conclusion: This comprehensive review will hopefully raise awareness of these possible powerful therapies for regenerative medicine for all of society, especially their wide variety of translational uses.

Key words: photobiomodulation therapy; tissue regeneration; low-level laser/light therapy; tissue repair.

ID 2096

利用光刺激进行神经操控的最新进展

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目的：本综述主要介绍了近期光操控研究涉及的原理与实验结果。

方法：伴随着光学方法在脑科学中的广泛应用，大脑原理的研究被显著推动，其中光操控神经集成活动对于理解脑功能和疾病具有重要意义。神经系统错综复杂，但通过单光子与双光子照明配合细胞中表达光感蛋白使用，可以实现对目标神经元不同层次的操控，如单光子在可见波段对神经活动的激活、抑制和在紫外波段驱动目标细胞的转化，双光子除调控与转化外还具有的消融功能等，以实现对神经环路间复杂关系的清晰刻画。

结果：在此方法的基础上，研究团队们使用数字微镜阵列（Digital Micromirror Device, DMD）、空间光调制器（Spatial Light Modulator, SLM）、声光偏转器（Acousto-optic Deflectors，AODs）等器件，改进硬件、算法等诸多方面，在不同的方法下实现了对光刺激各指标的提升。

结论：这些研究所提出的刺激精度高、模式响应速度快和刺激范围广的光操控系统，将为脑科学提供更有力的工具。

关键字：脑神经操控；光刺激；单 / 双光子；空间光调制器

ID 2100

High-speed Meso-SCAPE Microscope with Multi-millimeter FOV and Cellular resolution

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Objective: Swept confocally-aligned planar excitation (SCAPE) microscopy furnishes open sample space and translation-free 3D imaging with high volumetric speed, and proves highly valuable for biological and neuroscience studies. To expand the FOV towards multi-millimeter scale requires low-mag objectives, however, off-the-shelf objectives that can accommodate a 4-mm-diameter FOV affords no more than 0.5 NA, which limits the maximal tilting angle of the oblique illumination plane and eventually renders it extremely challenging for the tertiary Objective to collect any decent percentage of the fluorescence signal.

Methods: We proposed adapting an off-the-shelf fiber-optic taper as an image relay to bridge the secondary Objective (O2) to the tertiary (O3) Objective in the re-imaging geometry. The taper couples the stationary intermediate image formed by O2 into its small end with high efficiency (~70% as limited by the inherent fill ratio loss), relays it to the big end, and outputs a high-fidelity magnified replicate of the intermediate image with lower emission NA, which is easier to capture by O3. Furthermore, the small-end surface was angle-cut to refract the collection cone of the taper to better overlap with the emission cone of O2, thereby further promoting the collection efficiency.

Results: We built a meso-SCAPE system with a 5.8x4.1x0.5 mm3 FOV, cellular resolution, and excellent collection efficiency that enables fast 3D microscopy at over 10 volume per second (VPS). With this meso-SCAPE system, we demonstrated high-speed volumetric visualization of structural and functional dynamics of live organisms/samples including a freely-moving transgenic GCaMP6s-expressing hydra, an zebrafish larva with a beating heart in its entirety, as well as blood flow dynamics in the mouse brain vasculature in vivo.

Conclusion: The fiber-optic taper-based intermediate image coupling scheme enhances significantly the collection efficiency of the mesoscale SCAPE microscopy, and enables high-speed volumetric imaging (~10 VPS) of various samples across a multi-millimeter FOV with micron-level 3D resolution.

Key words: swept confocally-aligned planar excitation (SCAPE), mesoscale field of view, fiber-optic taper, fast volumetric rate

ID 2135

CD47 抗体靶向引导近红外分子成像诊断上尿路上皮癌的体外实验研究

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目的：研究 CD47 作为人上尿路上皮癌（UTUC）光学分子成像靶点的可行性，探讨细胞和分子水平精准诊断 UTUC 的新技术。

方法：GEO 数据库下载 UTUC 转录组测序数据，R 软件包鉴定差异表达基因；收集我院 57 例 UTUC 和 20 例癌旁正常上皮的组织石蜡标本进行免疫组织化学染色，评估 CD47 在蛋白水平的表达分布；12 例新鲜离体的根治性肾输尿管全长切除术（RNU）标本与抗 -CD47-Alexa Fluor 790 靶向示踪剂孵育后置于白光和近红外光下成像，分析肿瘤组织与正常组织的平均荧光强度（MFI）与肿瘤 - 背景比（TBR）。

结果：GEO 数据显示，CD47 mRNA 在 UTUC 中的表达高于正常组织（P ＜ 0.001, |log2FC|=1.43）；免疫组织化学染色显示，非肌层浸润性 UTUC 和肌层浸润性 UTUC 的 CD47 表达水平均高于正常尿路上皮（P<0.01），表达部位为肿瘤细胞的细胞膜；在体外成像实验中，肿瘤组织的荧光信号明显高于癌旁正常组织（MFI 为 54.67±16.17 和 19.11±6.41, P<0.001），TBR 为 1.7~4.09。

结论：在 CD47 靶向近红外分子成像下，视觉图像的对比度明显增强，有助于肿瘤的实时诊断。

关键字：上尿路上皮癌；CD47 ； 光学分子影像；靶向成像

ID 2178

Physics-driven Deep Photoacoustic Tomography with Incomplete Projections

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Objective: Photoacoustic tomography (PAT) is a fast-evolving biomedical imaging modality. To achieve high-performance imaging, signal acquisition in PAT should ideally meet conditions such as full-view detection, dense sampling, and medium being free of strong acoustic heterogeneity. However, these requirements can rarely be fully met in practice, leading to the ill-posed problem of image reconstruction from incomplete projections.

Methods: Here we propose a physics-driven deep learning-based filtered back projection (dFBP) framework to address this challenge. The dFBP network is inspired and constructed based on the physical model of the analytical filtered back

projection algorithm and consists of a filtering module, a back-projection module, and a fusion module connected in cascade. Distinct from state-of-the-art approaches, the dFBP network is driven by physics and is thus interpretable, easy to train, yet highly robust and versatile.

Results: Numerical and experimental Results on animals and humans show that dFBP-based PAT can achieve direct signal-to-image transformation with enhanced accuracy and reconstruct high-quality artifact-suppressed images from sparse-view, limited-view, and acoustic heterogeneity-contaminated projections.

Conclusion: The proposed dFBP provides a practical solution for high-performance PAT imaging under nonideal conditions.

Key words: Photoacoustic tomography, image reconstruction, deep learning, incomplete projections

ID 2206

生物医学微波热声成像

覃欢 *

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目的：以无损、高分辨获取深层活体生物组织的生理病理信息为目的。

方法：微波吸收作为微波与生物组织相互作用过程中能量耗散的主要机制之一。微波热声成像技术利用短脉冲微波作为激发源，从原理上突破光的生物组织穿透能力限制，利用脉冲微波激发出的超声递送深层组织中的生命科学信息，实现生物组织无损、数厘米深度、百微米分辨率的成像，能够较好地弥补目前高分辨光学成像技术成像深度的不足，在生物医学成像领域具有广阔的应用前景。

结果：作者致力于创新脉冲微波热声激发与探测新方法。通过探究偏振脉冲微波、超短 (10 ns) 脉冲微波激发生物组织的热声机理，发展偏振微波热声成像技术、微波场 - 超声场同轴热声成像技术、新型微波热声肿瘤诊疗技术，推动微波热声成像技术的跨越式发展与临床应用转化。

结论：微波热声成像技术有望成为新医学影像工具。

关键字：微波热声成像

ID 2216

Integrating Sphere-based Fluorescence Phantom System for Standardized Imaging Performance Test

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Objective: To develop a standardized optical phantom system with accurate simulation of fluorescence excitation spectrum and emission spectrum for evaluating the performance of fluorescence imaging in surgical treatments.

Methods: An integrating sphere was used to simulate the spatial distribution of emitted fluorescence, and a spectral simulation method based on linear variable filters was utilized to automatically simulate specific fluorescence emission

spectra. The output stability and spectrum simulation accuracy were quantified and compared with the liquid phantom made with FDA-approved near-infrared fluorescence contrast agent, Indocyanine Green. The phantom system was used for standardized characterization for different near-infrared fluorescence imaging instruments.

Results: The proposed system demonstrated improved spectrum simulation accuracy (less than 10% for maximum spectrum difference at each sampling wavelength within the target wavelength range), stability (less than 5% over 3 hours), and the ability to quantify the performance of fluorescence imaging instruments. The sensitivity of various imaging instruments was successfully assessed and compared using the optical phantom system.

Conclusion: The optical phantom system presented in this study offers a standardized method for evaluating the performance of fluorescence imaging in surgical treatments. With improved accuracy, stability and no photobleaching, the system has the potential to serve as a valuable tool for standardizing the testing of fluorescence imaging performance.

Key words: optical phantom, fluorescence simulation, imaging standardization

ID 2258

面向生物组织内应力场表征的偏振敏感光学相干层析技术

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目的：生物组织的病变伴随着内部力学性能的变化，内应力场表征为临床诊断提供了判据。偏振敏感光学相干层析技术 (PS-OCT) 是内应力场表征的新手段，但缺乏基于 PS-OCT 定量表征内应力场的有效方法，应力大小与应力方向的准确性难以保证。本文研究基于 PS-OCT 的内应力场定量表征方法，从而为生物组织病变的早期诊断和评估提供判据。

方法：本文提出了一种基于圆偏振态 PS-OCT 的内应力场定量表征方法。首先，发展了基于圆偏振态 PS-OCT 应力测量理论。之后，提出了基于深度分辨的色散补偿方法，提高相位延迟图像质量。最后，对相位延迟图像应用提出的内应力解析算法以获得内应力大小；校正快轴取向以获得内应力方向。

结果：深度分辨色散补偿显著提高了相位延迟图像的成像质量，内应力大小由内应力表征算法获得，其准确性较前人文献有了显著提高（最大误差 12.3%）。校正后的应力方向填补了前人 PS-OCT 应力测量的空缺。双层生物组织仿体实验验证了所提出方法在深度方向上应力场表征能力。

结论：本文提出了一种基于圆偏振态 PS-OCT 的内应力场定量表征方法，实现了对材料内应力场的定量测量，扩展了 OCT 的成像功能，有望为生物力学测试和疾病诊疗提供新的技术。

关键字：圆偏振态；偏振敏感光学相干层析技术；深度分辨色散补偿；内部应力分布；内部应力方向

ID 2427

使用近红外光谱术研究针刺疗法中的血液动力学参数变化

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目的：针刺是一种可靠的中医传统经典疗法之一，具有数千年的历史。它被用于治疗或缓解一些疾病的症状，比

如腰痛，腿痛以及压力性尿失禁等。尽管针刺广泛应用于国内及海外多个国家，它的内部作用机理依然不明确，缺少量化参数来评估针刺过程。因此，针刺的效果依赖针灸师的经验，且针刺调控的过程不够透明。本研究使用近红外光谱术（NIRS）检测针灸穴位附近的血液动力学参数变化，通过血氧动力学参数变化来深入认识针灸机制。

方法：我们研制了一个中间开孔的 NIRS 探头，包含一个光源两个探测器组成两个探测通道，源探间距为 3 cm。选取血海穴位开展针刺实验。NIRS 探头放置在穴位处，中间孔用于针刺入。光源和探测器分布在孔的两侧，探测血海穴位组织氧合血红蛋白，脱氧血红蛋白以及总血容的变化。实验招募了 17 名健康被试，他们在年龄，受教育程度上均无显著差异。

结果：结果表明在针刺开始后，脱氧血红蛋白和总血容有显著上升，并在提针后缓慢下降回到基线。而氧合血红蛋白浓度在全程没有明显变化。脱氧血红蛋白变化曲线可以用一个四次多项式进行拟合。同时，我们一个实验案例表明：NIRS 可以提前预警晕针，在被试报告自己晕针反应前一分钟左右检测到显著的氧合血红蛋白下降及脱氧血红蛋白上升。

结论：针刺可以增加穴位周围的氧耗和氧代谢。本研究证明了 NIRS 在针刺疗法中具有很大的潜力，针刺过程中的血氧动力学参数变化有望成为评估针刺疗法的量化指标。该研究可以进一步扩展生物医学光子学在中医疗法中的应用。

关键字：近红外光谱术，中医疗法，针灸

ID 2501

Real-time Evaluation of the Efficacy of Liver Microwave Ablation Based on Temperature and Reduced Scattering Coefficient

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Objective: Objective: The principle of microwave ablation (MWA) is to cause irreversible damage to tumor cells at a certain temperature by heating, thereby destroying the tumor. After a lot of experimental verification, it can be found that there is a clear correlation between the reduced scattering coefficient and the degree of tissue damage. However, there is currently no research that combines temperature (T) and reduced scattering coefficient (μs') for the evaluation of the efficacy of MWA. This paper focuses on the real-time evaluation of MWA based on T and μs', combined with the analysis of the cell activity of the tissue in the ablation zone.

Methods: Methods: The in vivo MWA experiment was conducted with liver, the two-parameter simultaneous acquisition system was designed and used to obtain the T and μs' of the liver tissue during MWA.

Results: Results: The T and μs' of the completely damaged tissue are significantly different from those of normal tissue. The μs' of the coagulation zone is in the range of 16~19 cm-1, 6~16 cm-1 in the transition zone, and 2~6 cm-1 in the normal zone. The quantitative relationship between T and μs' is established, enabling the quantitative estimation of μs' of liver tissue based on T. Comparing the actual μs' with the predicted μs' which is calculated by the correlation model, the corresponding error is calculated to verify the reliability of the correlation model. The maximum absolute error, the minimum absolute error and the mean absolute error of μs' are 3.835 cm-1, 0.003 cm-1 and 1.128 cm-1, respectively. Finally, combining the cell viability Results of different zones after MWA, a preliminary MWA efficacy evaluation model was established.

Conclusion: Conclusion: This study contributes to the further establishment of multi-parameter MWA effectiveness evaluation model. It is also valuable for clinically evaluating the ablation outcomes of tumor in real time.

Key words: MWA; temperature; reduced scattering coefficient

ID 2515

快速光声显微结构与功能成像及其应用

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目的：在宽电磁波谱中，光，尤其是可见光和近红外光，是唯一能与几乎所有类型的分子直接相互作用的频带。利用光，我们可以获得细胞和组织的结构、代谢和分子信息。 然而，由于光学折射率的分布高度不均匀，光在复杂介质中的传播会发生强烈的散射。光声成像 (PAI) 可以将在深层组织中的漫射光转换为非散射或弱散射超声波，为克服上述挑战提供了一种有前景的策略。光学分辨率光声显微 (OR-PAM) 利用波长相关的光吸收特性和微米级成像能力，广泛用于绘制和计算目标组织区域的各种功能参数。 功能性 OR-PAM 需要多个波长、超快激发和足够的能量。目前获得功能成像多波长主要包含组合激光器，电光调制器切换不同波长和受激拉曼散射生成波长三种方法。受激拉曼散射可以通过一次脉冲激发获取不同的波长，因此该方法相对更稳定，但现在传统的长光纤延迟意味着拉曼散射阈值较低，会带来能量不足以及波长切换不够快的问题。

方法：在此背景下，我们提出了一种超快的光学分辨率光声显微系统以及其相对应的算法；

结果：可以缩短所使用的光纤长度，并带来更高的能量输出和更快的波长切换时间等好处。

结论：可将所设计的快速光声显微系统应用于多个结构与功能成像的应用中。

关键字：光声成像；波长切换；结构功能成像

ID 2580

基于比尔 - 朗伯定律散射项修正的血氧测量

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目的：目前在可见光 OCT 眼底血氧测量中，理论模型缺乏对光子多次散射行为的描述，血氧结果无法呈现其空间分布，针对于这些局限性，本研究旨在探究更为准确地对眼底血氧进行像素级测量的方法。

方法：对比尔 - 朗伯定律进行散射项修正，并结合蒙特卡洛仿真和在体成像实验进行理论验证和应用研究。散射项修正的比尔 - 朗伯定律（dcBLL）模型从辐射传输方程出发，采用扩散近似模型得到其近似解，进而计算出与吸收和散射相关的光衰减方程。我们设计了一套拟合 - 筛选策略，将 dcBLL 模型应用可见光 OCT 光谱数据中沿深度进行最小二乘拟合，得到估计的含氧和脱氧血红蛋白浓度，再经过筛选步骤得到拟合优质的测量点的血氧值。

结果：在仿真实验中，不同血氧水平下测量结果的均方根误差（RMSE）均小于 5%，比采用传统模型的 RMSE 小了 5 ～ 10 倍。在人眼在体实验数据中，实现了像素级血氧测量，展示了眼底血氧的投影图，提供了血氧的空间分布。

结论：基于 dcBLL 模型的方法实现了更加准确的像素级血氧测量，可展现血氧的空间分布，为采用可见光 OCT 进行眼底代谢机制研究及眼底疾病诊断提供了新的方法。

关键字：可见光 OCT，血氧成像，辐射传输方程，比尔 - 朗伯定律

ID 2612

Recent Advances in Neural Manipulation by Using Light Stimulation

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Objective: This review mainly introduces the principles and experimental Results of recent research on optical manipulation.

Methods: With the widespread use of optical Methods in brain science, the study of brain principles has been significantly promoted, in which light manipulates neural integration activities of great significance for understanding brain function and disease. The nervous system is complicated, but the use of one photon and two-photon illumination combined with the expression of photosensitive proteins in cells can realize the control of target neurons at different levels, such as the activation and inhibition of neural activity by single photon in the visible band and the transformation of target cells in the ultraviolet band. In addition to the regulation and transformation, the two-photon also has the function of ablation. In order to achieve a clear description of the complex relationship between neural circuits.

Results: On the basis of this method, The research team used the Digital Micromirror Device (DMD), Spatial Light Modulator (SLM), and Acousto-optic Deflectors (AODs) and other devices, improve hardware, algorithm and many other aspects, under different Methods to achieve the improvement of the optical stimulation indicators.

Conclusion: The light manipulation system with high stimulus precision, fast mode response and wide stimulus range proposed by these studies will provide a more powerful tool for brain science.

Key words: cranial nerve manipulation; light stimulation; one/two photons; space light modulator

ID 2833

光片照明高通量三维成像表征斑马鱼血管发育

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目的：斑马鱼具有繁殖周期短、可大规模培养、通体透明等特点，进行发育、疾病机制以及药物筛选研究中大量使用的动物模型。但是目前还缺乏对斑马鱼对进行高通量三维成像的仪器装备，成为其大规模表征、分析中的瓶颈。

方法：因此我们开发了基于流式和光片照明的高通量三维活体成像技术与系统。可实现对一次孵育的上百条斑马鱼胚胎样品在半小时内进行细胞分辨率的高通量全自动三维成像。开发了相关的软件进行斑马鱼三维姿态的配准，并针对成像得到的大量三维图像，开发了基于改进的深度学习 U-Net 网络进行躯干血管和脑部血管结构进行增强、分割、定量统计。

结果：采用本成像系统，对斑马鱼血管发育过程和血管生长抑制药物作用过程的异质性进行研究。

结论：结果展示了在生长发育机制和药物筛选过程中进行高通量表征的必要性和本高通量三维成像系统的强大功能。

关键字：斑马鱼，光片照明，高通量，三维成像

ID 3192

紫外脉冲冷激光系统与泛血管斑块减容技术

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目的：激光斑块消蚀技术利用脉冲激光将斑块消融成小的微粒，从而达到血管腔内减容的目的。当前临床使用的308nm 准分子激光系统有启动时间偏长、操作复杂、成本较高、钙化病变减容效果不佳等问题。本研究开发了一种基于三倍频固体激光的 355nm 紫外脉冲激光减容系统，并通过离体生物样品实验初步验证了该系统的安全性和有效性。

方法：搭建基于三倍频固体激光的 355nm 紫外脉冲激光减容系统，解决激光光束整形、功率控制、重频控制、光纤耦合等问题；开发基于石英光纤集束的血管介入消融导管，获得可用于腔内减容的能量密度；通过动物及人类离体动脉血管样品，测量健康血管组织损伤阈值、斑块减容效率等指标，得到最佳激光输出参数组合。

结果：在同等能量密度的条件下，355nm 系统在造影剂环境下造成的光机械效应比 308nm 激光弱；对于动物肌腱类组织的减容效率是 305nm 系统的 4 倍；在完全闭塞病变和支架内再狭窄病变离体样品中，355nm 激光均有良好的管腔获得。

结论：355nm 紫外脉冲冷激光系统为泛血管斑块减容提供了一种新方式，在减容效果等方面有潜在获益性。

关键字：冷激光，泛血管，斑块减容

ID 3301

微瓶透镜辅助的超分辨成像技术

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目的：微颗粒透镜辅助的超分辨成像技术是近年来新兴的一个研究领域，它是通过常规光学显微镜与微颗粒透镜的结合来实现超分辨成像的，具有非标记、无光毒性、成像速度快、白光宽场照明和器件结构简单等优势，广泛应用于病毒、亚细胞器、半导体芯片和子表面纳米结构等的成像。成像当中所使用的微颗粒透镜主要有球形和柱形两种类型，其中球形微颗粒透镜能够实现各向同性成像，而柱形微颗粒透镜只在圆形截面的方向成像。

方法：本研究基于 Plateau–Rayleigh 不稳定性和液 - 固界面之间的润湿性，构建了由微光纤芯层和紫外固化聚合物附着层构成的瓶形微颗粒透镜，并与光学显微镜一起用于超分辨成像研究。

结果：该微瓶透镜对条纹宽度和间距均为 200 nm 的方形迷宫图案、条纹线宽和间距均为 150 nm 的 L-Bar 结构在瓶形轮廓曲面和圆形曲面两个相互垂直的方向，能够实现具有不同放大率和像平面位置的超分辨成像。

结论：研究表明在柱形和球形透镜之间存在这种中间过渡形态的微颗粒透镜，能够实现不同方向不同模式的成像，对于微颗粒透镜的结构设计、成像本质和机制理解等方面有非常重要的意义。

关键字：超分辨成像；微颗粒透镜；微瓶透镜

ID 3363

Simultaneous Multi-site Deep Tissue Raman Measurements by a Multi-Needle Fiber Probe and a Single Spectrometer

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Objective: This study reports a novel multi-needle fiber Raman technique for simultaneously multi-site measurements of deep tissue Raman spectra.

Methods: This approach employs a micrometer multi-needle Raman probe with a coaxial laser excitation and Raman collection design and fabrication. Multi-site Raman photons collected by multi-needle Raman probe are projected on a single spectrometer's charge-coupled detector (CCD) through a round-to-parabolic fiber coupler. Raman spectra retrieval algorithm is developed based on the projection relationship between multi-needle Raman probe and CCD to retrieve multi-site Raman spectra from the image output of the spectrometer.

Results: The system was tested with different biological tissue types having different Raman spectra (e.g., muscle, fat, grey matter, and white matter in porcine brain), showing the ability to simultaneously measure the Raman spectra of different samples. The result suggests that high-quality tissue Raman spectra covering both the fingerprint (800-1800cm-1) and high-wavenumber (2800-3300 cm-1) regions can be simultaneously acquired from multiple sites by a single spectrometer within 5 seconds.

Conclusion: It opens a new avenue for in vivo multi-site monitoring, diagnosis, and characterization of deep tissue in different organs.

Key words: Raman spectroscopy, brain tissue, Fiberoptic needle Raman probe.

ID 3462

Assessment of UCNPs-mediated Photodynamic Therapy in Live Cancer Cells with Stimulated Raman Scattering and Transient Absorption Microscopy

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Objective: We employ hybrid stimulated Raman scattering (SRS) and transient absorption (TA) microscopy to investigate the dynamic interplay between live cancer cells and novel mitochondrial-targeting up-conversion nanoparticles (UCNPs) synthesized during photodynamic therapy (PDT).

Methods: We develop a lanthanide-doped up-conversion nanoparticle-based PDT nanomedicine (UCNP-Rb-TPP) with conjugation rose bengal (Rb) and triphenylphosphonium (TPP) molecules, which are used as photosensitizers and mitochondria-targeting ligands, respectively. We employ the rapid hybrid hyperspectral SRS/TA imaging technique developed to real-time monitor the UCNP-Rb-TPP interactions with live cancer cells at the subcellular level.

Results: Rapid TA imaging reveals the uptake pattern and subcellular distribution of UCNPs within live HeLa cells. While hyperspectral SRS/TA imaging uncovers the oxidative damage to the key cellular biomolecules in live cancer cells and the subsequent subcellular organelle disruption within cancer cells during PDT through simultaneous assessment of morphological and molecular spectral information.

Conclusion: Our study provides valueble insights into the drug delivery and therapeutic mechanisms of UCNPs-based PDT nanodrugs in live cells.

Key words: stimulated Raman scattering imaging; transient absorption imaging; photodynamic therapy; up-conversion nanoparticles

S15
第五届医学免疫与临床应用（SFICA）分会场
The 5th Summit Forum on Immunology and Clinical Application

ID 958

OE-MSC-derived Exosomes Enhance the Immunosuppressive Capacity of Myeloid-derived Suppressor Cells to Suppress Experimental Sjögren's Syndrome

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Objective: To investigate the role of mesenchymal stem cells-derived exosomes (MSCs-Exo) in regulating myeloid-derived suppressor cells (MDSCs) function and its implication in treating experimental Sjögren's syndrome (ESS).

Methods: ESS was induced in C57BL/6 mice immunized with salivary glands (SG) proteins. The suppressive capacity of MDSCs was examined in co-culture with T cells. Both phenotype and function of MDSCs upon MSCs-Exo treatment were analyzed in vitro and in vivo. The effect of IL-6 in modulating MDSCs function was evaluated by blocking the IL-6 pathway in MDSCs. The proteomics analysis was performed by LC-MS/MS.

Results: In culture, MSCs secreted exosomes with characteristic phenotype and morphology. MSCs-Exo significantly increased the suppressive function of MDSCs with up-regulated Arginase, ROS and NO expression on T cell proliferation, but reduced the levels of CD40, CD80, CD86 and MHC-II expression on MDSCs. Upon intravenous infusion, MSCs-Exo markedly attenuated the disease progression in ESS mice. Mechanistically, IL-6 secreted by MSCs-Exo was found to enhanced the suppressive function of MDSCs. Moreover, the abundant S100A4 in MSCs-Exo was identified as a key factor in mediating the endogenous production of IL-6 via TLR4 signaling in MDSCs.

Conclusion: Our Results have demonstrated that MSCs-Exo possess the therapeutic potential to alleviate ESS progression via modulating the immunosuppressive function of MDSCs, which may represent a new strategy for the treatment of Sjögren's syndrome and other autoimmune diseases.

Key words: mesenchymal stem cells, exosomes, MDSCs, Sjögren's syndrome

ID 978

CD38 通过激活钙通路促进调节性 T 细胞分化和功能诱导移植后免疫耐受的机制研究

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目的：调节性 T 细胞（Tregs）在肝移植后免疫耐受的诱导中起着重要作用。然而，由于 Tregs 的异质性，探索器官移植后 Tregs 的表型和功能特征是有帮助和必要的。

方法：通过流式细胞术，我们分析了肝移植后不同免疫状态的患者的免疫细胞，包括免疫耐受患者、免疫抑制剂摄入患者和健康个体。我们根据 CD38 将 Tregs 进行分类，讨论 CD38 在 Tregs 功能和代谢能力方面进行比较，蛋白质组分析揭示 CD38 信号转导的重要机制。

结果：与其他患者或健康个体相比，耐受患者的 T 效应细胞和 NK 细胞相当或更活跃，且外周血中 CD38+Tregs 的比例更高。与 CD38-Tregs 相比，该 Tregs 亚群具有更强的免疫调节功能和 OXPHOS 水平。CD38 升高 Tregs 的基础钙水平，钙信号传导增强了 RAS/NF-kb，延长了 Tregs 的存活和稳定性。此外，在异种 GVHD 的人源化模型中，上调 CD38 或牛磺酸的添加延长了 Tregs 的存活和抑制功能，能更有效地介导移植免疫耐受。

结论：这一结果表明，CD38+Treg 参与了耐受的诱导，通过细胞内钙水平促进 Ras 信号传导和代谢。我们的工作为肝移植后诱导耐受提供了强有力的理论基础。

关键字：CD38，调节性 T 细胞，移植免疫，钙离子

ID 1053

Sublytic C5b-9 Induces CCL3/4 Production and Macrophage Accumulation in Thy-1N Rats via PKC- α/p65/IRF-8 Axis

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Objective: Mesangioproliferative glomerulonephritis(MsPGN) is a chronic kidney disease.The mechanism of MsPGN involves in complement activation, inflammatory cell infiltration, leading to glomerular mesangial cell (GMC) proliferation and renal tissue fibrosis. Studies have proved that the deposition of complement C5b-9 and the production of pro-inflammatory cytokines including chemokines are increased simultaneously in the glomeruli of patients, the relationship between C5b-9 formation and cytokine expression in MsPGN has not been fully illuminated.

Methods: We examined CCL3/4 production, Mφ chemotaxis and IRF-8 expression, investigated the roles of IRF-8 in

CCL3/4 production in the GMCs treated with sublytic C5b-9, and the effects of CCL3/4 on Mφ chemotaxis. The levels of p-PKC-α and p-p65 and their regulatory roles in IRF-8 expression were assessed. The effects of silencing renal PKC-α, p65, IRF-8 and CCL3/4 genes on the corresponding protein expression or phosphorylation, Mφ accumulation, GMC lesion and proteinuria of Thy-1N rats were evaluated. the expression of p-PKC-α, p-p65, IRF-8, CCL3/4 and the accumulation of Mφ in the renal tissues of MsPGN patients were also observed.

Results: Sublytic C5b-9-induced CCL3/4 production from the GMCs involved in the activation of PKC-α/p65/IRF-8 pathway, and contributed to the Mφ chemotaxis. The Results in vivo displayed that PKC-α silencing decreased the levels of p-p65, IRF-8 and CCL3/4, and p65 silencing reduced the expression of IRF-8 and CCL3/4 but not p-PKC-α, additionally IRF-8 silencing inhibited the production of CCL3/4 rather than p-PKC-α and p-p65. Moreover, knockdown of renal PKC-α, p65, IRF-8 and CCL3/4 genes respectively could markedly abolished Mφ number, GMC proliferative changes and urinary protein production of Thy-1N rats.

Conclusion: PKC-α/p65/IRF-8 axis could promote renal CCL3/4 expression, Mφ increase and tissue damage of Thy-1N rats . Meantime, the expression of p-PKC-α, p-p65, IRF-8, CCL3/4 proteins and the accumulation of Mφ in the renal tissues of MsPGN patients not only markedly increased, but also showed positive relationship.

Key words: mesangioproliferative glomerulonephritis, Thy-1 nephritis, sublytic C5b-9, CCL3/4, macrophage

ID 1566

青蒿琥酯抑制实验性干燥综合征发病及免疫机制研究

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目的：研究青蒿琥酯（Artesunate, ART）对实验性干燥综合征（Experimental Sjögren's syndrome, ESS）小鼠的治疗效果及免疫相关机制。

方法：将唾液腺蛋白免疫诱导的 ESS 小鼠分为两组，分别给与溶剂和 ART 处理。检测小鼠的唾液流速变化、血清自身抗体水平并进行唾液腺组织病理分析。流式细胞术分析小鼠脾脏，引流淋巴结和唾液腺中 T 细胞，B 细胞等免疫细胞亚群的数目。体外培养 CD4 T 细胞和 B 细胞并进行 ART 处理。流式细胞术检测 Th17 细胞和浆细胞的分化水平。激光共聚焦显微技术，流式细胞术，环己酰亚胺蛋白稳定性实验等检测 IRF4 蛋白稳定性和相关通路的激活。2-NBDG 检测细胞对葡萄糖的摄取速率。海马生物能量检测仪测量细胞糖酵解代谢水平。

结果：ART 处理显著提高 ESS 小鼠的唾液分泌，降低自身抗体水平，并减轻唾液腺炎性细胞浸润。ART 显著降低了模型小鼠中 Th17 细胞和浆细胞的数目。ART 促进 IRF4 的降解，抑制了 IRF4 通路的激活，降低糖酵解水平，并影响 Th17 细胞和浆细胞的分化，减轻炎症反应。

结论：ART 通过抑制 B 细胞和 Th17 细胞反应有效缓解 ESS 小鼠发病。

关键字：实验性干燥综合征，青蒿琥酯，Th17 细胞，浆细胞，糖酵解

ID 1624

CGRP-CRLR 信号通路在系统性红斑狼疮患者 B 细胞分化中的作用及机制研究

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目的：探究 CGRP-CRLR 通路在 B 细胞分化、SLE 发病中的作用及机制。

方法：（1）流式细胞术、免疫组化（IHC）、qRT-PCR 检测 SLE 患者皮损和外周血中 CGRP、CRLR 的表达；体外细胞实验探究 CGRP 对健康人 B 细胞分化的影响。（2）流式细胞术、IHC 检测野生型（WT）小鼠和 *Cgrp*-/- KO 小鼠脾脏、淋巴结的淋巴细胞亚群比例、生发中心（GC）形成情况及 CRLR 表达；以及 SLE 弥漫性肺泡出血（DAH）造模小鼠肺出血、炎症浸润程度。（3）RNA-seq、qRT-PCR 探究 CGRP-CRLR 通路调控 B 细胞分化的分子机制。

结果：（1）狼疮患者外周血、皮损 B 细胞均高表达 CRLR；CGRP 可促进健康人外周血 PC 的分化。（2）*Cgrp*-/- KO 小鼠的体液免疫应答受到抑制，且 SLE DAH 造模后其肺出血和炎症浸润轻于 WT 小鼠。（3）CGRP-CRLR 通路可能通过 MAPK 通路调控 B 细胞分化。

结论：过度活化的 CGRP-CRLR-MAPK 信号通路可促进 SLE 患者浆细胞的分化，因此该通路是 SLE 的潜在治疗靶点。

关键字：SLE；CGRP；CRLR；B 细胞；分化

ID 1634

EZH2 and HDAC6 as Synergistic Targets for Lupus Erythematosus by modulating B-cell Biology

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Objective: Autoreactive B cells are responsible for functional contribution to tissue damage and ongoing inflammation in lupus erythematosus, but current depletion therapies might prove efficacious in some but not all patients. Disruption of an epigenetic profile may explain the high degree of plasticity in immune responses and can be pharmaceutically reversible compared to genetic changes. Here, we identified a novel epigenetic modulation signaling pathway driven by histone deacetylase HDAC6 and the methyltransferase EZH2 as valid targets for lupus therapy.

Methods: Multiplex immunofluorescence was performed to analyze the HDAC6 and EZH2 expression and distribution in skin lesions. Flow cytometric cell sorting and analysis was managed to assess the potential of HDAC6 and EZH2 dual inhibition in antibody-secreting cell differentiation. Drug application was conducted to evaluate the treatment efficacy and B cell biology in vivo.

Results: Immunofluorescence staining showed that HDAC6 and EZH2 were overexpressed in skin lesions of both lupus patients and mouse models. In vitro, dual inhibition of HDAC6 and EZH2 could significantly reduce B cell proliferation and functional differentiation under the stimulation of cytokine interleukin-21 and toll-like receptor signals. We further

showed that topical application of HDAC6 and EZH2 inhibition could synergistically ameliorate the lupus-like patchy erythema in both humanized CLE model and pristane-induced CLE model through the regulation of histone H3 lysine-27, followed with significant reduction of B cell infiltration and immune complex deposition. In addition, intraperitoneal injection of HDAC6 and EZH2 inhibition in MRL/lpr mice displayed a significant reduction in skin lesions, renal involvement and alter aberrant B cell differentiation, especially plasma cell and age-associated B cell.

Conclusion: Thus, this study not only updates mechanistic discoveries of HDAC6 and EZH2-dependent epigenetic modulation of histone H3 lysine-27 in pathogenic B cells, but also proposes the repurposing of HDAC6 and EZH2 dual inhibition as a new therapeutic option for patients with lupus erythematosus.

Key words: Lupus erythematosus; B cell; HDAC6; EZH2

ID 1688

Positive Antiphospholipid Antibodies Are Associated with a Higher Risk of Cerebral Microbleeds

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Objective: Persistent presence of antiphospholipid antibodies (aPLs) are important thrombosis-related laboratory parameters, as well as an indication of anticoagulation use which usually cause higher bleeding risk. Cerebral microbleeds (CMBs) are strongly associated with both bleeding propensity and ischemic events. This study aimed to explore the association between aPLs and CMBs.

Methods: 31 PAPS, 50 SAPS, 19 SLE with positive aPLs, 44 SLE without positive aPLs and 16 aPLs carriers were enrolled from 2018 to 2021. Clinical data, aPLs profile and susceptibility-weighted imaging (SWI) data were collected. Univariate and binomial logistic regression (prediction model 1) analysis was conducted to investigate the risk factors of CMBs. Differences in CMBs between those with or without aPLs were analyzed by machine learning (supervised K-Nearest Neighbor (KNN) classification and unsupervised K-means clustering analysis) in SLE patients. Then, an image recognition analysis (prediction model 2) was conducted to build a model to predict the disease subtypes. Receiver operating characteristic (ROC) curve and nomogram representation of binomial logistic regression analysis for CMBs risk and ROC curve of the image recognition analysis were set up. The area under the curve (AUC) was calculated to reflect the model performance. The Results of machine learning were visualized by dimension reduction.

Results: Anti-cardiolipin antibody (aCL) IgG, lupus anticoagulant (LA), and apL-positive number showed a significant difference in univariate analysis. In prediction model 1 (AUC=0.86), LA played an important role ($p<0.05$, OR(95%CI): 1.31–13.24). The Results of machine learning illustrated that SLE patients with positive aPLs had more CMBs numbers, more CMBs sites, and the possibility of infratentorial region hemorrhage (more life-threatening outcome). In addition, prediction model 2 (AUC=0.81) possessed good accuracy to predict the disease subtypes.

Conclusion: APLs were closely related to CMBs, of which LA played the most important role. It could be considered to screen CMBs by SWI in aPLs-positive patients.

Key words: Systemic lupus erythematosus, antiphospholipid antibodies, cerebral microbleeds, Susceptibility weighted imaging

ID 1790

GDNPs Reprogram Macrophages to Regulate Arginase-1 Release for Relieving T Cell Exhaustion in Tumor Microenvironment

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Objective: Lines of evidence indicate that immune checkpoints (ICs) inhibitors enhance T cell immune response to exert anti-tumor effects. However, T cell exhaustion is still a major obstacle to antitumor immunotherapy in colorectal cancer patients. Our previous studies showed that ginseng-derived nanoparticles (GDNPs) inhibited the growth of various tumors by reprograming tumor-associated macrophages (TAMs) and downregulated the ICs expression on T cells in tumor microenvironment (TME), but the underlying effector mechanisms remained unclear.

Methods: GDNPs were isolated and characterized from Panax ginseng C. A. Mey. We analyzed associated surface markers and arginase-1 (ARG1) production of macrophages treated with GDNPs. Mice bearing MC38 colonic cancer cells were treated with GDNPs therapy. Tumor growth were assessed, and the functions of T cells sub-clusters were evaluated by single-cell sequencing, FACS and spatial metabolomics.

Results: In this study, we demonstrated that GDNPs reprogramed TAMs via reducing ARG1 production. Moreover, normalized arginine metabolism relieve T cell exhaustion through mTOR-T-bet axis, resulting in reduced ICs expression, enhanced cytotoxic effect and CD8+ T cell expansion.

Conclusion: These Results provide new insights in understanding the mechanisms involved in reversing T cell exhaustion, which may facilitate the development of new therapeutic strategy for cancer treatment.

Key words: Ginseng-derived nanoparticles, Arginase-1, Tumor-associated macrophages, T cell exhaustion, mTOR

ID 2864

肿瘤内菌群通过乳酸化和免疫调节促进结直肠癌肝转移

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目的：明确肿瘤微生物在临床 CRC 患者肝转移过程中发生，发展以及疾病预后的影响，阐明肿瘤微生物直接调控肿瘤内巨噬细胞极化的分子机制，进一步探讨乳酸化修饰的巨噬细胞对免疫微环境的影响及机制，通过药物阻断相关通路，探讨其诊断和治疗疾病的价值。

方法：建立小鼠肠癌肝转移模型，通过体内外实验明确肿瘤微生物对 CRLM 进展的调节作用，进一步验证乳酸化修饰对 RIG-I 结合 MAVS 启动 NF-κB 通路的调节作用以及 对巨噬细胞极化的影响机制，筛选抑制 RIG-IIys852 乳酸化的天然小分子化合物探索临床转化应用可能。

结果：肿瘤内菌群增加了瘤内乳酸浓度，通过 RIG-I 乳酸化抑制 NF-κB 信号通路，促进 M2 巨噬细胞极化。RIG-I 的乳酸化抑制了 NF-κB 在巨噬细胞中向 NIrp3 启动子的募集，从而降低了其转录。NIrp3 的缺失影响了 Tregs 和 CD8+T 细胞的抗肿瘤活性。天然小分子化合物筛选发现了一种 RIG-I 乳酸化抑制剂，可抑制 M2 极化，并使 CRLM 对 5-FU 增敏。

结论：饮食习惯改变了微生物群的组成，肿瘤内微生物群可能是预防和治疗 CRLM 的潜在靶点。

关键字：结肠癌肝转移，瘤内菌群，乳酸化修饰，巨噬细胞，RIG-I

ID 2893

Underweight in Patients with Early Rheumatoid Arthritis and its Association with Increased Soluble Interleukin 2 Receptor

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Objective: Adipose tissue with proinflammatory properties and obese body mass index (BMI) are involved in onset and disease activity of rheumatoid arthritis (RA). However, less attention has been focused on underweight BMI in RA, especially early RA. We investigate the prevalence and clinical significance of underweight in early RA and potential mechanism.

Methods: This cross-sectional study was carried out retrospectively based on our Chinese RA cohort and healthy controls. Early RA patients (disease duration ≤ 12 months) and age- and sex-matched controls (1:2 ratio) were included in this study. Serum inflammatory cytokines including TNF-α, IL-6, IL-1β, IL-8, IL-10 and soluble interleukin 2 receptor (sIL-2R) were detected.

Results: ① Among 1511 RA patients recruited in the cohort, there were 293 (19.4%) patients with early RA, and 221 early RA patients (mean age 49.4 years with 69.7% female) and 442 age- and sex- matched (1:2 ratio) controls were eligible for analysis. ② Compared with matched controls, early RA patients had a lower BMI (mean 21.9 kg/m2 *vs.* 23.3 kg/m2) together with more underweight (16.3% *vs.* 2.0%, both $P < 0.05$). Surprisingly, compared with females, male patients with early RA had a lower BMI (mean 21.1 kg/m2 *vs.* 22.3 kg/m2) together with more underweight (22.4% *vs.* 13.6%). ③ Compared with those without underweight, early RA patients with underweight were younger, more male, more active smoking (all $P < 0.05$). ④ Early RA patients with underweight had a higher level of sIL-2R than those without (median 7.8×102 U/ml *vs.* 4.9×102 U/ml, $P < 0.001$). ⑤ Multivariate logistic regression analysis showed that sIL-2R (OR = 1.127, 95% CI 1.058-1.401) was positively associated with underweight in patients with early RA.

Conclusion: This first controlled study revealed a higher prevalence of underweight and its association with increased serum sIL-2R in early RA. Their clinical implication is worth further exploration.

Key words: Rheumatoid arthritis; underweight; soluble interleukin 2 receptor

2917

CCF-01 Ameliorates Psoriasis via Modulation of Gut Microbiota-derived SCFAs

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Objective: Excessive activation of T helper type (Th) 17 and Th1 cell are critical events in psoriasis pathogenesis and inhibition of Th17 and Th1 is a therapeutic target for psoriasis. Therefore, it is desirable to identify small molecules for treatment of *via* suppression of Th17 and Th1 cells. In the current study, we identified the effect of CCF-01, a small molecule on

amelioration of psoriasis and elucidated the underlying mechanism correlated to suppression of Th1 and Th17.

Methods: To investigate the effect of CCF-01 on psoriasis, imiquimod-induced psoriasis mice were orally administrated with CCF-01 (1.25, 2.5 and 5 mg/kg) . Skin and colon lesion were assessed by pathological score and histological analysis. CD4+ single T lymphocytes were sorted by magnetic beads and T cell subsets polarization was analyzed by flow cytometry. Cytokine secretion and mRNA expression was assessed by ELISA and quantitative real-time PCR. Metabolomics was applied to examine the expression of short chain fatty acids.

Results: Our Results demonstrated that CCF-01 restored the pathological lesions in skin and inhibited the expression of inflammatory cytokines including IL-17, IFN-γ, IL-22 and IL-6. Meanwhile, CCF-01 significantly inhibited Th17 and Th1 cells rather than Th2, Treg or IL-10+ B cells. In addition, CCF-01 improved mucosal barrier function and regulated the expression of genes encoding for tight junction proteins including claudin2, claudin4 and ZO-1. Mechanistic studies demonstrated that CCF-01 alleviating psoriasis resulted from induction of gut microbiota-derived SCFAs.

Conclusion: Collectively, CCF-01 inhibited Th17 and Th1 cell activation to ameliorate psoriasis and modulated intestinal barrier function and SCFAs expression. The study not only provided a lead compound to treat psoriasis but also suggested that regulation of SCFAs probably is a potent therapeutic strategy to alleviate autoimmune diseases.

Key words: CCF-01; psoriasis; short chain fatty acids.

ID 2967

肿瘤调节性 T 细胞的表观遗传调控机制和干预策略研究

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目的： Treg 是一种负向调节的免疫细胞亚群，理论上靶向 Treg 可以很好的改善肿瘤微环境，但是系统性 Treg 对于机体的免疫稳态也不可或缺，只有找到选择性靶向肿瘤 Treg 而不影响外周 Treg 的策略才可用于肿瘤免疫治疗。因此本研究的目的是鉴定肿瘤 Treg 特有的表观遗传调控机制，应用于特异性靶向肿瘤 Treg。

方法： 通过组学分析，对比肿瘤 Treg 和外周 Treg 在表观遗传调控方面的差异，结合 Crispr-cas9 筛选特异调控肿瘤 Treg 的表观遗传分子，构建条件性敲除小鼠进行功能和机制的研究，结合临床病人样品分析上述发现的意义。合作筛选小分子化合物抑制剂，评估其抗肿瘤作用。

结果： 发现 JMJD1C 在肿瘤 Treg 高表达。条件性敲除 Treg 中的 JMJD1C 不影响外周 Treg 和系统性免疫稳态，然而显著降低了肿瘤 Treg 比例，导致肿瘤生长减缓。在机制上，JMJD1C 缺失通过上调 AKT 和 STAT3 信号通路导致肿瘤 Treg 脆弱而丢失。利用深度学习的人工智能筛选方法，鉴定到 JMDJ1C 的高效小分子抑制剂，并具有良好的靶向肿瘤 Treg 和抑制肿瘤生长的功能。

结论： 鉴定了肿瘤 Treg 的特异性表观遗传调控分子，并开发了抑制剂。

关键字： 调节性 T 细胞

ID 3140

单细胞测序揭示干燥综合征患者唇腺和外周血的细胞异质性及分子特征

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目的：原发性干燥综合征（pSS）是一种以外分泌腺体损伤为特征的自身免疫病，其发病机制尚未阐明。本项目拟通过单细胞转录组测序（scRNA-seq）揭示 pSS 患者唇腺和外周血的细胞异质性及其分子特征。

方法：本研究共纳入 11 例 pSS 患者和 5 例对照，获取唇腺组织样本，使用 10XGenomics 平台进行 scRNA-seq。另收集 5 例 pSS 患者和 3 例健康对照的外周血进行 scRNA-seq。

结果：共计得到了 72, 853 个唇腺细胞，对细胞进行聚类和注释后鉴定出 11 个细胞群。研究发现 ACKR1+ 内皮细胞亚群在 pSS 患者唇腺中显著扩增（P=0.011），该群细胞能够促进淋巴细胞的跨内皮迁移。差异基因（DEGs）分析发现 pSS 患者上皮细胞的再生功能受损，其调控的关键转录因子 SOX9 在 pSS 患者肌上皮细胞中表达下降。对唇腺和外周血免疫细胞进行整合分析，发现 BANK1+ B、VPREB3+ B 和 IGHD+ B 细胞在 pSS 患者的唇腺组织中富集，外周血 B 细胞具有不同的分化途径。细胞互作分析发现，成纤维细胞发挥破坏细胞外基质形成和促进炎症进展的关键作用。

结论：本研究揭示了 pSS 患者唇腺的免疫微环境，为 pSS 发病机制的研究和治疗提供了线索。

关键字：干燥综合征；单细胞测序；发病机制

ID 3145

Phenotypical Changes and Clinical Significance of CD4+ /CD8+ T Cells in SLE

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Objective: To better understanding the phenotypic abnormalities of T cells in SLE will help us to clarify disease immunopathology and to find promising biomarkers for disease monitoring and control.

Methods: Peripheral blood CD4+ and CD8+ T cells and their subsets were determined by flow cytometry. The percentages of these cell subsets between patients with SLE and HCs and their relationships with disease activity and autoantibody titers were analysed.The changes in the frequencies of these cell subsets and their relationships with renal response were analysed.

Results: An imbalance of CD28+ and CD28- cells in CD4+ T cells was observed in the SLE patients. We found that the expanded CD4+CD28− T cells did not decrease after treatment in patients who had impaired renal responses. It was very interesting to exhibit a negative correlation in the frequency between the CD4+CD28−T cells and T regulatory (Treg) cells and a positive correlation between the frequency of CD4+CD28+ T cells and Treg cells in this study. Increased CD8+HLADR+ T cell and CD8+CD38+HLADR+ T cell counts were observed in SLE patients, suggesting an impaired cytotoxic capacity of CD8+ T cells in SLE. Additionally, we found that CD8+CD38+HLADR+ T cells were closely associated with disease activity, autoantibody titres and renal prognosis. CD4+ CXCR5−PD1+ T cells were expanded in SLE patients in this study and were associated with disease activity in SLE.

Conclusion: The proportions of CD4+CD28−T cells, CD4+CXCR5−PD1+ T cells, CD8+HLADR+ T cells and CD8+CD38+HLADR+ T cells increased in SLE patients and could be associated with disease activity and renal prognosis.

Key words: T cells, Systemic lupus erythematosus, biomarkers

ID 3402

复发性多软骨炎 44 例临床分析

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目的：分析复发性多软骨炎（Relapsing polychondritis，RP) 的临床特征、实验室检查特点及治疗转归，为早期诊断 RP、改善疾病预后提供科学依据。

方法：回顾性分析 2007 年 1 月至 2021 年 9 月在山东省立医院风湿免疫科住院 , 并确诊为 RP 的 44 例患者的临床特点、实验室检查资料及治疗转归。

结果：44 例 RP 患者中男性 27 例，女性 17 例。发病年龄 19-85（48.6±15.6）岁。首发症状主要为耳廓红肿，其次分别为关节症状、眼部症状、声音嘶哑，发热。从首次症状到确诊时间为 18 天 -7 年。在整个病程中 , 有耳廓症状者 43 例，眼部症状者 24 例，关节症状者 19 例，呼吸道症状者 12 例，神经系统症状者 10 例，鼻受累者 11 例。血沉升高者 23 例（57.5%），C 反应蛋白升高者 17 例（68%）。IgG4 升高者 4 例（13.8%），IgG 升高者 13 例（33.3%）。抗核抗体阳性者 17 例（41.5%）。44 例 RP 患者中 43 例患者接受糖皮质激素治疗，大部分患者同时加用免疫抑制剂治疗，2 例应用生物制剂，43 例患者治疗后病情好转。

结论：RP 可累及全身多个系统，耳廓受累最常见。糖皮质激素联合免疫抑制剂治疗可作为一种有效的治疗手段。

关键字：复发性多软骨炎；临床特点；治疗转归

ID 3428

脐带间充质干细胞治疗原发性干燥综合征系统受累的疗效分析

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目的：评价脐带间充质干细胞（UC-MSCs）移植治疗对合并多系统损伤的 pSS 患者长期预后的影响。

方法：回顾性分析 2011 年 7 月至 2019 年 9 月于南京大学医学院附属鼓楼医院住院治疗的 pSS 患者 60 例，收录分析临床资料及相关辅助检查，并通过 2-10 年随访，评价 UC-MSCs 移植治疗 pSS 患者的长期疗效及安全性，以及对不同系统受累预后的影响。采用配对样本 t 检验、Mann-Whitney U 检验、Log-Rank 检验、COX 回归分析处理数据。

结果：纳入 60 例 pSS 患者，10 例死亡，10 年生存率 83.33%，欧洲 SS 患者报告指数（ESSPRI）移植后显著下降 [N=50，2.00（1.25, 3.33）vs.3.00（1.92, 4.42），P<0.01]，总体有效率 48.33%。高疾病活动度的患者接受 MSCs 治疗获益更大，多次 UC-MSCs 治疗是患者生存的保护因素。所有患者均无移植相关并发症。

结论：对于多系统受累的 pSS 患者，UC-MSCs 移植治疗长期安全有效。

关键字：原发性干燥综合征；多系统受累；间充质干细胞

ID 3457

托法替布治疗 11 例难治性成人斯蒂尔病疗效及安全性评估

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目的：研究托法替布治疗难治性成人斯蒂尔病 (adult-onset Still’ s disease，AOSD) 患者的疗效及安全性。

方法：经过糖皮质激素联合其他免疫抑制剂或生物制剂治疗的 11 例难治性 AOSD 患者效果欠佳，加用托法替布治疗后观察治疗前后患者临床症状变化，评估血常规、肝功能、血沉 (erythrocyte sedimentation rate，ESR)、C 反应蛋白 (C-reactive protein，CRP)、血清铁蛋白水平在其治疗前后有无变化，并记录不良反应评估其临床安全性。

结果：托法替布治疗 4 周后，患者常见临床症状，发热、关节痛等环节，临床指标血常规白细胞、中性粒细胞、血清铁蛋白水平下降，差异均有统计学意义 (均有 P ＜ 0. 05) 。治疗后无明显不良反应。

结论：托法替布能改善难治性 AOSD 患者病情，减少糖皮质激素用量，降低疾病活动度，安全性好。

关键字：still 病，成年型；托法替布；治疗结果

ID 3508

Bregs 调节 Th17/Treg 失衡影响系统性红斑狼疮并发动脉粥样硬化

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目的：本研究旨在探讨调节性 B 细胞 (Bregs) 和 Th17/Treg 细胞在系统性红斑狼疮并发动脉粥样硬化小鼠模型中的比例及其作用，以及下游炎症因子在动脉粥样硬化早期小鼠模型中的释放。

方法：1. 选取 8 周龄雌性 LDLr-/- 小鼠腹腔一次性注射 0.5mlPristane，再行高脂饲料喂养 14 周构建系统性红斑狼疮并发动脉粥样硬化动物模型，作为实验组；同周龄雌性 C57 小鼠作为对照组。2. 采用流式细胞术分析小鼠脾脏 PBMC 中 Bregs、Th17 和 Treg 细胞的比例；3.ELISA 检测血清 IL-10、IL-17 的表达水平的变化。

结果：(1) 实验组小鼠脾脏 Bregs 和 Treg 比例较正常组低（p<0.05），Th17 升高；（2）小鼠血清中 IL-10 升高，IL-17 升高，差异具有统计意义。

结论：SLE+AS 小鼠中 Breg 比例降低，存在 Th17/Treg 失衡现象。

关键字：系统性红斑狼疮；动脉粥样硬化；调节性 B 细胞；TH17/Treg

S16
人工器官
Artificial Organs

ID 216

一种基于细菌纳米纤维素的新型血液透析膜的研究

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目的：细菌纳米纤维素（BNC）的三维网络状孔隙不满足血液透析中截留必需蛋白质的要求。因此本研究采用不同浓度壳聚糖在细菌纤维素膜内原位合成壳聚糖纳米粒（CSNP），实现纤维网络孔隙尺度的有效调控，获得一款用于血透的新型壳聚糖纳米粒 / 细菌纳米纤维素（CSNP/BNC）复合膜。

方法：将不同浓度的壳聚糖溶液通过负压浸渍与细菌纤维素膜复合，再通过硫酸钠沉淀法得到 CSNP/BNC 血液透析膜。研究其纤维结构、比表面积及孔隙率、力学性能、血液相容性、筛分系数和透析性能。

结果：随壳聚糖浓度升高，CSNP 粒径变大；膜的比表面积和孔体积减小；膜的杨氏模量和弹性强度提高；复合膜未造成血液成分的破坏；3%（w/v）CSNP/BNC 复合膜对尿素、溶菌酶和白蛋白的筛分系数分别为 0.68±0.07、0.50±0.03 和 0.06±0.03，对尿素和溶菌酶的清除率分别为 16.37%/cm^2 和 3.54%/cm^2，对白蛋白的截留率为 98.04%/cm^2。该复合膜对中小分子的清除率为已知文献数据的 2~14 倍。

结论：本研究制备得到的 CSNP/BNC 复合膜机械性能和血液相容性优异，能有效截留大分子和清除中小分子，是一种具有潜力的新型纤维素基血液透析膜。

关键字：细菌纤维素；壳聚糖；血液透析

ID 479

Light-sheet Traction Force Microscopy Used for Organ-on-chips

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Objective: As the field of organ-on-a-chip(OOCs) research continues to develop, there is a need for measurement techniques that can be applied to more and more scenarios. Active cells can generate mechanical stress to move, divide, modify and sense their extracellular environment. To investigate the role of cellular traction forces arising in various physiological and pathological processes, a traction force microscopy (TFM) technique implemented on a light-sheet fluorescence microscope (LSFM) has been first reported in this article.

Methods: The imaging Methods used in conventional traction force microscopy has insufficient volume imaging speed to enable full 3D-TFM. The unique plane-scanning method of LSFM allows for enhanced imaging speed and greatly reduced

phototoxic and photobleaching, allowing for more rapid acquisition speed for 3D-TFM volume image row data so that we can calculate a more dynamic cellular force process and record long-term pathological processes that evolve in OOCs.

Results: In addition, a greedy algorithm based on the minimum acceleration motion model to optimize the displacement field reconstruction process has been introduced, which solves the limitation that conventional TFM cannot most total long-range displacement. We propose a simulation data generation method to validate the technique, and the Results show that the traction force field Results are consistent with the simulation standard results.

Conclusion: A mechanical dynamics of a tumour sphere invading a matrix gel for 24h has been recorded. We believe that this technique will provide a powerful research tool in areas such as biological cell mechanics and drug screening.

Key words: Traction force microscopy, light-sheet microscopy, organ-on-chips, cell mechanics

ID 605

CT 层面计数一种简单准确定位长期透析导管尖端位置方法的研究

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目的： 留置 TDC 可能出现感染，血栓甚至上腔静脉闭塞等并发症，引起导管功能不良，缩短导管使用寿命，甚至影响患者长期生存质量。目前研究认为导管尖端位置与导管功能，导管使用时间，感染密切相关。CT 定位可以准备判断导管尖端的定位，本文旨在通过单中心回顾性研究 CT 层面计数在长期管尖端位置定位的临床应用。

方法： 收集 2022 年 1 月 1 日至 2022 年 3 月 31 日浙江大学医学院附属第一医院肾脏病中心留置 TDC 患者的临床资料，共有患者 234 例，新留置导管 170 例，新留置导管中股静脉及左颈 34 例，右颈内静脉留置 136 例，术后未进行胸片复查 73 例，复查胸片 63 例，CT 定位组患者 27 例，X 线定位组 46 例

结果： CT 定位组尖端位置均在右心房上 1/3 处，X 线定位过浅 9 例，过深 12 例，位置良好 25 例，与 X 线定位相比，CT 定位准确，位置达标率更高。

结论： CT 定位简单可行，可作为一种简单精准的长期管定位方式。

关键字： CT，长期管，定位，尖端位置

ID 1032

Bioorthogonal-engineering Strategy for Facilely Preparing High Quality Heterogeneous Cancer Cell Spheroids

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Objective: The tumorigenesis of oral cancer is a complicated process, and a deep understanding of treatment mechanisms is urgently needed for preventing cancer crisis. Multicellular tumor spheroids provide a powerful platform for investigating oral cancer growth and anticancer treatment due to their characteristics of closely mimicking in vivo tissue environment. However, currently available fabrication Methods are difficult to build high-quality spheroids containing different types of cells, but generate irregular and loose cell aggregates, lacking of tissue physiological architectures and gradients.

Methods: Herein, we presented the first bioorthogonal-engineering strategy (BEST) for preparing superior oral cancer cell spheroids (OCCS). BEST employed the cellular biosynthetic machinery to incorporate bioorthogonal azide reporters into cell surface glycoconjugates, followed by clicking with dibenzoannulated cyclooctyne functionalized hyaluronic acid (DIBO-HA), resulting in rapid and effective construction of spheroids.

Results: We identified that BEST could successfully assemble different types of cells together to construct heterogeneous spheroids, allowing for accurately mimicking tumor features, such as structural components, intercellular interactions, and physiological microenvironment. Importantly, BEST could construct high-quality spheroids with good cell viability, function and pluripotency, and significantly improved the establishment of subcutaneous xenograft model after transplantation.

Conclusion: All in all, BEST represents an optimal strategy for developing tumor spheroids and has the potential of bridging gaps between in vitro and in vivo research.

Key words: multicellular tumor spheroid; bioorthogonal-engineering strategy; mimicking tumor features

ID 1264

潮式腹膜透析与持续循环自动化腹膜透析的临床效果对比分析

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目的：观察自动化腹膜透析潮式模式（TPD）与持续循环模式（CCPD）在 CAPD 患者中的治疗效果、临床症状及并发症，总结自动化腹膜透析模式选择的科学方法。

方法：选择 CAPD 患者 82 例进行 APD 治疗，随机分成 2 组：TPD 组 41 例和 CCPD 组 41 例。比较两组患者 APD 前后血肌酐、尿素氮、尿酸、钾、钠、钙、磷、ALB 和 HB 的指标变化，观察超滤及心血管并发症、导管异位、腹膜炎、腹胀、腹痛等发生情况。

结果：透析量均为 10L，治疗时长为 14h/ 天，周期为 5 天。

超滤量 CCPD 组高于 TPD 组（P<0.001）。血肌酐清除率两组结果无统计学差异（P=0.094），血尿素氮清除率 TPD 组低于 CCPD 组（P<0.001），血尿酸清除率 TPD 组低于 CCPD 组。电解质：磷的清除率 CCPD 组高于 TPD 组（P<0.001）其余电解质钙、钠、钾两组间无统计差异。营养指标：ALB 和 HB 两组前后无差异。

并发症：两组患者均未发生心血管并发症、腹膜炎、渗漏、导管异位等并发症，腹痛症状两组无统计学差异，腹胀症状 TPD 组较 CCPD 组高（P<0.001）。

结论：APD 能较好清除代谢废物和水分，发生腹膜炎、渗漏、导管异位及心血管并发症的几率都非常小。

关键字：潮式腹膜透析；持续循环腹膜透析；毒素清除；脱水；腹膜透析并发症

ID 1292

释放尺寸对于人工心脏瓣膜的影响规律研究

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目的：临床医生多基于患者的 CT 图和经验选择瓣膜尺寸，无理论数据支撑，忽略了释放尺寸对瓣膜功能性和耐久性的影响。基于此，本研究通过控制瓣膜的释放尺寸，利用脉动流、加速疲劳和有限元分析研究释放尺寸对瓣膜的影响。

方法：1. 根据国标 ISO-5840，用脉动流仪分析释放尺寸（18、20、22 和 23 mm）对 23 mm 瓣膜的瓣叶卷曲、开闭和耗能的影响。记录瓣膜主动脉压和流量，比较瓣膜的有效开口面积、跨瓣压差和反流率；2. 用疲劳机测试不同释放尺寸的瓣膜在加速疲劳下的功能失效情况，分析瓣叶纤维结构、力学和热力学性能等；3. 建立支架和瓣叶模型，组装瓣膜。用双轴拉伸获取瓣叶力学参数，用 Ogden3 阶模型拟合。将瓣膜植入不同尺寸管道，施加健康人体主动脉压波形，研究释放尺寸对瓣膜应力分布的影响。

结果：1. 释放尺寸越小，瓣叶卷曲程度越大，瓣膜的有效开口面积和反流率越小，而跨瓣压差和耗能越大；2. 释放尺寸越小，疲劳测试后瓣叶纤维断裂，力学和热力学性能降低；3. 释放尺寸越小，瓣膜自由边和缝合区有更多高应力区，加剧瓣叶衰败。

结论：瓣膜释放尺寸对瓣膜影响较大，术前获得患者解剖学信息并选择合适尺寸或自适应尺寸的瓣膜，有助于术后瓣膜发挥功能性。

关键字：TAVR、释放尺寸、血流动力学、耐久性、有限元分析

ID 1675

人工心脏脉动工作模式调控血流动力学参数的多尺度数值仿真分析

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目的：人工心脏的辅助血泵在恒速模式下会降低血管脉动性，导致心室塌陷的抽吸现象以及多种并发症。而脉动转速可以增加血管脉动性并改善动脉内皮功能。然而目前血泵转速的脉动工作模式调控血流动力学参数的规律尚不明确。本项目旨在基于多尺度数值模型研究人工心脏脉动工作模式对血流动力学参数的影响。

方法：利用集中参数模型建立人工心脏的反馈控制系统，在提高血管脉动性的同时预防抽吸现象并保证足够的生理灌注。根据与反馈控制结果吻合的恒速和脉动转速模式下的动物实验数据，结合多尺度血流动力学流固耦合建模及计算流体力学仿真，分析人工心脏在恒速及脉动转速下产生的壁面剪应力、血压、牵张应变等血流动力学参数

结果：与恒定转速相比，设计的反馈控制系统可以在人工心脏脉动转速下将主动脉脉压提升至正常人的水平，同时完全预防抽吸现象并提供足够的生理灌注；利用集中和分布参数模型得到主动脉压力和血流量在总体上相匹配；上述结果也分别通过轴流式和离心式人工心脏进行了验证，证明了研究方法的鲁棒性。

结论：人工心脏脉动转速可以增加血管脉动性，改善心肌功能和终末器官灌注，并最大限度减少因恒定转速产生的一系列不良事件（国家自然科学基金面上项目，No.32071314）。

关键字：人工心脏，脉动工作模式，血流动力学，自适应控制，计算流体力学

ID 2027

细菌纤维素 / 壳聚糖微球 / 肝素小口径人造血管

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目的：小口径人造血管尚未有市售产品，本研究制备了具有抗凝和快速内皮化的细菌纤维素 / 壳聚糖微球 / 肝素复合型小口径人工血管—BC/CSNPs-Hep 管，评估了该管的各项性能，为 BC 基管材在小口径人工血管领域的应用提供更多可能性。

方法：利用具有自主知识产权的模具发酵制备 BC 管，然后采用离子凝胶法将 CS 固定在 BC 网络中，并利用 EDC/NHS 法将 Hep 接枝 CSNPs 表面，得到 BC/CSNPs-Hep 小口径人造血管。用 qPCR、材料测试仪以及大鼠腹主动脉移植模型评价了管的各项性能。

结果：BC/CSNPs-Hep 管无细胞毒性，较 BC 管的血浆复钙时间显著增加，全血凝固曲线中 OD 值下降的幅度减小，vWF 基因表达量上调，表明复合管具有更强的抗凝血性能，且溶血率小于 5%，满足三类医疗器械的要求；其表面的炎症因子（TNF-α、IL-6、MCP-1）表达量显著下降；动物实验显示，当该人造血管植入大鼠体内 5 个月后，血流仍畅通，且材料的外表面被少量自体组织包裹。

结论：BC/CSNPs-Hep 管具有良好的抗凝血性和生物相容性，具有作为小口径人工血管的巨大潜力，本研究为该复合管在小口径人工血管领域的应用提供了理论依据和动物实验基础。

关键字：细菌纤维素；壳聚糖；肝素；小口径血管；抗凝血

2122

Large-scale Tissue Fabrication and Micro-scale 3D cell Migration

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Objective: Human tissues are complex physiological systems composed of basic cells at the microscale, which require biofabrication strategies such as bioprinting to have control over high deposition resolution and complex geometries of blood vessels while also supplying the environment to regulate intrinsic cell signaling. However, current approaches have limited success in creating multi-scale vascular connections due to the lack of coordination between cell-laden materials and the stability of perfusion channels. Developing new bioactive materials to enhance cell viability remains a significant challenge, as the nutritionally deficient environment caused by limited nutrient penetration when cells are encapsulated within biomaterials.

Methods: We present a method for fabricating centimeter-scale soft liver-like tissue with high viability and precision using multi-material bioprinting with low viscosity inks and a specially designed temperature-controlled printer. Additionally, we have established a platform for engineering skeletal muscle tissue using a combination of 3D printing and sequential dynamic culture techniques.

Results: The printed constructs could be perfused with branched vasculature with a well-formed 3D capillary network and lumen, which would potentially supply the cellular components with sufficient nutrients in the matrix and mimic a mature and functional liver tissue with increased functionality in terms of synthesis of liver-specific proteins and vascular anastomosis with the carotid artery and jugular vein rescuing the rat with acute hepatic failure (AHF). The effects of confined printing on the skeletal muscle during maturation, which impacted the myotube alignment, myogenic gene expression, and mechanical forces, were observed.

Conclusion: We have introduced a cutting-edge, scalable 3D printing platform, offering a simple and efficient engineering approach to fabricate complex and macro-sized tissues with precision, thus opening up new opportunities in the field of tissue engineering and regenerative medicine.

Key words: 3D bioprinting, cell movement, regeneration, organ fabrication

ID 2474

经皮置入式心室辅助装置研发中的血液动力学问题

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目的：经皮置入式心室辅助装置 (pVAD) 能够为心力衰竭患者提供短期的心室辅助治疗，达到减轻心脏负荷，增加心输出量的功能。解决研发中的血液动力学问题，就要对 pVAD 的关键技术进行研究。

方法：本研究采用基于人工智能（AI）的全自动优化方法设计叶轮。基于磨损性 - 密封性协同设计方案，对微型电机进行研发。针对凝血问题，利用灌注液对电机轴进行液封。针对叶轮高速旋转产生的汽蚀问题，对 pVAD 叶轮进行引流设计。开发压力传感系统，实时监测主动脉压。通过体外搏动平台，对 pVAD 系统的性能进行实验研究。

结果：设计的混流式叶轮满足水力学性能和溶血指标。通过电机轴的液封技术，解决了轴与轴承的磨损问题，同时耦合叶轮引流技术，增强了 pVAD 抗凝血特性。叶轮的引流设计，还打通了高低压流动区域，抑制了空化现象。通过压力传感器监测的主动脉压，可以用于准确评估 pVAD 的辅助流量。具体来说，研发出了一款尺寸不大于 15 Fr，最大负载转速不低于 45000 rpm 的电机。当工作转速达到 45000 rpm 时，pVAD 的平均流量达到了 3.0~3.5 L/min，达到了国际同类产品的水平。

结论：通过对关键技术的研究，可以解决 pVAD 研发中的血液动力学问题。

关键字：pVAD ；叶轮；电机；血液动力学

ID 2816

微型介入式人工心脏灌注系统优化研究

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目的：近年来，随着人们生活节奏加快，心血管疾病发病率逐年升高，由此引发的急性心血管事件，特别是心源性休克 (CS) 事件在逐年攀升。研究表明，作为一种可以经动脉植入左心室的血泵，微型介入式人工心脏具有手术创面小、手术快、提供心脏灌注治疗效果好的特点，然而由于其尺寸的限制以及输出功率的需求，在设计此类人工心脏时

不可避免地需要进行电机驱动的温度控制，而通常的做法就是为电机预留灌注系统，通过生理盐水的灌注带走额外的热量，并且在液体出口处能够起到冲刷机体，防止血栓聚集的功能。在本研究中，针对上述需求为此类血泵进行电机灌注系统的尺寸设计。

方法：首先建立了电机驱动的参数化设计模型，确定设计空间；之后利用电机结构的对称性进行 2D 计算电磁学仿真，并与三维 CFD 仿真进行耦合计算，得到了电机驱动的电磁 - 热流耦合计算模型；进而求解得到了设计空间的响应空间；基于 NSGA-II 算法选出了三组设计方案，分别计算了对应的电机常数。

结果：计算结果保证了电机工作效率在额定工作情况下达到 55% 以上，机体表面额定工作情况下温度不超过 38.5℃，且对于血泵本身的工作效率影响小于 10%。

结论：综上，所选设计方案能够实现电机驱动的热管理功能。

关键字：介入式血泵 空心杯电机 遗传算法 多物理场仿真

ID 3095

Toxicity of Microplastics in Liver Disse Organoids from Healthy Donors and Patient-derived Induced Pluripotent Stem Cells

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Objective: The ubiquitous existence of pollutants threatens human health, such as increasing the risk of steatohepatitis. Human induced pluripotent stem cell (hiPSC)-derived organoids carry the inherited genetic information of the donor, potent in personalized toxicology. The liver Disse space play roles in hepatic pathogenesis. However, given the limited understanding of the regulatory cues in multilineage maturation, the generation of hiPSC-derived Disse-like organoids (DOs) is challenging, hampering investigation of the hepatotoxicity and mechanisms from the perspectives of multicellular interactions in three-dimensional space and genetic characteristics.

Methods: Here, we bioprinted multicellular DOs based on healthy donors and alcoholic liver disease (ALD) patient-derived hiPSCs. The hiPSC-derived hepatic endoderm cells (HEs), endothelial progenitor cells (EPCs) and hepatic stellate cells (LX2) were mixed with alginate and laminin 511 as bioink. The bioink was bioprinted into microspheres with diameters within 300-500 μm using electroassisted inkjet bioprinting. After 8 days of coculture, the DOs were developed with little cell death in the microspheres.

Results: Alginate/laminin bioinks offered appropriate microenvironment, facilitating multicellular crosstalk and mutually enhanced the maturation of hiPSC-derived cells. The DOs mimicked the microstructure features and transcriptional profiles of hepatic Disse space. Compared to healthy donor-derived DOs, ALD patient-derived DOs represented specific disease transcriptional profiles. With DOs models, we investigated the hepatotoxicity of microplastics (MPs), which were widely present in daily life and accumulated in human liver. MPs preferentially entered endothelial cells and then dispersed throughout the organoids. Intriguingly, MPs at environmentally relevant dosages elevated the pathological transcriptional expression and biochemical profiles in patient-derived DOs but not in the healthy-derived.

Conclusion: hiPSC-derived multicellular organoids could represent the transcriptional features of the ALD. Inherited hereditary factors and microplastics exposure synergistically contribute to susceptibility to microplastics. This study exemplified the values of biofabricated hiPSC-derived organoids in personalized environmental toxicology.

Key words: Liver organoids, hiPSC, Bioprinting, Environmental toxicology.

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医学检验工程——医工协同 融合创新
Medical Laboratory Engineering: Medicine and Industry, Fusion and Innovation

ID 1571

Replica Microbial Cultures from Microwell Arrays for Rapid and High-Throughput Screening of Bacteria

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Objective: Replica plating is a well-known microbiological technique for differentiating the variant colonies. However, the conventional replica plating Methods are laborious and time-consuming, and it is also difficult for them to simultaneously screen a large number of bacterial colonies. Here we developed a novel replica plating method by combining PicoArray microbial cultures and gel-based replica molding. This method allows a large number of colonies to be rapidly and simultaneously screened for many phenotypes in a single experiment.

Methods: A sample digitization based on vacuum-assisted sample loading and oil-induced dewetting was used to stochastically confine single bacteria in PicoArray, a microfluidic device containing an array of picoliter-sized isolation microwells. Subsequently, the confined single bacteria were cultured within the microwells for 2h to allow growth of microcolonies. Next, a low melting gel containing a particular assay medium was casted on the device and then peeled off from the device. This separation splits each cultured microcolonies into two replicas, both maintaining the identical pattern of colonies. The PicoArray replica can be used to preserve cells in a viable state for future use and the gel replica can be used to screen selectable phenotypes.

Results: Using a PicoArray containing 110432 microwells, we validate the proposed method by isolating and culturing Staphylococcus aureus, a major bacterial human pathogen, from a clinical sample. Due to the stochastic single bacteria confinement, this method offers another important advantage over the conventional plating methods, precisely quantifying the population densities of targeted bacteria in a complex sample.

Conclusion: A novel replica plating method has been proposed for simple, fast, and high-throughput screening of bacteria. We believe that this method will be widely used for not only differentiation/isolation of the variant colonies but also screening of antibacterial substances.

Key words: replica plating, microwell array, gel-based replica molding, high-throughput screening

ID 2057

基于环化荧光蛋白技术的神经元烯醇化酶探针

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目的：神经元特异性烯醇化酶是重要的肿瘤标记物，临床检测主要基于抗原抗体结合反应进行，存在反应时间长、假阳性高、特异性低、灵敏度差等问题。本课题基于环化荧光蛋白技术针对神经元烯醇化酶设计高灵敏、高特异性的 cpFP 探针，用于快速检测神经元烯醇化酶。

方法：采用噬菌体展示技术进行筛选神经元烯醇化酶的特异性亲和肽，经过分子对接实验验证后以此为基础设计环化荧光蛋白探针的结合臂，构建 cpFP 探针。探针蛋白经大肠杆菌表达纯化后，使用蛋白标准品进行探针的功能验证。

结果：构建的神经元烯醇化酶 cpFP 探针对白蛋白等多种蛋白无反应。设置标准蛋白溶液的浓度梯度是 10 - 104ng/mL，在不同浓度比例下的荧光强度能达到十倍以上。拟合结果显示，对应的标准曲线的 R2 值能达到 0.957，说明得到的标准曲线的线性度良好，能够基于此对样本中神经元烯醇化酶进行定量化。

结论：本课题设计的神经元烯醇化酶 cpFP 探针对生物体兼容性更好，毒性小，荧光动态变化大，特异性好，线性度好，可用于体外快速检测神经元烯醇化酶检测及体内动态监测，具有一定的临床检测实用价值。（大连市重点研发计划项目 No.2021YF18SN-023）

关键字：神经元烯醇化酶；环化荧光蛋白；噬菌体展示技术

ID 2543

MCP-1 介导单核细胞浸润在泡型包虫病肝纤维化中的作用

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目的：本研究旨在探讨肝泡型包虫病患者肝组织中单核细胞趋化蛋白 1(MCP-1) 的表达水平与单核细胞来源的巨噬细胞浸润程度、炎症及纤维化的相关性。

方法：采用 H&E 和 Masson 染色评估病理炎症改变和纤维化程度。采用 IHC 方法检测肝组织中巨噬细胞和单核细胞来源的巨噬细胞浸润情况及 MCP-1 表达情况。qRT-PCR 检测肝脏组织中 MCP-1 的基因表达。采用 ELISA 检测外周血中 MCP-1 的表达水平。

结果：肝泡型包虫病患者肝组织中 CD68+ 巨噬细胞 (P<0.001) 和 MAC387+ 单核细胞来源的巨噬细胞浸润明显增加 (P<0.001) ， MCP-1 表达水平显著增加 (P<0.001)。在肝脏组织中 MCP-1 的表达与 MAC387+ 单核细胞来源的巨噬细胞表达水平呈显著正相关 (R= 0.814;P <0.001)，与肝脏炎症的严重程度 (R = 0.813;P <0.001) 及纤维化评分 (R =0.719;P <0.001) 呈正相关。

结论：肝泡型包虫病患者肝脏组织及外周血中 MCP-1 表达水平显著增高，肝组织内 MCP-1 表达水平与单核细胞来源的巨噬细胞浸润情况，肝组织炎症分级及纤维化分期呈正相关。

关键字：肝泡型包虫病，巨噬细胞，MCP-1，MAC387，CD68

ID 3351

Associations of Gut Microbiota and Fatty Metabolism With Immune Thrombocytopenia

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Objective: To determine whether gut microbiota, fatty metabolism and cytokines were associated with immune thrombocytopenia (ITP).

Methods: In total, 29 preliminarily diagnosed ITP patients and 33 healthy volunteers were enrolled. Fecal bacterial were analyzed based on 16S rRNA sequencing. Plasma cytokines and metabolites were analyzed using flow cytometry and liquid chromatography-mass spectrometry (LC-MS), respectively.

Results: Bacteroides, Phascolarctobacterium, and Lactobacillus were enriched at the genus level in ITP patients, while Ruminococcaceae UCG-002, Eubacterium coprostanoligeues, Megamonas, and Lachnospiraceae NC2004 were depleted. At the phylum level, the relative abundance of Proteobacteria and Chloroflexi increased in ITP patients, while Firmicutes, Actinobacteria, and the Firmicutes/Bacteroidetes ratio decreased. Plasma levels of 5-hydroxyeicosatetraenoic acid (5-HETE), 6-trans-12-epi- leukotriene B4 (6t,12e-LTB4), and resolvin D2 (RvD2) were upregulated, and stachydrine, dowicide A, dodecanoylcarnitine were downregulated in ITP patients. Furthermore, RvD2 is positively correlated with order Bacteroidetes VC2. 1 Bac22, 5-HETE is positively correlated with genus Azospirillum, and 6t,12e-LTB4 is positively correlated with genus Cupriavidus. In addition, stachydrine is positively correlated with family Planococcaceae, dowicide A is positively correlated with class MVP- 15, and dodecanoylcarnitine is positively correlated with order WCHB1-41. Plasma levels of interleukin-6 (IL-6) and tumor necrosis factor-y (TNF-y) were upregulated in ITP patients.

Conclusion: Our study revealed a relationship between microbiota and fatty metabolism in ITP. Gut microbiota may participate in the pathogenesis of ITP through affecting cytokine secretion, interfering with fatty metabolism.

Key words: immune thrombocytopenia, gut microbiota, fatty metabolism, 16S rRNA, cytokines

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健康感知评估干预与融合创新
Integrated Innovation of Health Perception Assessment and Intervention

ID 352

Motor Imagery-Related Changes of Brain Function Connection in Unilateral Lower Limb Amputation

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Objective: In our previous study, the functional connectivity of patients with unilateral lower limb amputation was changed in the resting state. Exploring the changes in functional connectivity of unilateral lower limb amputation in the motor imagery state is of great significance for understanding brain plasticity changes.

Methods: Source localization was performed on the motor imagery EEG data of the lower limbs of the healthy group and left amputee patients. After the source signal was obtained, the whole brain was segmented to obtain the source activity signal of each brain region. The time period of interest is defined as 200ms to 400ms, the frequency bands of interest are alpha frequency band (8-13Hz), beta frequency band (14-30Hz), and the PLI of each frequency band of interest is calculated for analysis.

Results: Compared with healthy controls, patients with lower limb amputation showed a significant decrease in the functional connectivity of alpha frequency bands in multiple brain regions of the left parietal lobe and left occipital lobe when performing motor imagery tasks. The alpha-band functional connectivity in multiple brain regions of the right frontal lobe and right occipital lobe was significantly decreased. In the beta frequency band, functional connectivity was significantly reduced in multiple brain regions between the frontal lobes of the bilateral brain, as well as in the left frontal and left parietal lobes.

Conclusion: The effect of unilateral lower extremity on functional connectivity in the state of motor imagery is not limited to sensorimotor areas, but is reflected in a series of changes in multiple brain regions.

Key words: EEG; Source localization; Function connection; Amputee

ID 456

The proposal of New China Climate Changes Prevention Law As a Reference

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Objective: As I have been being a senior doctor treating and preventing patients and promoting the public health more than 35 years. I have the duty and the motive to do something to prevent and cure the climate changes and their impacts on public health. So in this research I especially create and propose a new draft law, the China climate changes prevention law, to speed, administrate and guard China doing well in preventing climate changes in China and the world.

Methods: Summarized the public health promotion and environment protection in China and in author own doing. Referenced the present new situation of climate changes in China and the world. Created the China climate changes prevention law in draft and in central strategies.

Results: The best way to prevent and even cure the climate changes impacts is to build law and regulation as soon as possible. So I have researched and proposed a China climate changes prevention law for the China law makers referencing. The 12 points of central strategies in China climate changes prevention law have been created.

Conclusion: The China climate changes prevention law in draft comes from the candid invention of the author by summarized the present situation of climate changes impacts in China and the world. The 15 paragraphs of the new China climate changes prevention law is valuable, as up to now, China has not built this kind of law. This proposal of the new China climate changes prevention law is worthwhile to referenced by China lawmakers, world countries lawmakers, the UN and its organizations and related others.

Key words: Climate changes; Climate changes impacts; Health promotion; Prevention

ID 664

Effect of Aerobic Exercise Under Blood Flow Restriction on Aerobic Capacity and Muscle Adaptation: A Systematic Review and Meta-analysis

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Objective: : The combination of blood flow restriction and aerobic exercise (BFR-AE) has recently been shown to promote aerobic capacity and muscular adaptation. However, the evidence that BFR-AE promote aerobic capacity and muscular adaptation in healthy individuals is controversial. To evaluate the efficacy of BFR-AE on aerobic capacity and muscle adaptations in healthy individuals and to explore its regulatory factors.

Methods: Seven electronic databases were searched to identify randomized controlled trials comparing BFR-AE to AE. Studies were selected based on inclusion and exclusion criteria. Mean difference (MD) or standardized mean difference (SMD) with a 95% confidence interval (95%CI) was calculated to compare outcome measures among groups and subgroup analyses were performed based on age, training level, exercise intensity, and intervention time. The methodologic quality of selected studies and the quality of evidence were evaluated for included studies.

Results: The meta-analysis included a total of 12 studies with a very low to moderate risk of bias. Summary Results

showed a more significant improvement in BFR-AE compared to AE, including VO2max (MD 2.88 [95%CI 1.44, 4.33], P < 0.001), muscle strength (SMD 1.09 [95% CI 0.47, 1.72], P = 0.0,006), and muscle cross-sectional area (MD3.28 [95% CI 0.96, 5.60], P = 0.006, I = 0%). In subgroup analysis, for VO2max, the Results of groups with no training experience, moderate-to-high exercise intensities and long-term intervention duration were not significant. For muscle strength, Results were not affected by subgroups. For muscle cross-sectional area, the Results were not significant for the older and short-term intervention durations groups.

Conclusion: Data from pooled studies shows that BFR-AE is better for aerobic capacity and muscle adaptations in healthy people than AE. However, this significant positive effect is affected by different regulatory factors. Future studies need to further clarify how each regulatory factor affects outcomes.

Key words: Blood flow restriction, Aerobic exercise, Aerobic capacity, Muscle adaptation.

ID 876

Heart Murmur Detection in Phonocardiogram Signals Using Support Vector Machine

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Objective: : The heart sound signal is an important physiological signal of the cardiovascular system, which contains crucial information about human heart activity, especially cardiac mechanical activity. Cardiac auscultation is also the most routine means of clinical cardiovascular disease risk screening. This paper aims to design an efficient model that can identify murmurs in heart sound signals and classify the signals with murmurs from those without murmurs.

Methods: The first step is signal preprocessing operation, including filtering and normalizing the heart sound signal. Then the hidden semi-markov model was employed to carry out the heart sound segmentation. The time and frequency domain features were extracted and input into the support vector machine (SVM) model for classification processing to realize the classification and recognition of murmurs in heart sounds.

Results: The murmur classification algorithm based on feature extraction was tested on the dataset from the George B. Moody PhysioNet Challenge 2022. The five-fold cross validation method was adopted. This operation also prevents the model from overfitting. The experimental Results exhibited that the sensitivity, specificity, and accuracy were 0.3650, 0.9973, and 0.8738, respectively.

Conclusion: In this study, we classified whether the heart contains a murmur or not based on the heart sound signal. The developed model was relatively simple to implement and conducive to rapid screening. However, in the final result, we noticed that although the performance in terms of accuracy was relatively high, the sensitivity was not very good. This is a limitation of this paper. The existence of noise will lead to the decline of segmentation accuracy. On the other hand, it could be due to data imbalance in the dataset.

Key words: heart sound, heart murmur, signal processing, classification

ID 974

基于深度图像学习的耳穴识别及辅助定位应用

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目的：耳穴疗法是一种特色的中医外治技术，但因为人耳郭形态具有较大的个体差异，导致不同人耳郭穴位的定位和分区也具有较大的差异性，影响了临床穴位使用的精准性和治疗的效果。因此，如何实现不同人耳郭形态下穴位定位，是耳穴疗法普及应用所必须解决的难题。

方法：本研究基于深度图像学习的耳郭分区识别算法，通过对左右耳各 500 张耳郭 32 个生理性特征点和耳穴分区划分的 59 个标志点的标注。在 AAM 基础上，通过归一化和主成分分析构建耳郭形状模型算法和纹理模型算法进行深度学习和训练，获取训练图片的形状和纹理特征。并进一步利用逆和成算法，通过对已有的耳郭形状和纹理模型变化方向进行改变，在最优求解多次迭代后获取一个和目标图像最相符的特征模型，从而更精准的实现对目标图片中耳郭 91 个特征点的搜索识别。并在已获得的耳郭 91 个特征点的基础上，通过增加相邻特征点之间的差值运算，重构耳郭穴位定位与分区的划分。

结果：通过耳穴专业人员对 100 张耳像图片的智能耳穴定位和分区效果检验，识别达到了 92.6% 的符合度。

结论：本研究实现耳像图片的智能化耳穴定位和识别，并在此基础上开发了测试应用程序，获得 2000 多人次的识别应用，是图像技术在智慧中医方面的应用尝试。

关键字：智慧中医；耳穴；穴位识别；耳像；深度学习；

ID 1099

Effectiveness of Acute Active Video Games on Executive Function in Obese College Students

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Objective: : Obesity is negatively associated with executive function (e.g., working memory, inhibition, cognitive flexibility). Physical exercise may improve executive function, although this is without consensus on adults with obesity. The purpose of study was to determine whether an acute AVGs improves executive function in obese college students.

Methods: We conducted a pre-post trial involving 20 male college students with obesity (age: 18.94±0.67yr, height: 168.72±9.05cm, weight: 81.62±7.08kg). Before and immediately after 20-min AVGs intervention, working memory, inhibition and cognitive flexibility were assessed by the Verbal Digit Span test, the Stroop test and the Trail Making Test, respectively. Statistical analyses were performed using SPSS 22.0 (IBM Corporation, Chicago, IL). Pre-posttest were compared using the T test of paired samples. A p-value < 0.05 denoted statistical significance.

Results: Statistical analysis showed that 20-min acute AVGs improved performance significantly in the tests for working memory and cognitive flexibility ($p < 0.05$). However, no significant changes in inhibition score were observed pre-post intervention ($p > 0.05$).

Conclusion: In conclusion, a 20-min acute AVGs interventions may improve working memory and cognitive flexibility in adults with obesity. It is feasible to identify adults with obesity for effective intervention to reduce their level of frailty and cognitive impairment. (Humanities and Social Science Project of Ministry of Education, NO.19YJC890044; Social Science Project of Liaoning Province, NO.L22BTY003).

Key words: Active Video Games; Executive Function; College Students; Obesity

ID 1428

Cardiovascular Autonomic Control Links with Survival in Treated Women with Gastric Cancer

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Objective: Compared with traditional time- and frequency-domain measures, the complexity of heart rate variability (CHRV) is believed able to sensitively capture the tiny changes in cardiac autonomic control even based on short-term electrocardiographic RR interval time-series. Cross-sectional studies suggest associations of CHRV with serum biomarkers for cancer severity in patients with gastric cancer (GC). However, it is unclear whether CHRV independently predicts overall survival in GC patients after treatment.

Methods: A retrospective analysis was performed on 61 GC patients (median age: 66 years; women: 16). Before receiving surgical treatments, all patients underwent ECG measurement in a resting supine position for 5 minutes. CHRV was assessed based on the distribution entropy applied to the 5-min RR interval time-series extracted to the ECG (the theoretical range of the distribution entropy is 0-1 with a greater value meaning higher complexity). Thirty-eight patients (12 women) died during a median follow-up period of 19 months. A Cox proportional hazard model was performed to associate CHRV with time to death, adjusting for age, sex, body mass index, hypertension, and lymph node metastasis. Separately, sex-stratified models with the same covariate (except sex) were performed.

Results: Baseline CHRV followed a normal distribution (0.629±0.096). The association between CHRV and survival was not significant statistically. However, in sex-stratified models, CHRV was associated with survival in women. Specifically, for each half SD decrease in CHRV, the hazard ratio of death is 1.77 (95% CI: 1.08-3.15; P = 0.02). The association in men was not statistically significant (P > 0.05).

Conclusion: Complexity of autonomic regulation is linked with survival in women with GC. The Results suggest that the distribution entropy of short-term HRV has the potential to serve as a non-invasive digital biomarker for GC prognosis, but replications in a larger-scale data set are required.

Key words: complexity; distribution entropy; heart rate variability; overall survival; sex difference

ID 1518

基于五通道心音信号耦合分析的冠心病识别研究

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目的：冠心病的早发现早治疗可有效降低其致死率，冠脉造影的有创有损性限制了其在冠心病筛查中的应用。本文旨在使用多通道心音信号分析构建一种能够有效识别冠心病的无损筛查方案。

方法：同步采集了 36 例受试者的五通道心音信号，冠心病组 21 例，健康组 15 例。将心音信号分割为第一心音、收缩间期、第二心音和舒张间期段，提取各心音段不同通道组合下的三类耦合特征：非熵特征 (NEF)、熵特征 (XEF) 和多变量熵特征 (MEF)。对特征进行统计分析，使用互信息 (MI)、递归特征消除 (RFE) 和随机森林 (RF) 进行特征选择，利用支持向量机实现冠心病的识别。

结果：统计分析结果表明，三类特征中具有统计差异性特征的占比均高于 60%。使用单类特征分析时，XEF、NEF、MEF 分别在 MI、RF 和 RFE 特征选择下模型分类准确率最高，分别为 0.928，0.806，0.743。联合三类耦合特征后，三种特征选择下模型的准确率均得到提升，其中 MI 下模型分类准确率达到最高，为 0.946。

结论：本研究表明，五通道心音信号单类耦合特征中 XEF 识别冠心病的性能最好，联合三类耦合特征可有效提升识别冠心病的准确性。证实了五通道心音信号耦合分析可实现冠心病的无损识别。

关键字：冠心病；五通道心音信号；耦合分析；熵

ID 1541

可穿戴设备获取皮电信号应用于多类型心理压力状态识别的可行性研究

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目的：长期压力会影响生活质量，甚至导致抑郁症等严重心理疾病，因此日常压力监测尤为重要。而问卷调查依赖于前一段时间的主观感觉，不具有实时性。可穿戴设备获取的皮电信号与心理压力相关且不受自主意识控制，为心理压力状态实时监测提供了可能。

方法：本研究使用可穿戴硅胶指环获取了 28 名健康受试者静息状态 (O) 和混合运算 (A)、连续减法 (B)、stroop 颜色测试 (C)、数字识记 (D) 四种压力状态的皮电信号，预处理后提取一般时域特征 (t)、上升下降时间特征 (r)、频域特征 (f)、非线性特征 (n)，分析特征统计差异性，使用递归特征消除法进行特征选择，使用支持向量机进行分类。

结果：单域特征分析时，t、r、f 和 n 分别适用于区分 O 与 D、A、A、C；区分 O 与 B、C、D 时，t 表现最好，区分 O 与 A 时，f 表现最好。联合多域特征来区分静息与压力状态 A、B、C、D 时，准确率分别为 0.945、0.982、0.929、0.929。

结论：研究结果表明，区分静息与压力状态时一般时域特征表现更好。相较单域特征分析，联合多域特征区分静息与压力状态的效果更好。其中，连续减法导致的压力状态更容易被识别。本研究证实了可穿戴皮电信号在心理压力状态识别领域的可行性。

关键字：可穿戴设备；多压力状态；多域特征；皮电信号

ID 1703

Application of the SEBT in Evaluating the Effect of Suspension Training on the Balance Ability of Surfers

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Objective: Surfing is an new Olympic sport, and surfers should have excellent balance ability, and suspension training can well enhance balance and stability in an unstable training condition. Therefore, suspension training was introduced into the balance ability training of surfing, and the effect of suspension training on the dynamic balance ability of surfers was evaluated by using the Star Excursion Balance Test (SEBT).

Methods: 32 surfers from the National Surfing Team were randomly divided into a suspension training group and a traditional training group, and the two groups were subjected to intervention training for 8 weeks, 3 times a week, about 30 minutes each time. The SEBT test was administered before and after the 8-week experiment to examine changes in the surfers' dynamic balance and stability.

Results: Results Both the suspension training and traditional balance training for 8 weeks can significantly improve the dynamic balance of the surfers ($p<0.01$). By comparing the distance of leg extension in 8 directions between the two groups, it can be concluded that TRX suspension training can significantly improve surfers' proprioceptive ability, neurological control ability and resistance to external interference under unstable conditions compared with the traditional balance training ($P<0.01$), which has incomparable advantages of the traditional balance training.

Conclusion: The 8-point star excursion balance test can more comprehensively reflect the body's ability to control the neuromuscular and maintain the stability of balance.(This study was supported by the East Lake Scholars Sponsorship Program of Wuhan Sports University in China, Science and Technology Team Foundation of Wuhan Sports University under Grant (21KT02); the 14th Five-Year-Plan Advantageous and Characteristic Disciplines (Groups) of Colleges and Universities in Hubei Province under Grant (2021-05))

Key words: surfing; TRX suspension training; dynamic equilibrium; Star Excursion Balance Test; intervention training

ID 1805

一种基于信息灰度共生矩阵评估心理压力的新方法

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目的：持续处于压力状态下会导致抑郁症，心血管疾病等心理或生理问题。本研究旨在提出一种基于信息灰度共生矩阵方法构建的脉率变异性分析模型，以探究心理压力状态下自主神经波动模式的复杂性。

方法：首先采用斯特鲁普色词测验作为心理压力诱导范式，采集了 35 名健康在校大学生的脉搏波信号。接着，从脉搏波信号中构建心动周期序列。然后，对心动周期序列构建出基于信息的灰度共生矩阵，并提取了 4 个纹理特征：对比度、相关性、能量和同质性。为了对比，又从心动周期序列中提取了 69 个多域经典特征。接着采用统计分析和斯皮尔曼相关性分析探究了每个特征的统计差异性和相关性。使用递归特征消除完成特征选择后，将纹理特征与经典特征的不同组合送入支持向量机，以识别被试是否处于压力状态。

结果：与其他纹理特征相比，能量不仅具有统计差异性，而且与心理状态的改变相关。特征选择结果表明，能量特征总是被选入最优特征集。经过特征选择后，单独纹理特征、单独经典特征以及经典和纹理特征组合的最高分类准确率分别为 88.57%、88.57% 和 98.57%。

结论：本研究所提新方法可以有效提高基于脉率变异性和心率变异性的心理压力实时检测的准确率，并为探究其生理病理学机制提供启示。

关键字：心理压力；脉率变异性；斯特鲁普色词测验；灰度共生矩阵；纹理特征

ID 1932

Dual-Layer Spectral CT-Based Machine learning models for Preoperative Prediction of Postoperative Lymph Node Metastasis in Non-small cell lung cancer

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Objective: Lymph node metastasis (LNM) is a key factor affecting the treatment of non-small cell lung cancer (NSCLC). Dual-layer spectral computed tomography (DLSCT) quantitative parameters have shown good performance in diagnosing LNM status in a variety of cancers. The aim of this study was to construct and validate machine learning models based on quantitative DLSCT parameters for preoperative prediction of LNM status in NSCLC patients.

Methods: DLSCT images of 91 patients with pathologically confirmed NSCLC were retrospectively analyzed at Jiangsu Cancer Hospital from September 2021 to November 2022. Thirteen DLSCT quantitative parameters were extracted from each region of interest (ROI). Recursive feature elimination (RFE) was used to select 7 features from 13 DLSCT parameters and for the construction of 6 machine learning predictive models, including Adaptive Boosting (AdaBoost), Gaussian Naive Bayes (GNB), Logistic Regression (LR), Random Forest (RF), Support Vector Machines (SVM), and Extreme Gradient Boosting (XGB). Evaluation metrics of predictive models included the area under the receiver operating characteristic curve (AUC), accuracy, precision, recall, and F1-score.

Results: AdaBoost had the best predictive performance (AUC = 0.900) and its AUC was statistically different from the other five models ($P < 0.05$, Delong test). The 5-fold cross-validation showed that AdaBoost has excellent stability. The specific performance indicators of AdaBoost were AUC (0.890, 95% CI: 0.809 - 0.971), accuracy (0.801, 95% CI: 0.724 - 0.878), precision (0.814, 95% CI: 0.733 - 0.895), recall (0.801, 95% CI: 0.724 - 0.878), and F1-score (0.800, 95% CI: 0.726 - 0.874).

Conclusion: The AdaBoost model characterized by DLSCT quantitative parameters showed superior performance in the preoperative prediction of LNM status in NSCLC patients. Of course, this study needs to be validated in an external cohort.

Key words: Non-small cell lung cancer; Lymph node metastasis; Machine learning; Dual-layer spectral CT

ID 1963

竞技跆拳道运动员下劈动作优势侧和非优势侧的生物力学参数差异性研究

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目的：探索跆拳道下劈技术动作下运动员肢双侧腿的生物力学特征差异性。

方法：采用 Vicon 系统、Kistler 测力台，采集 13 名优秀跆拳道运动员下劈动作时双侧腿的运动学和动力学数据，采用配对样本 T 检验的方法进行差异性分析。

结果：（1）进攻腿：弹腿时刻，矢状面脚横向速度、踝关节旋内力矩峰值优势侧大于非优势侧（$P < 0.05$）；下劈时刻，矢状面脚横向和垂直速度峰值优势侧大于非优势侧（$P < 0.05$），髋关节旋内加速度峰值优势侧大于非优势侧（P

< 0.01）。（2）支撑腿：弹腿时刻，矢状面脚横向速度、踝关节外翻力矩、踝关节旋外力矩峰值优势侧大于非优势侧（P < 0.01），踝关节跖屈力矩峰值非优势侧大于优势侧（P < 0.05）；下劈时刻，矢状面脚横向速度、踝关节外翻力矩、踝关节旋外力矩峰值优势侧大于非优势侧（P < 0.01），踝关节跖屈力矩峰值非优势侧大于优势侧（P < 0.05），踝关节旋外最大角度非优势侧大于优势侧（P < 0.01）。

结论：优势侧进攻腿髋关节有较好的运动表现，为了减少非对称性应补充非优势侧训练。

关键字：跆拳道；下劈；运动学；动力学；差异性

ID 2006

优秀个体的主动健康特征

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目的：每日能量消耗分为食物热效应、基础代谢和主动活动，前两类是动物界共有，从分子、细胞到器官各司其职；最后一类将前两类功能整合起来，其整合程度将不同级别的人类与动物分别区别开来。各种生物参数满足对数正态分布。本文根据心理物理学的韦伯 - 费希纳定律（WFL）研究主动活动的整合特征。

方法：1. 用各种参数的几何均值表征个体整合特征。2. 成长环境下地方汉语人名或关键词用拼音音节首字母数字化：将英文 26 个字母从 A 到 Z 按照顺序分别赋予数字 1 到 26，按照每个字拼音的首字母排成数。3. 卦象数字化：将阳爻和阴爻赋予数字 2 和 1，按照 64 卦的卦象排成数。4. 对数相关性：两个数对数正反两个比值中数字“7”的个数越多，相关性越大。

结果：结果：1. 阳明心学“心即理”对应于 WFL。2. 习惯性活动中，三类能量消耗在总能量消耗中的占比的几何均值守恒。优秀个体的高主动活动水平和低基础代谢具有“色即是空，空即是色”的特征。3. 优秀个体的社会关系是人人平等、活动平等和活在当下。4. 优秀个体才能体现出对数相关性：在朋友圈中存在相关性最大的朋友；在活动圈中存在相关性最大的主动活动。

结论：个体越优秀，越接近“心即理”。

关键字：每日能量消耗；韦伯 - 费希纳定律；几何均值；对数；阳明心学

ID 2077

经颅交流电刺激的谐波效应在非线性负载传递中的机制及其对干预大脑的影响

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目的：探索经颅交流电刺激 (tACS) 谐波非线性负载传递机制和对大脑调控的影响。

方法：实验 1，20Hz tACS 作用于非线性负载（大脑、手臂、猪肉、体模）和线性负载（假头、盐水），每次刺激 10 秒休息 15 秒，共重复 30 次并同步记录刺激区域电活动信号，为验证结果可重复性还分析了 tACS 同步脑电公开数据集。

实验 2，22 名健康大学生在两轮实验中完成 15 分钟 20Hz tACS(阳极：AF3，阴极：对侧肩膀；2mA) 和假刺激，在

刺激前后分别采集 5 分钟睁眼静息态脑电。

结果： 实验 1，刺激大脑期间采集的 20Hz 和其谐波脑电功率显著高于非谐波 (F=47.6,p<0.01)，在数据集中复现了该结果，且谐波只出现在非线性负载中，在线性负载上未观察到。

实验 2，相对假刺激，在刺激后效应中，刺激组在枕叶电极复现了 20Hz 夹带效应并在二次谐波上脑电功率也显著增强 (所有 p<0.05)，两者显著相关 (r=0.5，p=0.03)；此外谐波还显著改善了枕叶电极间功能连通性 (所有 p<0.05)。

结论： tACS 谐波只产生在非线性负载上，以增强振荡活动和改变功能连通性的方式影响大脑活动 , 不仅提示了其谐波对脑功能调控的潜在影响并为脑健康的干预提供了新的理解。

关键字： 经颅交流电刺激，谐波，脑电

ID 2171

基于高性能可穿戴柔性传感微系统的肺藏呼吸功能态势监测和肺气虚未病测评

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目的： 柔性传感微系统是新一代战略性和前瞻性柔性信息器件的组成单元之一，已经成为未来智能设备发展的重要研究方向。据 WHO 报告全球亚健康超过 60 亿，占 85%。中国亚健康达到 70%。Lancet 报道肺呼吸类相关未病占比大。《中藏经》：肺者，生气之源。肺气虚证是以肺的功能减退为主的全身性病变 , 肺气虚已成为老年人发病和死亡重要原因。根据肺气虚证的诊断标准主证的诊断是可以用呼吸运动来量化评测。

方法： 基于高性能高穿戴柔性传感微系统，利用利用液态金属和生物相容柔性基底，通过有限元分析和优化，设计了一种波浪形的微通道结构，该结构有效减小了柔性基底的应力松弛现象，降低由材料变形而引起的传感信号迟滞性。利用 SU-8 光刻胶加工出波浪形微结构，倒模相应的图案化结构，制备微流体应变传感器的制备。

结果： 能够监测高达 320% 拉伸应变。迟滞性由笔直微通道的 6.79% 降低低至 1.02%，降低 85%，信号灵敏度，准确度极大提升，灵敏度 GF 达到了 4.91，能够感知低至 0.5% 的相对应变变化。

结论： 该系统能够实时对呼吸运动数据监测并分析，实现肺藏呼吸功能态势监测，为中医生提供肺气虚未病测评客观数据，提高医生对疾病的把控能力和患者健康的主动管理能力。

关键字： 柔性传感；MEMS；运动监测；肺藏功能态势；中医未病测评

ID 2201

隐含于九宫八风图式中的黄金分割相关数学规律

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目的： 对于中医九宫八风理论的起源、发展和应用研究进行分析具有重大的理论价值和意义

方法： 本报告结合黄金矩形和黄金螺旋结构及其所隐含基本比例基础上给出了一个新的图示结构——黄金九宫弦图，该图不仅在数学上直接包含黄金矩形、黄金螺旋、九宫以及弦图的基本结构，同时与考古中发现的新石器文物中广泛存在的八角星形标志密切关联。

结果：黄金九宫弦图的发现，严格确立了生物数学、古天文和数学乃至新石器时代文化与中医基础理论研究之间的新的连接，对于从数学角度揭示九宫八风理论的起源和发展并挖掘其科学内涵，破译中国古文化和中医奥秘具有重要的理论意义和实践价值。

结论：因此，本报告所提出的黄金九宫弦图对于生物数学、中医学、古代天文学和数学乃至新石器时代文化研究都具有较为重要的参考价值，对于中医九宫八风理论的起源、发展和应用研究具有重大的理论价值和意义，在未来研究中对其中所隐含的其它几何结构和数学规律值得进行深入研究和探索。

关键字：黄金九宫弦图 黄金矩形 弦图 九宫八风

ID 2339

基于智能手表的寒热体质研究

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目的：探索中医寒热体质与可穿戴设备测得的脉搏波特征（24 小时平均心率）联系和对应关系。构建基于脉搏波的寒热体质判断标准。

方法：采取方便抽样的方式，收集疾病和体质资料，再根据体质特征对人群进行分组分析，根据智能手表测得脉搏波和体动数据，找出基于脉搏波的不同数值，最终构建基于脉搏波的不同年龄的寒热体质判断标准。

结果：通过分析运用 PPG+G-sensor 技术，100Hz 高频率采集人体数据的智能手表数据，能够有效的对寒热体质进行区分，为体质健康管理提供有效的参考数据。

结论：①在中医理论指导下，将中医理论与客观测评相结合，为具有中医诊疗特点的肾藏气化功能客观测评研究提供新思路与新方法，为中医临床调理、干预肾藏气化功能异常状态提供理论参考。

②本研究给寒热体质辨识出了客观量化的诊断参数，为客观测评中医寒热体质的新思路与新方法，属国内首创。

③本研究设计完成的寒热体质辨识方法，对寒热体质分型进行了详细的研究和分析，为寒热体质辨识进一步提升了辨识精度。

关键字：寒热体质；智能手表；心率检测

ID 2371

Prediction Models for Lymph Node Metastasis in Cervical Cancer Based on Preoperative Heart Rate Variability Analysis

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Objective: Lymph node metastasis (LNM) status is one of the key factors in determining the stage, treatment and prognosis of cervical cancer (CC). Heart rate variability (HRV) has been shown to be a noninvasive predictor of LNM in patients with CC. The aim of this study was to validate the feasibility of machine learning (ML) models constructed with preoperative HRV as a feature to predict CC LNM.

Methods: A retrospective analysis was conducted on 236 patients who were confirmed pathologically as CC. Six ML pre-

diction models were constructed by using recursive feature elimination (RFE) to filter 19 features from 38 HRV indices, namely Adaptive Boosting (AdaBoost), Gaussian Naive Bayes (GNB), Logistic Regression (LR), Random Forest (RF), Support Vector Machines (SVM), and Extreme Gradient Boosting (XGBoost). Model performance was evaluated using area under receiver operating characteristic curve (AUC), accuracy, precision, recall, and F1-score metrics.

Results: The RF and XGBoost models showed better predictive performance (AUC 0.877 vs. 0.870; *P* = 0.240), with tenfold cross-validation indicating the best overall performance of the RF model, as evidenced by AUC (0.899, 95% CI: 0.804 - 0.994), accuracy (0.823, 95% CI: 0.724 - 0.922), precision (0.834, 95% CI: 0.732 - 0.936), recall (0.822, 95% CI: 0.723 - 0.921), and F1-score (0.820, 95% CI: 0.721 - 0.919).

Conclusion: The RF model built by using preoperative HRV as a feature showed superior performance in CC LNM prediction. However, the prediction model presented in this study needs to be further validated by multicenter studies with larger data sets.

Key words: cervical cancer; lymph node metastasis; heart rate variability; machine learning

ID 2394

基于光谱 CT 参数的机器学习鉴别孤立性肺结节良恶性

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目的：本研究的目的是评估基于光谱 CT 定量参数的机器学习模型鉴别 SPN 良恶性的效能。

方法：回顾性分析 220 例 SPN 患者的术前光谱 CT 增强图像，勾画病灶并提取 15 个定量参数。将极端梯度提升（XGB）算法特征重要性的前 8 个特征建立六种机器学习模型。模型评估指标包括受试者操作特征曲线下面积（AUC）、准确率、精确率、召回率和 F1-score。

结果：特征重要性前 8 的参数是 NED、NZ、SAR_{70Kev}、△ 70Kev、△ SA70Kev、NIC、△ 40Kev 和 SAR_{40Kev}。六种机器学习模型中，随机森林模型的预测性能最好（AUC=0.871）。10 倍交叉验证后的具体指标为 AUC（0.900,95%CI:0.846-0.954），准确率（0.865,95%CI:0.825-0.905），精确率（0.857,95%CI:0.800-0.914），召回率（0.858,95%CI:0.802-0.914）和 F1-score（0.858,95%CI:0.805-0.911）。

结论：基于光谱 CT 参数的机器学习模型能有效地预测 SPN 的良恶性。

关键字：孤立性肺结节；鉴别；光谱 CT；机器学习

ID 2412

用于骨质疏松症治疗的可穿戴静磁腰带的研制与临床研究

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目的：我国骨质疏松症发病人口接近 1 亿人。本团队前期发现静磁场曝露能够调节骨重建，抑制骨质流失。本研究旨在研制一种用于骨质疏松治疗的可穿戴静磁腰带，并评估其对绝经后骨质疏松症的影响。

方法：利用电磁仿真设计，然后加工可实现腰椎部位静磁场曝露的腰带；基于物联网技术设计制作可与腰带集成的穿戴信息监测系统。临床试验通过中国临床试验注册中心注册审核和伦理审查后招募 55-70 岁绝经后妇女，根据纳入排除标准遴选，并随机分为三组：无磁可穿戴器械治疗组 (对照组)、静磁可穿戴器械治疗组 (试验组) 及脉冲电磁场治疗组 (阳性对照组)，各组均接受抗骨质疏松药物常规治疗。每天佩戴磁腰带 6 小时，连续治疗 90 天后评估治疗效果。

结果：研制的可穿戴静磁腰带可以实现受试者腰椎部位的磁场曝露并有较高的依从性；信息监测系统可以有效监测受试者静磁腰带佩戴时长和时间分布等信息。对招募的 145 名受试者筛选入组、干预和数据分析，初步研究结果显示：可穿戴静磁腰带干预增加了受试者的腰椎和髋部骨密度，改善了受试者骨代谢水平，缓解了受试者腰背部疼痛。

结论：研制的可穿戴静磁腰带对绝经后妇女腰椎及相关部位的骨质疏松具有治疗作用，为骨质疏松症提供了一种新的临床治疗方案。

关键字：可穿戴静磁腰带；骨质疏松症；临床研究

ID 2567

中医舌诊图像信息处理与分析的研究现况及思考

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目的：中医舌诊图像采集处理与信息分析是当前中医舌诊现代化与客观化研究的重点，探索近十年中医舌诊仪研究进展。

方法：通过检索 94 篇近十年中医舌诊仪研究相关文献，分析并总结了目前中医舌诊仪采用的硬件技术、图像信息处理方法与分析方法。

结果：优化舌诊仪的硬件结构，采用计算机算法对舌象进行预处理，利用色彩空间转换、光谱法和深度学习算法研究舌象等数字图像分析技术已成为当今中医舌诊仪的研究热点。

结论：目前中医舌诊仪存在便携化与智能化程度低、客观化研究尚未形成统一标准、中医药临床结合困难等问题。针对以上问题，提出使用超声波测距传感器与微型摄像头减小舌诊仪体积、建立中医药大数据库、培养医工交叉人才等解决方案，以探索中医舌诊仪走向客观化面临的机遇与挑战。

关键字：舌象采集；舌象信息处理；舌象数据分析；舌诊仪

ID 2577

基于 Unet 舌像分割的参数优化

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目的：针对 U-Net 网络结构在舌像分割中的应用优化，本文将基于前期研究结果，对自然光线下采集的舌像数据，通过 U-Net 网络进行训练实现舌像分割，从而探索 U-Net 网络应用于舌像分割时的最优卷积层数，实现舌像分割精度和计算成本的优化，为轻型卷积神经网络在智能终端的普及应用做出有益的尝试。

方法：基于此，本文提出基于浅层 U-Net 卷积神经网络的舌像分割实验方法。具体包括采集并建立舌像数据集、设置不同深度的卷积神经网络进行训练、筛选最优网络参数模型、测试和评价最优模型的分割图像结果。

本文的主要内容如下：

1. 舌像采集和数据集建立：通过附属医院门诊收集到共 406 组舌图像，构建训练集、验证集、测试集，比例划分为 6：2：2。运用 Labelme 手动标注后对舌像分割模型进行训练和测试。

2. 参数调整

结果：实验通过调整学习率、batch size 等参数，得到一个较为理想的实验结果，最后模型的平均交并比为 94.79%、类别平均像素准确率为 97.39%、精确率为 97.20%，召回率为 97.39%。

结论：本文选择的适用于小样本训练的 U-Net 网络结构，不但能有效规避网络模型大、参数多、过拟合等问题，同时也能达到一定的精度。

关键字：舌诊；深度学习；舌像分割；U-Net 卷积神经网络

ID 2579

基于非线性拓扑数据分析的心率失常分类

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目的：心电传感信号可视为人体心脏非线性系统的观测，基于心电传感信号提取有效表征信息能够实现心率失常的分类。

方法：本文采用非线性拓扑数据分析的方法提取拓扑特征进行心率失常的分类。该文首先采用延迟嵌入方法将心电时间序列映射到相空间形成点云，其中延迟参数 τ =5，嵌入维度为 d=2；其次，基于计算拓扑中的持续同调工具，

提取心电点云中的拓扑印记；接着，采用拓扑描述的持久性态势图，构建心电传感信号的拓扑特征；最后基于不同大小训练集进行心律失常分类。

结果：在仅使用 20% 数据量的模型上进行测试，其中正常心率的识别率为 100%，对室性异位搏动的识别率成为 97.13%，室上性异位搏动心率的准确率为 94.27%，融合心率识别率为 94.27%。

结论：从心率失常的分类结果能够看出，拓扑数据分析方法是一种有效的心律失常分类方法，为基于心电信号和其它生理信号的研究提供一种新思路。

关键字：心率分类、拓扑数据分析、非线性系统、持久性态势图

ID 2603

基于深度自动编码器和谱聚类的心电信号分类

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目的：心电图 (Electrocardiogram, ECG) 是用于诊断心血管疾病的重要手段之一。通过心电图观察心电信号是否异常，能够对心血管疾病提前预防或诊断。

在临床检查中，心电图的数量繁多，医护人员的诊察具有主观性以及心律失常的形态较复杂，传统的人工识图方式，效率较低，而且存在着误诊漏诊的情况。为了提高 ECG 的诊断效率，本文提出基于深度自编码器和谱聚类的 ECG 信号无监督分类方法对 ECG 数据进行自主聚类，进而将 ECG 片段分为不同的类别，方便医师诊断。

方法：主要内容包括：使用 Z-score 方法对心电信号做标准化处理，设计自动编解码器对数据进行降维特征提取，使用谱聚类的方法对降维数据进行分类，最后在已有的实验数据上对该模型进行了验证。

结果：实验结果表明该模型能够达到预期的目的，提高了心电图的诊断效率。

结论：本文对某医院 3000 位病人的临床 ECG 数据进行聚类，经过聚类后的 ECG 数据片段再通过医生临床分辨，剔除干扰信号，发现异常信号，实现临床医学诊断的目的。相比以往临床医生对长时间 ECG 信号的辨别与分析，本文提出的方法大大降低临床医生的诊断时间，提高了医疗诊断效率。

关键字：深度自动编码器；谱聚类；心电信号；特征提取；无监督分类

ID 2693

Future Health and Medicine from Theory to Practice

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Objective: To investigate safety and effectiveness of HIPM-CPET guided PPE-HPM to evaluate human functional capacity continuously in MCCVM-NICDs patients, public healthy subjects, athletics and astronauts.

Methods: Since 2014, we managed total 186 severe MCCVM-NICDs patients with more than a decade history of multi-hyper in BP, HR, glucose, fat acid, urine acid and body mass etc and/or with diagnosis of stroke, CHF, CAD, cardiac ischemia, arrhythmia, rheumatic heart valvular disease with stenosis and regurgitation, hypertrophy and dilated cardiomyopathy, myocardial insufficiency, T-II-DM, COPD, sleep apnea, PAH and chronic heart failure etc.

Results: All patients and subjects were safe without any risk and dangerous event during CPET and intensive PPE-HPM. Compared to normal range of 80-120%pred, at baseline, all severe MCCVM-NICDs patients had significantly limited Peak

O2（67.66±14.05%Pred), multi abnormal and unstable parameters of BP, HR, glucose, fat acid, urine acid and body mass etc., breathing, sleep, and memory loss etc even treated by traditional medical care over decade.

Conclusion: In MCCVM-NICDs patients, HIPM-CPET guided PPE-HPM can safely and effectively increase the functional capacity, reverse the abnormal parameters back to the normal level. For the more widely public servicing, HIPM-CPET guided PPE-HPM-HEM can do similar thing in healthy subjects and many special kinds of professionals.

Key words: Holistic Integrative Physiology and Medicine; CardioPulmonary Exercise Testing; Gas Exchange; physiology;

ID 2737

可视化智能手持式舌诊仪的研制思路与方法

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目的：为了实现中医舌诊的客观化与标准化，基于超声波测距技术与图像处理技术设计了一套可视化智能手持式舌诊仪。

方法：以微型摄像头、收发一体式超声波测距传感器、LED 冷光源为主体，采用单片机控制技术构建舌象采集模块。使用小波降噪算法、交互式图像分割、反光点检测模型和 CDD 图像修复方法对舌象进行预处理，基于 OpenCV 实现 RGB 色彩空间数值的提取并根据相应数值进行舌色分类以完成舌象分析。

结果：通过使用收发一体式超声波测距传感器控制舌象拍摄间距、LED 冷光源控制舌象拍摄环境以及舌象处理分析技术，实现了标准化舌象采集、舌象预处理、舌体分割、舌色分析等功能，能够准确进行舌色分类。

结论：通过创新性地提出舌体分割与唾液反光处理解决方案，提升了舌象预处理效果，进一步提高了舌象分析的准确性。本设计可有效避免医生因环境因素、主观因素误判舌象。

关键字：手持式舌诊仪；舌象采集；舌象处理；舌象分析

ID 2750

基于 CiteSpace 的国际电针研究现况与前沿分析

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目的：通过对有关电针的文献进行可视化计量学分析，探索该领域近 11 年的发展状况、研究热点及动态前沿。

方法：以 WOS 中 SCI-E 收录的 2012 年至 2022 年相关论著为研究对象，应用 CiteSpace 进行共现分析和共被引分析，以及对关键词聚类分析和突现检测，探索国际电针领域的研究热点和趋势，并绘制相关可视化图谱。

结果：共纳入 1233 篇文献，年累计发文量增长方程为 y=113.24x-76.418（R2=0.99）。中国、美国和韩国为发文量排名前三的国家，中国中医科学院为发文量最大的机构。高产作者主要为中国人，尚未形成稳定的核心作者群，提示作者间应注重合作交流。研究热点关键词主要为小鼠模型、刺激、机制、激活、疼痛和大脑，可形成 10 个聚类群。通过关键词突现分析得出，随机对照试验、氧化应激和肠道菌群这三个关键词从 2020 年开始突现且持续至今。其中，随

机对照试验的突现强度最大，说明随机对照试验为近几年应用最多的研究方法且影响最大，为近期该领域的研究前沿与热点。

结论：应用 CiteSpace 进行国际电针文献计量可视化分析，直观地展示了该领域的研究热点与发展方向。

关键字：电针；科学计量学；可视化分析；Web of Science；CiteSpace

ID 2772

数据挖掘技术在中西药治疗慢性荨麻疹疗效预测评估中的应用

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目的：由于慢性荨麻疹病情周期长且病因复杂，一直以来没有特别有效的治疗方案。将数据挖掘技术应用于中西药治疗慢性荨麻疹的疗效预测中，可帮助医师制定最佳治疗方案。

方法：基于上海市中医医院皮肤科门诊数据，选取 30 例服用健脾养血方治疗（中药组）和 29 例服用盐酸西替利嗪片治疗（西药组）的气血不足型慢性荨麻疹患者为研究对象，选择患者接受治疗前的 5 项指标数据和完成 8 周随访治疗后所取得的疗效进行数据挖掘分析。

结果：使用随机树算法，中、西药组各得到了 5 条关于患者治疗前身体指标与所取得疗效之间的规则，总体准确率均高于 70%；利用支持向量机算法得出各组数据中的支持向量，构建起准确率均高于 80% 的疗效预测模型；完成人工神经网络对支持向量的深层分析，透析出患者治疗前 5 项指标与两组药物治疗所得疗效之间的隐性关联，并分析出了两种药物治疗各自取得最佳疗效时的患者在接受治疗前的身体特征。

结论：通过对慢性荨麻疹患者在两组药物治疗的疗效分析，建立了疗效预测模型，这将有助于辅助临床医师制定最佳的治疗方案。

关键字：慢性荨麻疹；疗效预测；数据挖掘；中西药治疗

ID 3119

基于机器学习的多分类症状实体识别方法

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目的：电子病历作为临床诊疗过程和结果的重要载体，包含了临床表现、诊断、干预、评估等内容，蕴含着丰富的医生临床诊疗知识以及患者健康信息。但对于其中症状信息的自动识别仍是一个难点，特别是在中医电子病历中。症状描述不仅形式多样，且在识别症状实体及关系时存在交叠现象，利用人工智能技术难以实现自动分类，给智能中医诊疗带来了较大困难。为了解决这一难题，本文提出了一种基于机器学习技术的多分类症状实体识别方法，对症状实体进行多级分类，提高机器识别症状的准确率。

方法：首先建立症状实体分类及关系分类模型，然后通过模型选择找出最优的症状实体识别模型和关系抽取模

型，最后进行实例研究以验证方法的有效性。

结果：最终建立了症状实体的多分类模型和实体关系模型，并遴选出了 BERT-BiLSTM-CRF 和 BiGRU-Attention 模型分别作为症状实体识别和关系抽取模型，选择某中医院 300 条肝硬化电子病历进行实例研究，症状实体识别的平均 F1 值为 97.63%，关系抽取的 Accuracy 值为 85.83%，并构建了肝硬化知识图谱。

结论：利用本方法可对电子病历中的症状实体进行有效识别，有助于临床研究人员开展后续挖掘工作，提升中医智能化水平。

关键字：电子病历；症状；实体识别；关系抽取

ID 3207

新冠大流行后民众健康意识与行为重塑——健康的态度和行为引领的趋势预测

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目的：新冠大流行对与全球民众的生活影响是巨大的，以中国为例，为期三年的严格管控和政策调整，对民众的健康意识和行为已经产生巨大的影响，本文通过问卷调查对因新冠肺炎大流行而导致的民众健康意识变化和行为改变进行分析与评估，并以此预测未来民众的短期及长期的健康需求。

方法：随机抽样中国城市人口 1230 人，自行设计问卷进行线上问卷调查。

结果：本文通过分析 1201 人的调查数据显示，超过 70% 的中国城市人群认为他们对健康的重视程度超过了新冠大流行之前，90% 以上的人群报告在新冠大流行期间，他们的医学知识更加丰富了；所有研究样本均报告在此期间他们养成了一些对于健康有促进作用的习惯。

结论：新冠大流行不仅改变了民众的健康感知和健康定义，还改变了其行为方式和医学信息获取习惯等内容，本文基于对调查结果的分析，对未来民众健康需求变化和行为习惯可能引领的健康领域创新趋势，做了初步预测。

关键字：健康意识 健康促进行为 健康态度 创新趋势

ID 3232

皮穿支点与穴位点的对应性的初步研究

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目的：初步确定皮穿支穿出点与经典穴位之间的对应关系

方法：1、选取年龄 20-60 岁之间，体型中等的志愿者。在全身穴位中，在四肢选取 10 个常用穴位（孔最、阳陵泉等）。

2、由一名显微外科医生用多普勒超声仪在十个穴位区域确定皮穿支的位置，并使用荧光笔做好标记，并以纵轴和横轴做十字标记。荧光笔记号不可见。

3、由五名主治医师及以上资质的中医针灸医生依次取穴，确定进针点后，用荧光笔做好标记。

4、打开荧光灯，每一个穴位区域共有一个十字，及五个点。测量五个点所在的区域以及与十字中心点的距离。

并用白纸拓印，留作资料。

5、临床统计。

结果：五个中医师取的穴位点，围绕皮穿支点分布。两个所取穴位点最大间距为 5 厘米。

结论：皮穿支与穴位对应关系密切。

关键字：皮穿支、穴位

ID 3377

“粒脑”可能是线粒体通过穴位和经络方式存在并负责氧气需求记忆的“第三大脑”

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目的：对穴位和经络的物质基础进行分析，旨在为健康感知和干预提供参考依据。

方法：通过理论分析，提出科学假说，探讨线粒体与穴位和经络之间的可能关系。

结果：从生命起源与进化角度出发，结合“人”是由人体与共生微生物尤其是肠道菌群联合组成“超级共生体”的新认识，在此前发现“饥饿源于菌群”进而提出由肠道和肠道菌群联合构成人体对以碳源为基础的食物记忆的“第二大脑”即“菌脑”基础上，结合线粒体通过对碳源进行氧化磷酸化为人体提供能量、而线粒体则是由 α - 变形菌在大约 24 亿年前进化而来，提出线粒体可能是人体对于氧气需求记忆的物质基础，从而形成由人体细胞内所有线粒体构成的集群系统可能是人体负责“氧记忆”的“第三大脑”（简称为“粒脑”），指出可将“粒脑”视为以线粒体为氧记忆的“类神经元”、穴位类似于氧记忆的“类神经节”、经络则类似于氧记忆的“类神经纤维”，从而为人体的氧需求从“粒脑”的角度提供新解释，有望为以穴位和经络为调控靶点的健康感知与干预提供新思路。

结论：线粒体可能通过穴位和经络方式存在，以“第三大脑”即“粒脑”负责氧气需求记忆，推动人体能量代谢和气血运行。

关键字：线粒体；穴位；经络；氧脑；第三大脑

ID 3382

Cardiopulmonary Exercise Testing (Cpet) to Evaluate the Safety and Efficacy of Intensive Personalized Precise Exercise (ppe) Training with Holistic Protocol Management (HPM) in Severe Patients with Multi Cardiovascular, Cerebrovascular and Metabolic Chronic Diseases (Mccvmcds)

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Objective: To study the symptom-restricted extreme cardiopulmonary exercise testing (CPET) to evaluate the improvement of the overall function of patients with long-term intensive PPE-HPM for 3 months.

Methods: We selected 20 severe patients with MCCVMCDs who were intensively managed by our team from 2014 to

2017. After signing the informed consent form, based on the Results of CPET and continuous functional tests, we formulated the HPM with moderate intensity of PPE as the core individually. After 3 months, CPET was repeated. Each patient's changes of CPET parameters from baseline were analyzed and calculated. The difference and percentage difference were calculated.

Results: Twenty severe MCCVMCDs patients were 18 male and 2 female, age (55.75±10.80, 26~73) yr, height (172.20±8.63, 153~190) cm and weight (76.35±15.63, 53~105) kg. There was none of any risk and dangerous events during CPET and intensive PPE-HPM.

Conclusion: CPET can safely, objectively and quantitatively evaluate the holistic function and therapeutic effects, and guide the formulation of individualized intensity of PPE. The intensive PPE-HPM in hospital can safely and effectively reverse the holistic function in severe patients with MCCVMCDs.

Key words: Cardiopulmonary Exercise Testing; Objective Quantitative Holistic Functional Assessment;

ID 3389

正常分钟通气量机械通气不同潮气量和频率影响活体山羊颈动脉血氧连续动态变化的初步实验研究

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目的：在初步验证超快反应聚合物基质光纤氧传感器及其测定系统记录颈动脉氧分压（PaO2）连续动态变化使用基础上，为了分析探讨肺通气对 PaO2 连续动态变化的影响，我们设计本活体整体动物实验观察研究。

方法：选择杂种山羊 4 只，全身麻醉气管插管空气机械通气下，切皮直接暴露把后接测定系统的氧传感器直接插入左侧颈动脉连续记录 PaO2 动态变化。

结果：活体山羊正常通气量机械通气实验时心率和血压均稳定；肺 - 颈动脉延迟时间为 1.4-1.8s（约为此时的 3 次心跳）。

结论：本文结果表明正常肺通气的吸气和呼气是颈动脉 PaO2 上升和下降的始动因素。正常通气量机械通气下减半潮气量和倍增潮气量显著改变 PaO2 升降幅度，但 PaO2 平均值仅小幅改变，而肺 - 颈动脉延迟时间相近。

关键字：超快反应聚合物光纤氧传感器；整体整合生理学医学；活体整体山羊；

3417

连续逐搏取血血气分析对正常呼吸活人体动脉血气波浪式变化特点的实验证据

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目的：自从 2011 年我们 首先报告肺吸气产生的信号 (动脉血氧上升、二氧化碳下降）经过肺静脉 - 左心房 - 左心室到主、颈动脉的化学感受器中断吸气，呼气信号再中断呼气；从而实现呼吸切换，创立“整体整合生理学医学“新理论。

方法：择心功能正常，需要连续监测动脉血流动力学变化的患者 6 例，4 男 2 女，年龄 (59±16.64) 岁，体质量 (71.67±10.37)kg，左心射血分数 (LVEF)=(61.33±2.16)%。患者签署知情同意书后，选择心功能正常需要监测动、静脉血流动力学变化的患者 6 例，连续同时桡动脉、颈内静脉逐搏取血，测定 PaO2。选取 2 个典型呼吸周期，用于分析同时段动、静脉血气的波浪式变化。分别比较患者相邻最高和最低值，以验证同时段动静脉血气是否都存在周期性波浪式信号变化。此外，将患者动脉、静脉血气周期性波浪式信号的变化幅度进行统计学 t 检验分析，比较有无差异。

结果：与动脉血气组相比有明显统计学差异 (P<0.05)。

结论：说明动脉血气波浪式信号主要是由于肺通气过程中吸气和呼气期产生肺泡中氧分压规律性上升和下降，通过离开肺毛细血管与肺泡氧气压力平衡的动脉化血液，经过左心室搏血进入动脉血管系统所致。

关键字：动脉血气；静脉血气；呼吸调控；逐博取血；波浪式信号

ID 3424

Intensive and Weak Management of Personalized Precise Exercise and Holistic Protocol

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Objective: Use cardiopulmonary exercise testing (CPET) to evaluate the cardiopulmonary-metabolic functional changes under intensive or weak control of PPE-HPM in patients with severe MCCVM-NICDs.

Methods: Forty seven severe MCCVM-NICDs patients with multi-hyper in blood pressure, glucose, fat acid, urine acid and body mass and/or stroke and cardiac ischemia etc., were managed by 30min Δ50%(midway between anaerobic threshold (AT) and Peak) intensity PPE-HPM for 30d, and performed two CPET at baseline and after respectively.

Results: At baseline, all MCCVM-NICDs patients had significant limited exercise capacity (Peak V(•)O2 70.2±20.6%pred), and there was no significant difference between two sub-groups. Compared with baseline, PPE-HPM intensive management significantly increased Peak V(•)O2, AT, Peak O2P, Peak WR and Peak CO by 23.0~32.5% respectively, and increased OUEP by 11% (all P<0.01), while the lowest V(•)E/V(•)CO2 and V(•)E/V(•)CO2 slope decreased by 5% and 8% respectively (all P<0.05).

Conclusion: Compare with weak management out hospital, in hospital PPE-HPM intensive management is more conducive and powerful to improve holistic cardio-pulmonary-metabolic function in MCCVM-NICDs patients. The intensity of personalized precise exercise can ensure the safety and effectiveness.

Key words: Personalized precise exercise training, intensive management, weak management

ID 3425

基于智能传感技术的健康感知与干预

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目的：探讨便携式与穿戴式等智能传感检测技术在健康感知评估与干预中的应用。

方法：随着智能手机的日益普及，其高速的分析处理能力、高清的图像采集装置和优秀的人机交互界面，尤其是其所能提供的完善的互联网服务，都已使得智能手机逐步成为了与便携式及穿戴式传感技术相结合的研究热点，可望成为一个全新的面向用户个体的移动检测新平台。本报告将结合浙江大学多年来在生物医学传感与检测领域的系统探索，结合柔性贴皮式电子电路与器件，对近年来发展迅速的穿戴式与便携式传感方法进行介绍。

结果：侧重于健康管理及中医药领域应用，以人体呼出气传感检测系统的研发及在体干预系统的探索为例，对相关的便携式与穿戴式传感检测结果进行展示。

结论：以便携式与穿戴式为代表的智能可穿戴技术，在人体健康监测、疾病干预等方面展现了巨大的应用潜力，值得进一步深入研究。

关键字：柔性电子，可穿戴技术，电子皮肤、呼出气检测、健康管理

ID 3432

The Characteristics of Exercise Pathophysiology During Cardiopulmonary Exercise Testing in Patients with Hypertrophy Cardiomyopathy (HCM)

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Objective: To investigate CPET pathophysiology in patients with HCM.

Methods: Since2017 we performed symptom limited CPET in 219 patients with HCM and 25 normal subjects (NS) as healthy control, after signing the informed consent form in Fuwai Hospital. The CPET parameters were graphed and calculated using standard methods, and their similarity and difference were analyzed.

Results: ① HCM was 46.7±12.8(16-71)yr and NS was 46.8±12.8(26-61)yr which with similar general information (P>0.05). ② HCM had limited functional capacity during CPET: peak oxygen uptake (peak O2 65.1±13.9(22.8 ～ 103.4)%pred, anaerobic threshold (AT) 66.4±13.0(33.7 ～ 103.5)%pred and peak O2 pulse (84.2±19 .0(90.9~126.0)%pred which were significantly lower than those of NS (P<0.001). Meanwhile, HCM had almost normal ventilation efficiency: oxygen uptake efficiency plateau (OUEP)99.1±13.4(69.1~155.5), lowest E/CO2108.1±13.3(70. 4~154.0)%pred and E/CO2 slope108.7±18.0(66.9~164.9)%pred which were significantly different from those of NS (P<0.05). Individually, some patients were still within the normal range of functions. ③ In CPET, peak O2 is positively correlated with other core indicators AT, OUEP, peak O2 Pulse, peak systolic blood pressure. However, with E/CO2-lowest and E/CO2slope show negative correlation.

Conclusion: The CPET characteristics in HCM patients are limited functional capacity and almost normal ventilation efficiency. According to HIPM, CPET can accurately assess functional capacity and guide safe and effective management in clinical application.

Key words: Hypertrophy cardiomyopathy; CardioPulmonary Exercise Testing; functional capacity, ventilation efficiency, Holistic Integrative Physiology and Medicine.

ID 3433

人体通气状态对动脉血气波浪式幅度的影响

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目的：根据整体整合生理学医学新理论，动脉血气波浪式信号源自呼吸过程中肺泡 O2、CO2 分压的连续动态变化，血液流经肺脏时进行气体交换后，随着血液离开肺泡毛细血管时间的不同，连续到达体动脉的信号呈现波浪式变化。这种波浪式信号不仅是吸呼相切换调控的核心，也是生命功能一体化自主调控的核心。然而非正常呼吸模式下的动脉血气变化特点目前没有相关研究。本研究旨在发现不同通气模式下动脉血气的变化特点。

方法：选择心功能正常，需要连续监测动脉血流动力学变化的患者 6 例，4 男 2 女，年龄 (59±16.64) 岁，体质量 (71.67±10.37)kg，左心射血分数 (LVEF)=(61.33±2.16)%。

结果：共 6 例 ICU 住院监护患者，抽取动脉血液充满肝素化细长塑化管需要 15-16 次心跳，即取血需要 15-16 次心跳，全部覆盖超过 2 个呼吸周期。

结论：分别于三种通气状态下采用连续逐搏动脉取血血气分析法证实，患者高通气状态呼吸时动脉血气的周期性波浪式变化信号增强，憋气时波浪式呼吸变化变弱，说明肺通气是直接影响动脉血液波浪式信号幅度决定性因素。

关键字：非正常呼吸模式；动脉逐搏取血；波浪式呼吸；呼吸调控

ID 3436

超快速反应聚合物光纤氧测定装置及其用于活体动物机械通气下动脉血氧分压连续动态变化的初步实验报告

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目的：我们在中国尝试使用超快反应聚合物光纤氧感受器置入整体活动物动脉血管，再通过光电转换测定系统以记录活体动物颈动脉 PO2（PaO2）连续动态的快速变化，为完善整体整合生理学理论体系中循环参与呼吸调控和呼吸循环代谢一体化调控提供实验依据。

方法：在实验室加热总长 2m 光纤的远端 5mm 部分，拉动直到它成锥形尖端，清洁并干燥后，将 1mm 锥形光纤尖端浸涂到发光体掺杂聚合物溶液中，在溶剂快速蒸发同时将其缓慢抽出来形成氧气感测尖端，室温干燥 24h。对完成制作的感受器进行性能标定，并于第 37d 重复标定。

结果：该置入式超快反应氧传感器在液相的响应时间为 100ms。活体山羊实验 60-40% 氧气机械通气心率和血压稳定，左和右颈动脉 PaO2 随着呼吸机的吸气和呼气呈现波浪式上升和下降的呼吸交替现象，幅度高达 25mmHg；左侧股动脉位置记录的信息噪音显著干扰 PaO2 变化。

结论：活体动物置入动脉的超快反应氧传感器及其测定系统可测定 PaO2 生理性波浪式变化，能为整体整合生理

学医学新理论体系中解释吸气和呼气相互切换的机制提供实验依据。

关键字：超快反应聚合物光纤氧传感器；整体整合生理学医学；活体整体动物；动脉血氧分压波动幅度；肺 - 动脉时间延迟；

ID 3439

新生儿首次呼吸前后脐带静、动脉连续逐搏取血血气分析血氧变化探索呼吸调控机制的初步报告

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目的：胎儿没有实际上的呼吸功能，新生儿出生后才开始呼吸，我们假设人的第一次呼吸是由于低氧而触发。本研究对流主动脉体外周化学感受器后的脐带动脉血液氧分压（PuaO2）变化规律和下限进行分析以探讨新生儿自主呼吸产生机制。

方法：在新生儿出生后还没有呼吸之前，以尽可能快地暴露脐带，在脐带动脉和脐带静脉分别向新生儿和胎盘方向穿刺置入肝素化的动脉留置针后，共完成 14 名新生儿在自主呼吸开始前成功完成了脐带动脉或者静脉置管，分别连接预先卷曲好肝素化的塑胶取血管，均按照监护仪心跳指示进行逐搏取血 ~0.15mL，所有血样马上放入预先准备冰水浴中，立即尽快使用血气分析仪进行顺序血样测定

结果：虽然准备了数十产妇，但在新生儿自主呼吸开始前完成了脐带动和或静脉置管采样仅采集脐带动脉（Pua）样本 9 例，脐带静脉（Puv）样本 8 例；其中仅有 3 例同时采集到 Pua 和 Puv 血液样本，6 例仅采集到 Pua，另 5 例仅 Puv 血液样本。

结论：胎儿娩出为新生儿后自主呼吸前 PuaO2 随时间（心跳次数）逐渐降低，在达到触发呼吸的阈值就诱发第一次吸气开始自主呼吸。

关键字：新生儿出生后呼吸前；脐带动脉和脐带静脉连续逐搏取血；血液气体分析；脐带动脉血氧分压；呼吸调节控制信号

ID 3442

无睡眠呼吸异常年轻正常人睡眠期间呼吸源性血压变异的初步研究

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目的：基于整体整合生理学医学新理论，我们假设呼吸是循环指标变异性的起源，通过连续逐搏血压监测技术分析血压变异性与呼吸的关系来初步验证此观点。

方法：本研究分析了进行心肺运动试验（CPET）、多导睡眠图鼻气流、连续指端脉搏波和心电图监测的 8 例无疾病诊断的健康年轻正常人，分析睡眠期间鼻气流的呼吸周期与血压变异周期的关系。一个完整的呼吸周期包括吸气过

程和紧接着的呼气过程，分析计算呼吸周期数（B-n）、平均呼吸周期时间（Bn-t）等指标。

结 果： 正常人受试者具有基本正常的整体功能状态：峰值摄氧量（83.85±8.93%Pred）、无氧阈（77.53±9.94%Pred）及 SBP-m（97.50±8.22 mmHg）和 DBP-m（61.88±5.80 mmHg）；夜晚睡眠期间呼吸暂停低通气指数为 1.71±1.30 次 / 小时。

结论： 正常人夜间睡眠期间血压变异与呼吸存在极其相似的一致性，其血压变异的始发因素为呼吸所致。

关键字： 整体整合生理学医学；心肺运动试验；多导睡眠记录；鼻气流

ID 3444

存在睡眠呼吸异常长期慢病（慢病 -OB）患者呼吸源性血压变异的初步研究

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目的： 运用多导睡眠图（PSG）连续逐搏血压监测慢病 -OB 患者在夜间睡眠 OB 期间的血压变异特征与呼吸之间的关系。

方法： 选择 AHI³20 次 /hr 的慢病 -OB 患者 16 例，分析其 OB 期间与连续逐搏血压的血压变异指标和呼吸规律及其相关关系，并与本组非 OB 的指标以及本实验室同期正常人和无睡眠呼吸异常的高血压患者进行统计学分析比较。

结果： 存在睡眠呼吸异常的慢病患者在夜间正常平稳呼吸期呼吸周期数与收缩压和舒张压变异周期数的比值均接近于 1，与本实验室同期的正常人和无睡眠呼吸异常的高血压患者相似，说明血压变异为呼吸源性；OB 期间比正常平稳呼吸期间血压变异（特别是收缩压）升降幅度显著增大，在 OB 期间不仅有每一次呼吸的吸气与呼气节律，而且还有 OB 的过度通气与低通气 / 呼吸暂停的交替节律，每个波浪式呼吸几乎都能引起一次收缩压的大幅上升和下降。

结论： 本研究表明 OB 期间的血压变异为呼吸源性，而且睡眠呼吸异常可能是高血压的发病机制之一。

关键字： 慢病，波浪式呼吸，舒张压变异性，光电容积脉搏波，收缩压变异性

ID 3467

基于心电与呼吸信号的生理疲劳检测方法研究

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目的： 人在从事体力工作或者体育锻炼的过程中会产生生理疲劳，生理疲劳会使机体生理过程无法维持预定的运动强度，从而使运动功能暂时下降。例如，运动员、士兵等职业会在训练过程中产生生理疲劳，如果没有得到适当的休息，就可能引发危险；体力工作者长期工作，也会出现不同程度的生理疲劳，可能对生命财产造成不可挽回的损失。本文提出了一种基于心电和呼吸信号的人体生理疲劳进行监测的方法。

方法： 该方法采用超限学习机加长短期记忆网络“后处理”的结构，通过可穿戴设备获取人体生理信号后，经过噪声去除等预处理获取纯净信号，根据经验提取出心电信号和呼吸信号对应特征，基于超限学习机模型对当前时刻生理信号进行分类判断，得到并记录当前疲劳状态，将记录的历史疲劳状态加入到评估中，基于长短期记忆网络模型进行训练，

可得到当前人体所处的疲劳场景，疲劳场景分为四种情况：“体力充沛期”（不疲劳）、“发力期”（疲劳逐渐加深）、“力竭期”（持续疲劳）、“恢复期”（疲劳逐渐减缓），然后根据人体疲劳场景对当前疲劳状态进行二次评估与修正。

结果：检测的准确率可达到 88.89%。

结论：与传统机器学习方法相比，该方法具有较好的生理疲劳识别效果。

关键字：生理疲劳；心电信号；呼吸信号；超限学习机；长短期记忆网络

ID 3515

Effects of Animal-assisted Interventions on Normal Children’s Social Development: Evidence from EEG Hyperscanning

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Objective: Animal-assisted interventions (AAI) are usually used in special education and have been shown to improve symptoms such as autism and depression. Yet there are few neurophysiological studies in this area for normal children. This study innovatively used EEG hyperscanning to investigate the AAI effect on normal children’s social development and its brain dynamics in a naturalistic context.

Methods: The subjects were 24 children aged 6-7 years who were randomly divided into three groups on average, and the experimental site was a zoo primate house. The 32-conductor portable EEG devices were used to collect the resting-state EEG signals before, after, and during the intervention (simple observation and lecture observation, 3 min each). We used an A-B-A design to test whether the intervention had an effect on the frequency band indicators at the baseline level.

Results: EEG topography revealed that the α-rhythm varied more in the prefrontal and posterior temporal regions during the interventions. During the eyes-closed resting state, the asymmetry of the frontal α-rhythm was calculated using F8 and F7 channels. It was significantly increased after the intervention ($p<0.05$), which exhibited the decreased relative power of the left α-rhythm indicating enhanced left frontal activity (the asymmetry of the frontal α-rhythm). The μ-rhythm (9-11 Hz) relative power values at C3 and C4 electrodes were significantly lower in the posttest than in the pretest ($p<0.05$).

Conclusion: AAI has a potential boosting effect on children's social functioning by influencing immediate emotion regulation to generate positive emotions, indexed by frontal α-rhythm effect. μ-rhythm inhibition indicates the activation of mirror neurons, which are related to social information processing such as motor observation and emotional function, whereby AAI can effectively promote children's social development.

Key words: animal-assisted intervention; EEG hyperscanning; frontal α-rhythm asymmetry; μ-rhythm

青年优秀论文复赛

S01
生物医学检测、处理与分析
Biomedical Signal Processing

ID 145

A Risk Probability Prediction Model for Sudden Cardiac Death Based on Heart Rate Variability Metrics

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Objective: The estimated annual number of sudden cardiac death(SCD) is approximately 4 million cases worldwide and approximately 50% of SCDs are unexpected first manifestations of cardiac disease. The identification of subjects at high risk for SCD is of great importance as the prevention of SCD events would be possible with the implantable cardioverter defibrillator(ICD). However, there is no reliable method to estimate individualized SCD risk for prevention. In this paper, we introduced a novel approach to predict individualized SCD risk probability based on heart rate variability metrics(HRV).

Methods: First, we selected 11 commonly used HRV metrics. The heart rate(HR) corrected HRV metrics(HRV_C) and ventricular beat rate(VBR) from 1 h electrocardiogram(ECG) segments were extract as candidate features. Then, the feature dimension was reduced by recursive feature elimination. Finally, training set of normal control and SCD victims was employed to build multi-layer perceptron(MLP) model. To evaluate the model's predictive ability, best cut-off threshold of high and low SCD risk was determined using Youden index.

Results: The SCD risk probability based on 1 h HRVC was 0.00±0.01 for normal control and 0.99±0.01 for SCD victims. The near-perfect results were achieved for discriminating SCD from normal control.

Conclusion: Our method not only estimated individualized SCD risk probability reliably, but also had higher prediction accuracy than the existing methods.

Key words: Sudden cardiac death, Risk probability, Heart rate variability

ID 272

A Faster Single-Channel SSVEP-Based Speller Using Peak Filter Extended Canonical Correlation Analysis

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Objective: Steady-state visual evoked potential (SSVEP) based brain-computer interface (BCI) can provide an effective

speller for disabled people. With the attempts in building user-friendly BCIs, training-based systems using a single electroencephalogram (EEG) channel attract attention increasingly. One important step for training-based BCIs performance improvement is to construct clean templates. However, since band-pass filters can not precisely extract the fundamental and harmonic frequency components, there remains much noise in the templates extracted by existing methods.

Methods: A novel peak filter extended canonical correlation analysis (PF-eCCA) was proposed in this work. Firstly, a peak filter strategy was developed to construct templates, which can emphasize the specific frequencies and suppress unrelated components. Then, eCCA was employed for classification.

Results: This method is evaluated on the Benchmark dataset and achieved the highest information transfer rate (ITR) of 138.7 bits/min, which significantly outperformed the state-of-the-art method.

Conclusion: The proposed peak filter strategy can also be used to improve several other existing Methods with low additional computation costs.

Key words: Brain-computer Interface, Electroencephalogram (EEG), Single-channel Detection, Steady-state Visual Evoked Poten-tial (SSVEP)

ID 476

Respiratory Function Monitor Based on Surface Diaphragm Electromyography

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Objective: To design a respiratory function monitoring system with surface diaphragm electromyography that can be used to monitor respiratory function in the home or with medical agents.

Methods: Based on the STM32F411VET6 microcontroller system, two electrodes were used to detect the surface EMG signals. Additional two circular disposable Ag/AgCl electrodes were applied for the output of high-frequency excitation and the input of ECG and bio-impedance signals.The hardware system included a diaphragm EMG detection circuit, ECG detection circuit, bio-impedance detection circuit, constant current source excitation circuit, and microcontroller. The analog signals were digitalized by the A/D mode of the MCU, and the digitalized signals were stored in a secure digital memory card through the secure digital input and output protocol. After the systemdesign, the system was validated by acquiring signals from 10 patients with mechanical ventilation due to respiratory dysfunction and 10 healthy adults. Fifteen respiratory function-related parameters were calculated and compared between groups.

Results: The signal-to-noise ratio of the signal collected by the system was >10 dB, the common mode rejection ratio was >80 dB. Compared with healthy adults,inhalation time, exhalation time, tidal volume, peak-to-peak value of the bio-impedance signal, variation of bio-impedance signal in one second, diaphragmatic EMG low-band power (LF, 20 ～ 40 Hz), diaphragmatic EMG high-band power (HF, 150 ～ 250 Hz), the ratio between high-band power and low-band power., diaphragmatic electromyography area, diaphragmatic electromyography peak-to-peak, and cardiopulmonary coupling coefficient were significantly lower ($P<0.05$), but heart rate was significantly higher in mechanically ventilated patients ($P<0.05$). In addition, there were no significant differences in respiratory rate, diaphragmatic electromyography time, and inhalation and exhalation ratio between the two groups.

Conclusion: The designed respiratory function monitoring system was demonstrated to be reliable. It can be used for continuously and non-invasively monitoring respiratory function in real time.

Key words: surface diaphragm electromyography, electrocardiography, bio-impedance, respiratory function monitoring

ID 667

Aortic Pressure Waveform Estimation Based on Variational Mode Decomposition and Gated Recurrent Unit

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Objective: Aortic pressure waveform (APW) can provide vital information for the diagnosis and treatment of cardiovascular diseases. Although various APW estimation Methods have been reported to avoid the risks of direct invasive measurement, more accurate and practical estimation models still need to be developed to promote the application of APW in routine monitoring. To solve this problem, a hybrid model based on variational mode decomposition (VMD) and gated recurrent unit (GRU) named VMD-GRU was proposed to estimate the APW from the brachial pressure waveform (BPW).

Methods: Invasive APWs and BPWs from 34 subjects were used to validate the proposed method. Initially, new samples were obtained from these measured APWs and BPWs using data augmentation technology. Subsequently, VMD was employed to decompose the augmented BPWs into multiple intrinsic mode functions (IMFs). Next, the GRU network was utilized to learn the complex relationship between the IMFs and augmented APWs. The trained GRU network can be used to estimate the APWs with the IMFs obtained from the BPWs and VMD approach. The root-mean-square-error of total waveform and mean absolute errors of commonly adopted hemodynamic indices in clinic including systolic and diastolic blood pressures and pulse pressure were used to evaluate the proposed method. The performance of the proposed method was obtained from leave-one-subject-out cross validation.

Results: The proposed method achieved smaller errors of total waveform (3.33 versus 3.50 mmHg, $P<0.05$) and pulse pressure (3.02 versus 3.64 mmHg, $0.05<P<0.10$) compared to the GRU.

Conclusion: The proposed method can provide more accurate APW in comparison to the GRU network.

Key words: Variational mode decomposition, gated recurrent unit, aortic pressure waveform, brachial pressure waveform.

ID 693

基于活性细胞膜的电化学传感器用于 GLUT1 抑制剂的研究

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目的：依托电化学检测方法，构建 GLUT1 高表达的细胞膜生物传感器（CMB），用于 GLUT1 抑制剂的研究。

方法：以高分子聚合物材料为载酶基底构建 CMB，使用扫描电镜（SEM）和原子力显微镜（AFM）验证传感器的完整性；通过计时电流法比较不同细胞来源的 CMB 电流响应，测定药物小分子调控 GLUT1 表达前后 CMB 的电流响应差异；使用 CMB 测试儿茶素类化合物对 GLUT1 转运的抑制作用。

结果：SEM 和 AFM 结果显示 CMB 表面细胞膜结构完整，能够用于 GLUT1 转运过程的实时监测；不同 GLUT1 表达水平的 CMB 电流响应信号存在差异，药物小分子敲降 GLUT1 表达后的 CMB 电流响应信号降低；儿茶素类化合物中表没食子儿茶素没食子酸酯（EGCG）能够抑制 GLUT1 的转运过程。

结论：所构建的 CMB 能够完成对 GLUT1 转运动力学的实时监测和 GLUT1 抑制剂的研究

关键字：细胞膜传感器；GLUT1 ； 电化学检测；抑制剂

ID 705

基于运动起始诱发电位的低延时动作观察异步脑 - 机接口

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目的：基于动作观察（AO）的脑 - 机接口（ BCI）能够同时诱发大脑视觉区稳态运动视觉诱发电位（SSMVEP）和运动区运动感觉节律。这种独特的双脑区激活在脑卒中康复具有很大的应用潜力。异步 BCI 可以让受试者在脑控态和非脑控态自主切换，相较于同步脑 - 机接口更具有实用性。但是，实现低延时和高准备的辨识仍然是异步 BCI 的挑战。

方法：目前基于 SSMVEP-BCI 的异步检测以分析脑电信号中 SSMVEP 的有无为主，而本研究提出以检测 AO 范式诱发运动起始诱发电位（mVEP）来实现低延迟高准确的异步 BCI。本研究分析了 18 名老年人的在 AO 范式下的脑电信号。并设计了基于主成分分析和线性判别分析（P+L）的方法以异步的模式来检测 mVEP，与基于卷积神经网络检测 SSMVEP 的方法进行对比。

结果：本研究设计的 AO 范式可以诱发 mVEP，其主要包含一个延迟 100-160ms 的正波 P1 和一个延迟 160-240ms 的负波 N2。使用 P+L 方法的检测延时为 266.1ms ± 28.6ms ；且使用 P+L 方法的检测延迟和假阳性率均显著的低于基于 CNN 方法。

结论：本研究首次证实了 AO 范式可以诱发 mVEP，并可以实现低延时的异步 BCI。

关键字：动作观察；运动起始诱发电位；异步；脑 - 机接口；康复

ID 806

Dielectric Properties for Identification of Gliomas and Normal Brain Tissues with Open-Ended Coaxial Probe

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Objective: The dielectric properties of biological tissues are the crucial parameters used in identification of normal or tumor tissue. Many studies have measured the DPs of different human tissues while the technique is still hard to apply in tumor resection. The main problem is that this technique cannot qualify the size of tumor. In this work, we examine the identification size of tumor by numerical simulation at 50 MHz to 500MHz.

Methods: To investigate the identification size of gliomas through OCP, we built a numerically computable gliomas dielectric model which was assigned the corresponding DPs values. Then, we calculated DPs based on the simulation data through OCP reconstruction algorithm. We examined a series of gliomas radius with three configuration probes and employ the Mann-Whitney U test to determine the minimal measurable radius, i.e., identification size.

Results: As mentioned above, it is determined that the identification size of gliomas is that the p values are both smaller than 0.01 for the measured DPs compared with gliomas. By testing the h value for each change of tumor size,for probe 1 the identification size is 0.51 mm radius, for probe 2 the identification size is 0.77 mm radius, for probe 3 the identification size is 1.40 mm radius.

Conclusion: In this study, we put emphasis on investigating identification size of three configuration probes. The influ-

encing factors are also discussed. First, we conclude that the identification size of three configuration probes. For probe 1 the identification size is 0.51 mm radius, for probe 2 the identification size is 0.77 mm radius, for probe 3 the identification size is 1.40 mm radius. The crucial factors, the size of the probe and the tumor, that can affect the DP measurements are discussed. In summary, the identification size of gliomas and crucial factors are investigated.

Key words: Dielectric properties, Open-ended coaxial probe, Gliomas, Tumor section, Identification.

ID 940

AGCN: Adaptive Graph Convolution Network with Hemibrain Differences of Resting-state EEG for Identifying Autism in Children

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Objective: Early identification of autism in children has become a great concern due to the increasing prevalence of autism. Recently, EEG has become a promising tool to identify autistic children with some advanced signal processing and machine learning methods. However, it is still challenging to achieve accurate and reliable result due to the complexity of EEG signals.

Methods: we propose a new adaptive graph neural network model by incorporating hemibrain differences (AGCN) of resting-state EEG to classify autistic children and typical developing (TD) children. First, a temporal feature learning module is designed to learn temporal dynamics of EEG signals. Then, to capture spatial correlations, we design an adaptive graph convolution network combined with spatial attention mechanism to learn the connectivity between nodes from the perspective of developmental abnormalities in the hemiencephalar and hemicerebral of autism.

Results: Through specific experiments, the current mainstream and competitive resting EEG classification models are compared, and it is clearly shown that the performance of AGCN is better than other baseline models, with an accuracy rate of 91.11%. The combination of this model with left-right brain differences is visually illustrated.

Conclusion: Our proposed method incorporates the difference between the left brain and the right brain of ASD, which can better learn discriminative features from the characteristics of the whole brain and left and right hemispheres of EEG data. It is clear from the results that the proposed model is superior to other baseline networks. And it can also be seen that the left and right brain differential thoughts do have a significant improvement effect in the resting EEG data of autism. In summary, AGCN is suitable for deployment in medical systems to assist in efficient diagnostic and therapeutic services.

Key words: Autism, Resting-state EEG, Hemibrain Differences, Adaptive Graph Convolution, Identification

ID 1237

一种结合非连续膜和限位效应的高均一化巨型脂质体的制备方法

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目的：巨型脂质体是微米大小的微型膜系统，已广泛应用于体外研究膜的相关现象。研究人员常采用温和水合法、电形成法、微流控等方法用于制备脂质体，但上述方法制备形成的脂质体均一度较差。近年来，基于图案化的高均一度巨型脂质体制备技术显示出均一度较好的特点，得到了研究人员的广泛关注。

方法：本文提出了一种基于图案化非连续脂质膜和囊泡挤压限位效应的高均一化单层巨型囊泡简易制备方法，通过构建阵列化、图形化脂质膜沉积微芯片，探讨了脂质膜连续度对囊泡生长过程的影响。

结果：囊泡制备实验过程显示非连续脂质膜能更好地形成均一的囊泡。实验中进一步发现在囊泡生成过程中，相互间的挤压限位效应，能够在一定程度上限制囊泡的无序生长，从而影响囊泡的形状和大小。通过优化图案化阵列微结构，本文所构建的方法能够制备高度均一化囊泡。

结论：可控制备粒径范围为 40-100 μm，均一度达到 41.37±2.19 μm 的良好水平，为制备用于特定大小的药物递送和定量生物测定的脂质体等研究提供了一种潜在技术手段。

关键字：巨型脂质体；磷脂膜；挤压限位效应；尺寸可控

ID 1397

液态金属基电极用于葡萄糖的电化学检测

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目的：镓基液态金属具有较低的机械和流体特性。这些特点使它们成为有前途的软生物电子和生物传感器设备的材料。但是液态金属容易被氧化和腐蚀，导致生理条件下的不稳定性和有限的电化学性能，这可能会阻碍它们在生物传感器装置中的应用和实施。将纳米材料电化学沉积到液态金属上，阻止氧化过程，改善生物稳定性，以提高液态金属在生理条件下的电化学性能。

方法：恒电位电化学沉积，以及恒电位葡萄糖检测。通过电化学沉积的方法在镓表面沉积导电聚合物聚（3,4- 乙烯二氧噻吩），铂纳米粒子以及普鲁士蓝纳米颗粒实现低电位还原过氧化氢，将电化学干扰降至最低。通过将葡萄糖氧化酶固定在普鲁士蓝表面，实现对葡萄糖的特异性选择。利用葡萄糖传感，验证液态金属纳米复合多层的电化学性能。

结果：电流强度与葡萄糖浓度呈现良好线性关系，具有极好的选择性。基于液态金属的生物传感器显示出 17.95 nA/mM 的灵敏度。此外，该纳米复合材料结构在各种代谢副产品下表现出卓越的葡萄糖检测选择性。

结论：本研究通过电化学和液滴沉积的方法来制造生物稳定和高性能的镓基液态金属电化学传感装置，使其生产简单且价格低廉，有利于未来液体金属装置的实际应用。功能化 Ga 电极具有高性能电化学葡萄糖传感能力

关键字：液态金属；PEDOT ；葡萄糖检测；电化学检测

ID 1713

基于光学相干弹性成像的巩膜力学特性定量测量

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目的：巩膜的力学特性对青光眼和近视的发病机制研究以及开发相应的诊断和治疗方案具有重要的价值。本文基于光学相干断层扫描（OCT）与压电堆栈激励结合的系统，搭建光学相干弹性成像平台（OCE），提出一种对巩膜力学特性定量测量的方法。

方法：压电堆栈作为激励系统，诱导巩膜局部应变，并产生剪切波。SD-OCT 系统以 M-B mode 进行扫描，基于相位敏感 OCT 技术，获取传播路径各点的振动位移，计算剪切波传播速度，估计组织的杨氏模量。

结果：本文基于光学相干断层扫描（OCT）与压电堆栈激励结合的系统，搭建光学相干弹性成像平台（OCE），提出一种对巩膜力学特性定量测量的方法。得到离体猪巩膜前部剪切波波速及杨氏模量分别为 4.3±0.2m/s，55.5±60.9KPa；巩膜赤道区剪切波波速及杨氏模量分别是为 6.1±0.16.1m/s，111.6±115.3KPa；巩膜后部剪切波波速及杨氏模量分别为 3.8±0.1m/s，43.3±45.6KPa。

结论：本文所使用的 OCE 系统定量测量巩膜力学特性的方法未来有望为青光眼和近视等发病机制研究的流行眼病的诊断和治疗提供重要的技术手段。

关键字：光学相干弹性成像（OCE）；巩膜；剪切波

ID 1780

用于脑微透析过程中葡萄糖和乳酸检测的微流控电化学传感器

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目的：创伤性脑损伤是临床上发病率和致死率较高的疾病，已成为青少年致死致残的首位病因。临床上常用微透析方法监测脑组织液中乳酸和葡萄糖的波动，通常每小时分析一次样本，检测速度比较受限。本工作提出了一种基于微流控芯片的电化学分析系统，该系统以微流控芯片作为检测平台，丝网印刷电极（SPE）作为传感器载体，与微透析探针相结合，可以实现对脑脊液乳酸和葡萄糖的实时监测。

方法：微流控芯片采用雕刻和热压键合的方法在 PMMA 基底上实现，芯片集合多路通道以防止传感器之间的串扰。生物识别元件酶被固定在自制的极小电极尺寸（直径 0.5mm）的丝网印刷电极上，用于特异性检测葡萄糖和乳酸。

结果：该系统只需要 7μL 的样品体积，能够在微透析过程中对 0.2 ~ 6 mM 范围内对葡萄糖 / 乳酸水平做出快速反应，在连续检测中对被测底物具有高灵敏度和特异性。

结论：该研究表明，利用该系统进行低成本的快速检测在大脑代谢物监测中是可行的。

关键字：微透析；微流控芯片；电化学检测；乳酸；葡萄糖

ID 1812

适于脑内信息提取的 EIT 电极参数优化设计仿真研究

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目的：电阻抗断层成像技术（EIT）是一种新型成像技术，具有实时，连续，无创，便携，使用方便等突出特点，有望用于脑损伤的实时监护。电极作为整个 EIT 测量系统的重要组成部分，其性能参数影响着对颅内病变信息的准确提取。本研究的目的在于探究能够提高脑 EIT 对颅内损伤目标敏感性的电极的电导率及尺寸大小。

方法：在三维颅脑仿真模型基础上探究了 4 ~16mm 之间的 7 种尺寸与 6.6 s/m、0.44 s/m 和 0.029 s/m 三种电导率的组合电极对枕叶中后部、脑室中心、顶叶中部的出血目标的敏感性。

结果：电极电导率越高，尺寸越大，对颅内出血目标的敏感性越高。

结论：在脑 EIT 应用中，10mm 是较优的选择，但不建议低电导率。

关键字：脑 EIT ； 电极；敏感性

ID 1944

基于子时段睡眠阶段的睡眠功能联系与分类策略探究

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目的：目前对睡眠脑电信号的研究大多是单通道和双通道的，忽略了对不同脑区之间关系的研究。脑功能连接被认为与大脑活动密切相关，可用于研究脑区之间的相互作用关系。连接网络用于分析不同睡眠阶段的连接机制和大脑相互作用。

方法：将整个脑电信号分成多个子时段，利用锁相值在子时段上进行特征提取。然后利用多个子时段的 PLV 进行特征融合，使用采用分类性能优化策略，讨论不同频段对睡眠阶段分类性能的影响，寻找最优频段。最后，利用融合特征构建脑功能网络，分析睡眠阶段不同频段的脑区相互作用。

结果：实验结果表明，当子时段数为 30 时分类结果达到 92.59%。N1 阶段的连通性大于 REM 阶段，N2 阶段大于 N3 阶段，N3 阶段和 W 阶段的连通性小于 REM 阶段。对于 N2、W 和 REM 阶段的比较，N2 阶段左右脑之间的连通性比 REM 阶段小，而在 W 阶段，不同脑区之间的连通性更强。

结论：该算法具有良好的睡眠分类性能，可有效促进脑电睡眠分类系统的开发和应用。

关键字：脑电图 (EEG)，睡眠阶段，分类，脑功能连接，锁相值 (PLV)

ID 1951

基于 PCA 和 SVM 的生物雷达非接触识别头部特定动作方法

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目的：基于生物雷达传感器非接触识别特定头部动作——静止、点头、左转、右转、后倾、张嘴、左点头、右点头，为正确识别阿尔茨海默病患者头部动作，增强患者社会交流做好方法准备。

方法：首先通过生物雷达非接触采集头部动作雷达回波信号；接着进行时域数据处理和时频分析得到时域和时频域图像数据；然后从时域和时频域数据中分别提取特征并利用主成分分析法 (PCA) 构建更为有效的新特征；最后运用支持向量机模型 (SVM) 对新特征进行分类。

结果：雷达系统采集数据共计 55 组，每组顺序包含静止、点头、左转、右转、后倾、张嘴、左点头、右点头 8 种动作类别，共计 440 个动作。将数据集按 8：2 比例划分为训练集和测试集，44 组数据通过支持向量机建立模型、11 组数据用来测试模型，最终得到约为 88.64% 的准确率。

结论：本研究通过生物雷达接收其传播路径上的八种头部动作——静止、点头、头部左转、头部右转、头部后仰、张嘴、左点头、右点头的雷达回波信号并进行数据分析处理得到两类图像特征；基于 PCA 在两类图像特征基础上构成联合特征集；最终构建 SVM 模型进行分类识别，得到的分类结果准确率约为 88.64%。

关键字：非接触检测；生物雷达；动作识别；头部动作

ID 1956

Quantitative Evaluation of Olfactory Function Using Neural Interface Technology

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Objective: Olfactory dysfunction (OD) is an early common symptom of a variety of diseases. OD is typically assessed by olfactory neuropsychological testing, electrophysiological detection, olfaction system structure or functional imaging, etc. However, Individual difference and subjectivity of test subjects will influence the test results, and there have been no standardized detection index established so far.

Methods: In this work, by utilizing the neural interface technology, we propose a novel method for quantitatively evaluate olfactory function. Specifically, we take advantage of flexible electrode array to record the spontaneous neural activities in olfactory epithelium and olfactory bulb. Then extract the feature signals which could represent the olfactory function, and decode the feature signals into measurement parameters.

Results: According to the quantitative description of olfactory function, we can develop an olfactory model for clinically simple, fast and reliable diagnosis of OD.

Conclusion: The coupling pattern between respiration-locked and gamma oscillation is significant different between mice with normal olfaction and OD, which may be a characteristic feature to evaluate the degree of olfactory dysfunction. Further, neural features among different OD types will be extracted and classified. This work will provide reliable theoret-

ical foundation and technical proposal for developing clinically objective, fast, and stable method that for the ultimate goal of early warning and screening the OD.

Key words: neural interface, biohybrid system, in vivo probe, micro/nano sensing technology, olfactory function measurement

ID 2232

基于卷积神经网络的药物心脏毒性评估方法

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之江实验室

目的：本研究提出了一种基于一维卷积神经网络的药物心脏毒性评估方法，充分地发掘心肌细胞搏动信号的特征，实现了利用心肌细胞搏动信号的药物心脏毒性高精度评估。

方法：利用叉指电极测量心肌细胞节律性收缩和舒张的阻抗变化，将采集到的心肌细胞搏动信号直接输入卷积网络模型进行分析，最终输出药物心脏毒性评估结果。

结果：该模型对药物是否具有心脏毒性的评估精度为 1.0，对不同药物或同种药物在不同浓度下的总体识别精度也均大于 0.75。同时，为了测试此方法泛化评估药物心脏毒性的能力，利用两种未使用过的药物加载后的心肌细胞搏动信号数据集模拟新开发药物，均获得了较优异的评估结果：对于无心脏毒性药物其识别精度为 0.39~1.0；对于有心脏毒性药物其精度为 0.97~1.0。

结论：所提出的基于一维卷积神经网络的药物心脏毒性评估方法避免对心肌细胞搏动信号进行额外的特征提取，相较于传统方法，该方法在计算高效性和评估精确度方面都有较大提升，为药物心脏毒性评估提供了新思路，有利于加速新药研发的进程。

关键字：深度学习；卷积神经网络；心脏毒性；心肌细胞；药物开发

ID 2510

基于多源信息融合的步态检测和康复仿真

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目的：提出一种基于多源图像融合的步态检测和基于多智能体强化学习的步态康复仿真方法，并检验方法的信效度。

方法：从步态检测的角度，我们提出了一种基于多源图像融合的骨骼跟踪方法来捕捉个体的步行运动。首先，基于神经网络的二维姿态估计器将红外图像作为输入，从背景中分割人体，然后从人体轮廓中提取二维关节位置。然后，在二维位姿估计结果的指导下，使用对齐的点云深度图像来回归位姿深度。最后，使用信息融合方法获得三维关节位置；从步态康复仿真的角度，我们利用多智能体协作的深度强化学习方法来模拟步态障碍个体的康复过程，并通过专家模拟实验测试了所提出的方法。

结果：与同类的先进计算机视觉方法相比，所提出的步态检测方法产生的结果与参照标准有更高的相关性和一致性，而且置信区间减少了；同时仿真实验结果表明，多智能体深度强化学习能够有效地仿真从病理步态到正常步态的过渡。

结论：多源图像融合驱动的步态检测方法是精准有效的，有望作为一种补充方法在步态评估项目中应用。同时多

智能体强化学习有潜力用于解决模拟步态康复过程中的任务，为康复处方的制定和评估提供定量资料支持。

关键字： 多源图像融合；人体姿势估计；多智能体；强化学习；步态康复

ID 2683

基于免疫组测序技术探讨肉芽肿性乳腺炎的发病机制

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目的： 对照筛选患者与健康志愿者血清中与 GLM 发生相关的特异性免疫标志物，查找特征性免疫因子，为肉芽肿性乳腺炎的临床诊断、治疗、预后提供新的手段和方向。

方法： 采用多重 PCR 技术扩增 BCR 或 TCR 互补决定区，使用高通量测序平台检测和组间多样性分析方法，以血液 T 淋巴细胞为研究对象，将患者与健康志愿者血清对照筛选本病发生相关的特异性免疫标志物。

结果： 高通量测序平台检测及组间多样性结果提示，外周血中 V-J 组合的数量显著高于乳头溢液；GLM 患者和对照组在外周血中的 TCRβ 多样性明显不同于乳头溢液；GLM 患者比对照组外周血中 V-J 组合的丰度更为均匀；根据序列丰度结果建立分类器模型发现，外周血 TCR 表达谱比乳头溢液 TCR 表达谱更能代表肉芽肿性乳腺炎患者的全身免疫反应。

结论： 通过高通量测序平台检测及组间多样性分析，我们发现了肉芽肿性乳腺炎患者和健康志愿者之间、肉芽肿性乳腺炎患者的外周血和乳头溢液之间的免疫差异，这为我们下一步的工作提供了基础和方向，并提示了可能的新的诊疗手段。

关键字： 肉芽肿性乳腺炎；高通量测序；作用机制

ID 2801

基于电阻抗的癫痫发作前期与发作期分形维数的研究

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目的： 分析大鼠慢性模型癫痫发作期间 EIT 的一维曲线和重建图像，并尝试使用 Higuchi 算法计算癫痫发作前期与发作期一维曲线的分形维数，探索适用于电阻抗信号的特征提取方法。

方法： 制备大鼠慢性癫痫模型，使用 EIT-EEG 同步监测系统监测，得到慢性模型 EIT 的一维曲线和重建图像以及脑电图记录。根据脑电记录，将数据分为癫痫发作前期与发作期，分析癫痫发作期间电阻抗变化趋势，使用 Matlab 平台实现 Higuchi 算法并计算不同阶段电阻抗变化的的分形维数。

结果： 癫痫发作期间，病灶区电阻抗呈现先下降后上升的趋势或者无明显变化；与发作前期相比，发作期的分形维数较大，并且两者存在显著性差异

结论： 首先，EIT 能够检测到癫痫发作期间由于脑血流灌注引起的电阻抗变化。其次，慢性癫痫发作前期与发作期的 HFD 存在显著差异，这说明分形维数可能可以作为区分发作前期与发作期的一个特征，为实现基于 EIT 的癫痫预测奠定了基础。

关键字： 电阻抗断层成像；癫痫；分形维数；Higuchi 算法

ID 2956

基于奇异谱分析的脑电节律与非节律成分提取算法设计

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目的：脑电中包含多种节律性成分，但少有研究关注脑电中的非节律性成分，该成分可能与多种脑状态和背景活动相关，目前仍无有效方法分离这两种成分。

方法：本研究提出一种结合奇异谱分析（Singular Spectrum Analysis, SSA）和聚类的脑电节律和非节律成分的分离方法，通过 SSA 分解对脑电中提取重复模式成分，并根据其时频特性将其聚类，从而完成成分的分离。

结果：本研究提出一种结合奇异谱分析（Singular Spectrum Analysis, SSA）和聚类的脑电节律和非节律成分的分离方法，通过 SSA 分解对脑电中提取重复模式成分，并根据其时频特性将其聚类，从而完成成分的分离。仿真数据分析表明，本方法能够有效提取脑电节律成分，保持其频谱和相位特性；真实脑电分离出的节律性成分和非节律性成分能够有效区分多种脑状态。

结论：本研究所提出的方法有望进一步丰富脑电节律和非节律分析与脑状态和功能的关系。

关键字：脑电；脑节律；非节律；奇异谱分析；聚类

ID 2999

基于智能优化参数变分模态分解的癫痫 EIT 仿真信号运动伪迹去除方法

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目的：针对电阻抗断层成像（EIT）在临床癫痫疾病检测及预测中容易受到体动干扰的问题，建立一个基于智能优化参数的变分模态分解方法去除 EIT 仿真信号中的运动伪迹，为 EIT 在后续临床应用方面的研究奠定基础。

方法：使用 COMSOL 和 MATLAB 联合仿真，制作包含三种频率运动伪迹的 EIT 仿真数据；针对 VMD 算法参数选取对运动伪迹特征提取影响较大的问题，使用了智能优化算法 - 粒子群优化算法（PSO）对 VMD 的重要参数择优，以最小熵为评判准则对比分析确定最佳 VMD 参数；然后对 EIT 仿真信号进行 VMD 分解和逆变换得到不含运动伪迹的仿真信号。

结果：在最小熵值为 3.4966 对应 VMD 参数 K=5 时，EIT 仿真信号实现了较好的频谱分离，有效识别出 5Hz、10Hz、15Hz 处的干扰信号。经 VMD 逆变换后得到了去除运动伪迹的 EIT 信号。

结论：PSO-VMD 算法能够准确有效地提取到运动伪迹的特征信息并去除。与经验模式分解（EMD）算法比较，PSO-VMD 方法分解精度高并且能够有效地防止模态混叠状况的发生。可满足对 EIT 运动干扰的预处理要求。

关键字：电阻抗断层成像；变分模态分解；体动干扰；干扰抑制

ID 3005

一次性使用心电电极交流阻抗特性的评价方法

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目的：在医药行业标准《一次性使用心电电极》（YY/T 0196—2005）中仅用 10Hz 下的交流阻抗值的模来评价一次性使用心电电极的交流阻抗特性，不完整。

方法：本文提出基于低频阻抗谱的一次性使用心电电极交流阻抗特性的评价方法，通过测试胶对胶连接的一次性使用心电电极对样品的低频交流阻抗谱，计算电极系统的频响；假定输入一理想的能量归一的体表心电图，计算该电极系统传递后的输出心电图；将电极系统输入输出心电图的最大互相关函数值作为评价指标。

结果：结果显示本文方法计算的一次性使用心电电极的评价指标，对同一电极对的不同次试验具有好的重复性，而对不同电极品种也展现出较好的特异性。

结论：本文基于交流阻抗谱的评价方案提出了规范化的评价指标，反映了整个复阻抗谱的值大小情况和由此带来的心电信号经过电极的失真情况。

关键字：一次性使用心电电极；交流阻抗谱；最大互相关函数

ID 3104

Recognition of VR Motion Sickness Level Based on EEG and Functional Brain Network

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Objective: To study the causes and cures of VRMS, the recognition of VRMS level is a precondition. So, we aim to study how VRMS modulates EEG in functional brain networks and extract EEG features to measure VRMS.

Methods: 23 subjects are recruited and their EEG are collected when they are in VMRS induced by "VRQ test". We introduce a functional brain network approach based on empirical mode decompose and phase locking value to analysis the EEG, and recognize the VRMS level using graph-theoretic indexes and machine learning.

Results: The results suggest that the high frequency mode (about 30-40Hz) of EEG has more significant features between low and high VRMS levels, and the classification accuracy in the task and the post-task rest states are up to 96.3% and 97.6% respectively.

Conclusion: This work firstly reveals the effects of VRMS on the functional brain networks and provides a method to assess and guide the comfortable VR products design.

Key words: Virtual reality motion sickness (VRMS); EEG; Phase locking value (PLV); Functional brain network (FBN)

ID 3118

基于样本熵和 EEMD 的 PPG 信号质量评估方法研究

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目的：为减少由于各种噪声和运动伪影对 PPG 信号造成的影响，提高信号在生理评估中的信号可靠性，本文从非线性特征角度提供一种评估 PPG 信号质量的方法

方法：从 PPG 信号本身以及经过 EEMD 分解得到的各分量中分别计算信号的样本熵值，并引入了机器学习算法 SVM, RF 和 GB，将获得的样本熵值作为输入进行信号质量好和差的预测。与其他方法相比，本文的方法考虑了 PPG 信号在不同尺度下的非线性特征，且无需参考模板。

结果：所用分类算法的 ROC 曲线下面积均达到 0.9 以上，其中 GB 算法表现出最优的性能，其 ROC 曲线下面积达到 0.963，分类准确率为 92.3%。

结论：所提出的 EEMD 分解与信号不同特征尺度下的样本熵结合的质量评估方法具有良好的性能，模型最高分类准确率为 92.3%，表明本文提出的方法在可穿戴设备和临床实践中具有应用价值。

关键字：PPG，样本熵，EEMD，机器学习

ID 3170

自适应滤波和运动状态相结合用于可穿戴 PPG 的心率提取

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目的：光体积描记术（PPG）技术是一种检测皮下组织血容量变化的方法，具有原理简单、成本低、无创和可持续监测的特点，广泛应用于可穿戴设备的心率监测。然而，单通道 PPG 传感器获得的原始信号包含大量噪声，尤其是运动过程中产生的运动伪影。

方法：利用不同方向的加速度数据和合成信号进行自适应滤波，并结合运动状态估计对心率数据进行修正。该方法提高了自适应滤波的鲁棒性。十名测试人员同时佩戴了带有三轴加速计和单通道 PPG 传感器的手表、Polar 心率袖带（Verity Sense）和 Polar 心率胸带（H10）。受试者进行了 30 分钟的运动，包括慢跑、跑步、跳跃和其他运动。三轴加速度信号被用作自适应滤波的参考信号，并估计用户的运动状态，根据运动状态确定心率变化率和范围校正心率结果。

结果：与 Polar 心率胸带数据相比，整个样本的平均绝对误差为 7.5bpm。

结论：当运动幅度不是特别强烈时，本文提出的算法可以更精确地识别心率。

关键字：光电体积描记术（PPG）；心率监测；自适应滤波器；加速计

ID 3230

基于心电节律多尺度熵视角下的房颤预诊指标分析

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目的：在生物计算与医学大数据飞速发展的背景下，通过采集心电信号的实时信息，利用机器学习挖掘其中心房颤动相关特征指标，为心房颤动的诊断提供新的客观参考。

方法：本研究选取来自 Long Term AF Database 中 84 位阵发性或持续性房颤患者的心电数据，以及来自 Autonomic Aging 数据库的 82 位符合年龄要求的健康志愿者的心电数据作为对照组，利用基于 matlab R2020a 平台进行的心电信号特征值算法设计，提取数据样本中的特征指标值包括 ECG 多尺度熵、RR 多尺度熵和 HRV 多尺度熵 140 项，对数据整理后进行差异性分析。

结果：筛选出 49 项特征指标存在显著差异（$p<0.01$），多项 HRV 多尺度熵指标显著下降。

结论：存在多项特征指标可能对房颤的诊断及治疗具有重要参考作用，本研究也为房颤诊断和治疗提供了新的思路与方法。

关键字：房颤诊断；心电信号；特征指标；多尺度熵

ID 3250

基于心电信号特征值算法设计的心率失常特征指标分析

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目的：本研究通过采集心电信号的实时信息，利用机器学习挖掘其中心率失常相关特征指标，为心率失常的诊断提供客观参考。

方法：提取 PhysioNet 数据库中 MIT-BIH 心率失常数据及健康衰老过程中心血管自主功能变化相关数据，基于 matlab R2020a 平台进行心电信号特征值算法设计，利用分尺度 RR 间期识别技术，精确识别 QRS 波形，并分别标记 Q、R、S 波峰。提取相邻周期的 RR 间期，利用差分方法获得心率变异的波动信号，并在此波动信号上进行标记，分析不同状态人群的心电信号特征。提取数据样本中的特征指标，进行差异性分析。

结果：基于心电信号特征值算法设计，筛选出 36 项心率失常诊断相关特征指标，包括 QRS 最大最小幅值比、ECG 多尺度熵等多项特征值。

结论：存在多项特征指标可帮助识别心率失常，提高诊断精度。

关键字：心率失常；心电信号；特征指标；诊断

ID 3410

基于微变放大的肺部结节识别算法研究

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目的： 随着医学影像学技术的发展，计算机视觉技术在医学诊断中得到了越来越多的应用。肺部结节识别是一种重要的影像诊断技术，用于辅助医师发现肺部肿瘤。然而，由于肺部结节的复杂结构，以及结节形态的多样性，传统的计算机视觉技术很难有效地识别和定位结节，目前迫切需要一种融合深度学习网络的识别技术。

方法： 本研究提出了一种微变放大的肺部结节识别算法，利用微变放大技术对结节上层肺表面纹理扰动进行放大，改进 Yolo 模型构建多尺度检测算法，提出一种改进的多拓扑卷积网络，有效地提高了结节的检测精度和定位准确度，同时论文构建了一个肺部表层图像数据库 (DLR)。

结果： 通过扰动放大的多拓扑卷积网络的处理，标注出患者肺部的结节，比较直观便捷。使用训练后的模型对测试组进行测试，综合准确率达到 92.28%。此外，在临床手术中，准确性也得到了验证。

结论： 相对于肺结节病灶术前定位的常规方法，本文提出的改进多拓扑卷积网络的肺结节定位方法，它利用改进的多拓扑卷积网络结构和多尺度检测方法，提高了结节的检测精度和定位准确度。同时对采集的视频进行扰动微变放大，放大细节上的变化，可以辅助术者进行手术。

关键字： 肺部结节；Yolo ； 微变放大；计算机视觉；多尺度检测

ID 3447

动态观察屏息过程中的血氧饱和度值量化评价气虚

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目的： 通过对屏息过程中的受试者进行实时 SaO2 及其相关数据的获取，实现量化的气虚程度的评价。探索气虚与血氧饱和度（SaO2）的相关性。

方法： 实时测量健康样本，轻度气虚样本和典型气虚样本在屏息过程中的实时血氧饱和度值，统计各样本组血氧饱和度最低值 SaO2min，每分血氧消耗量 CIO2，屏息时间 TBH 和血流速度 BV，寻找能够量化评价气虚程度的信息。

结果： 血氧饱和度最低值 SaO2min 在与相应的分组间表现出显著的相关性，且相关性呈现出轻度气虚 > 健康样本 > 典型气虚的排列特征。能够通过观察 SaO2min，对气虚的程度进行辨识。

结论： 通过在组内细分 SaO2min，对各组的健康程度进行分级。探索应用 SaO2min 值结合中医医师的初步辨识，实现量化评价气虚的可能性。

关键字： 动态量化评测技术；气虚；血氧饱和度；屏息

ID 3480

基于心肌细胞胞内动作电位记录和深度学习的生物传感器检测苦味物质

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目的：苦味的感知具有重要价值，尤其是在制药和食品工业中。最近，原代大鼠心肌细胞内源性表达苦味受体，苦味受体产生动作电位以响应苦味物质，原代大鼠心肌细胞的胞外动作电位已被用于检测苦味物质。但与胞内动作电位相比，胞外动作电位的信号强度和质量明显降低，可能失去原有动作电位的特性，导致苦味物质识别的准确率降低。这项工作开发了一种基于 HL-1 心肌细胞的胞内动作电位检测生物传感器，用于高通量苦味检测。

方法：平面电穿孔技术用于记录 HL-1 心肌细胞的胞内动作电位。通过优化电穿孔参数，我们的生物传感器记录了高质量和高信噪比的胞内动作电位。得到的高质量信号经过构建的深度学习算法，以进一步分析不同的典型苦味化合物。

结果：所构建的基于心肌细胞胞内动作电位记录和深度学习的生物传感器，对于典型的苦味物质，苯甲酸地那铵和熊果苷的模型训练准确率为 100%。

结论：我们构建的传感器和算法可以为苦味检测和药物筛选提供一个替代平台。

关键字：心肌细胞；胞内动作电位；电穿孔；电子舌

ID 3492

钙探针 GCaMP-X 的工程设计及应用

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目的：基因编码探针是实时定量监测钙动态等重要生物学指标的工具之一。传统上，探针开发主要依靠（大规模）随机性筛选，而如何实现探针的理性（工程化）设计是未来的方向和当前的挑战。GCaMP 是自提出以来得到广泛应用的钙探针，其性能指标也不断提升。GCaMP-X 是针对 GCaMP 细胞损伤方面的弊端通过理性设计实现的改进版本，并在活体成像和长时程成像方面的具有特殊优势。

方法：自抑制是蛋白质通过分子内关键结构 - 功能域的动态结合，实现精准特异的信号传导。受其启发，针对 GCaMP 损伤的核心 CaM 结构域，增加 apoCaM 结合片段，确保 GCaMP-X 在基态下锁定在自抑制状态，避免（意外）结合胞内重要 apoCaM 靶点，从而减少探针对细胞影响。

结果：自发性钙振荡是兴奋性细胞的重要特征之一，GCaMP-X 对皮层神经元及心肌细胞钙振荡的影响显著小于 GCaMP。此外，神经元突起生长、心肌机械搏动及细胞核钙动态的对比结果进一步表明 GCaMP-X 优异的细胞相容性。

结论：GCaMP-X 探针已在离体及活体展现出其优势，需要进一步完善及推广；同时，如何运用来源于基础研究及工程科学的设计准则，以实现基因编码探针的理性定量设计，是具有广阔前景的研究方向。

关键字：钙动态；GCaMP-X ；理性设计；自抑制；可兴奋细胞

S02
医学成像与图像处理前沿进展
New Frontiers of Medical Imaging and Image Processing

ID 517

Developmental Pattern of Individual Morphometric Similarity Network in the Human Fetal Brain

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Objective: The development of cerebral cortex during the fetal period is complex yet well-coordinated. MRI-based morphological brain network provides a powerful tool for describing this process at a network level. Due to the challenges of in-utero MRI acquisition and image processing, the fetal brain morphological network has not been established.

Methods: In this study, utilizing high-resolution in-utero MRI image, we constructed individual morphometric similarity network for each fetus based on multiple cortical features and characterized the spatiotemporal changes of morphological connections and the network topology.

Results: Edge analysis demonstrated a decline of morphological symmetry between hemispheres, especially for the parietal cortex. The limbic and parieto-occipital regions exhibited the most drastic changes of network connections. Graph theoretical analysis indicated that the small-world structure of the network appeared as early as 22 weeks and that the network topology exhibited an enhanced integration and reduced segregation during the prenatal period.

Conclusion: In summary, this study provides an important evidence for understanding the normal development of fetal brain connectome during second-third trimester.

Key words: fetal brain, in-utero MRI, morphometric similarity network, small-world, integration and segregation

ID 558

Site Effects in Multisite Fetal Brain MRI: a Morphological Study of Early Brain Development

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Objective: Studies have shown that the non-biological site-related effects may induce bias in multisite neuroimaging studies among adults and adolescents. It is unknown how site effects would affect fetal brain MRI and which acquisition factors are critical in quantitative analysis.

Methods: We applied generalized additive models (GAMs) in R to identify site effects, including manufacture, field strength, in-plane resolution, and slice thickness on structural subcortical volume and cortical thickness measurements in normal fetuses. For the removal of the site effects, we used ComBat-GAM harmonization procedure to capture the age-related nonlinear change.

Results: In this study, we found that the volume of subcortical brain structures depended on field strength and slice thickness and was less sensitive to manufacture and in-plane resolution. In contrast, cortical thickness was highly influenced by in-plane resolution. We also showed these site effects could be effectively removed with ComBat-GAM while preserving developmental patterns.

Conclusion: These results demonstrate that it is important to take these factors into account when planning multisite or longitudinal studies. Meanwhile, ComBat-GAM can effectively remove nuisance variabilities associated with the acquisition while maintaining the age effects in volume and cortical thickness. Therefore, it is crucial to harmonize the data when analyzing multicenter fetal brains for morphological development.

Key words: Multisite, fetal brain, morphological development, harmonization, cortical thickness.

ID 568

Efficient Multi-Label Attribute Classification and Recognition of Vaginitis Bacteria Based on Deep Learning and model fine-tuning

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Objective: Bacterial vaginosis (BV) is the most common gynecological complaint affecting the health of a large percent-

age of women worldwide. Traditional manual microscopy Methods are expensive and time-consuming, to improve accuracy and efficiency, computer-aided automatic bacterial identification devices with detection intelligence algorithms are urgently needed.

Methods: We propose a Fine-tuned SmallerVGG (FTS-VGG) convolutional network model-based multi-label classification method for bacteria. Due to the high cost of time and expertise of experienced clinicians, we use random erasing for data augmentation to address the challenge of dataset collection and annotation, experiments demonstrate its robustness to occlusion.

Results: Comparison experiments were deployed on several basic backbone networks, including transfer learning on pre-trained VGG19, demonstrating that the proposed method achieves the advantages of being lighter, faster, more accurate, and more efficient.

Conclusion: The confusion matrix and ROC curves reveal that the proposed model has the best performance in the evaluation metric. Our work has theoretical and practical implications and the potential to be widely extended to other microscopic imaging applications.

Key words: Bacterial vaginosis, Automatic diagnostic microbiology, Deep learning, Multi-label classification.

ID 649

Group Information Guided Smooth Independent Component Analysis Method for Brain Functional Network Analysis

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Objective: The non-neuronal signals such as head movements, physiological noises, and scanner artifacts can make the estimated functional networks (FNs) contain a lot of noise, which interferes with brain disease-related studies in identifying network-level biomarkers and even leads to some false conclusions. Previous Methods that remove the noise-related components obtained from independent component analysis (ICA) to reconstruct fMRI largely depend on the trained models and fail to directly optimize FN. Therefore, it is urgent to develop new Methods to extract smooth FNs with less noise and further, provide support for the definition of stable biomarkers and the prediction of mental illnesses.

Methods: we propose a group information guided smooth ICA (GIG-sICA) based on our previously proposed GIG-ICA for brain FN analysis. GIG-sICA can be divided into two stages. First, GIG-sICA extracts group independent components (GICs) by principal component analysis and standard ICA. Second, using the GICs as references, a multi-Objective function is constructed to optimize the independence, correspondence, and smoothness of the FNs and extract noise-free individual FNs. Specially, 13 voxel features are designed to construct the graph regularization term so as to achieve denoising.

Results: Based on four groups of simulated data with different noises, the spatial accuracy of FNs obtained by our method is higher than that obtained by GIG-ICA. Based on fMRI data of 134 healthy controls and 123 schizophrenia patients, our method yields greater group differences in two-thirds of the FNs compared with GIG-ICA and achieves denoising.

Conclusion: GIG-sICA extracts accurate and smooth FNs in addition to yielding greater group differences in most of the FNs compared with GIG-ICA. Importantly, different kinds of noises can be handled independently or jointly, adaptively or knowledge-based. Taken together, our method is effective in extracting smooth brain FNs with less noise, and is helpful to identify stable biomarkers and predict brain disease.

Key words: fMRI, independent component analysis, multi-Objective optimization, smoothness and denoising.

ID 651

大脑老化引起的脑网络内在和交互联合变化

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目的：本研究旨在发现衰老如何渐进地影响全脑水平上的脑功能网络、功能网络连接以及二者之间的交互联合变化。

方法：分析了 6300 名年龄分布在 49 岁至 73 岁之间的正常被试的静息态核磁共振成像数据。基于上述数据，我们使用 NeuroMark 方法来提取脑功能网络及其连接强度，提出了一种两级统计分析方法来探索 FNC 和 FN 中与老化相关的重要变化，并且创造性地提出一种融合方法来探索 FNC 和 FN 之间的联合变化。

结果：老化不仅影响着 FN 激活与 FNC 强度，还与它们之间联合变化有显著联系。联合变化主要涉及默认模式网络以及皮下层网络。此外，连接强度减弱的 FNC 与其相连的 FNs 之间主要存在协同变化，而连接强度增强的 FNC 与其相连的 FNs 以矛盾变化为主。

结论：本研究强调了大脑衰老的多样性，并为整个大脑的非病理性衰老提供了新的证据。

关键字：人类大脑老化；静息态核磁共振成像；脑功能网络；大样本；NeuroMark

ID 659

Explore the Effect of the Full Width at Half Maximum in Brain MRI Classification

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Objective: Full width at half maximum (FWHM) is an important parame-ter for the feature extraction of brain magnetic resonance imag-ing (MRI) preprocessing. Our previous study has confirmed that different FHWM values will significantly affect the classifi-cation performance of the convolutional neural network (CNN). However, the internal mechanism has not been revealed.

Methods: Information entropy is an important indicator of the spatial characteristics of gray matter (GM) density map, which may explain the relationship between FWHM values and classification accuracy. In this study, feature transfer learn-ing was used, and the AlexNet was taken as the basic CNN model. The T1-weighted MRI data from the ADNI database, included 191 Alzheimer's disease (AD) patients and 103 cognitive normal (CN) subjects. Extracted the GM density map features of convolution layers that play important roles in classification. The FWHM values were set 0 mm, 4 mm, and 8 mm respectively, then calculated the information entropy of each feature map. Furthermore, compared and analyzed the relationship among information entropy, FWHM value, and classification accuracy.

Results: The results showed that when FWHM = 0 mm, the infor-mation entropy and classification accuracy were both the high-est. And the values are completely opposite of FWHM = 8 mm.

Conclusion: It follows that information entropy can provide some explana-tion of why the FWHMs on CNN classification. This study also provides a reference for parameter selection of MRI prepro-cessing in the future.

Key words: FWHM, Information entropy, Transfer learning, Gray matter density map, AlexNet

ID 668

An Attention Guided Multi-scale Network with Channel-enhanced Transformer for Coronary Arteries Segmentation

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Objective: Coronary artery disease is a major cause of mortality and morbidity. Automatic segmentation of the coronary artery is a key step for the diagnosis of coronary artery disease. This study aims to propose an attention guided multi-scale fusion network with channel-enhanced Transformer for automatic segmentation of coronary arteries on coronary computed tomography angiography (CCTA).

Methods: To improve the segmentation performance, an attention guided multi-scale fusion (AGMF) module and channel-enhanced transformer (C-Trans) module are proposed. The AGMF can effectively extract and fuse multi-layer features to locate and segment multiple small coronary arteries accurately. Specifically, the AGMF module not only can extract representative coronary artery features in the encoding process but also can accurately locate and segment coronary arteries in the decoding process. To select the effective channel features, the C-Trans is introduced to obtain the channel features with token. This module can effectively screen out the channel features in each layer of U-net to improve the accuracy of segmentation.

Results: Experimental results show that our proposed method obtains the IoU of 0.6996 and the Dice of 0.8224, which are more than 1% higher than the existing model.

Conclusion: From the results, it is found that the network outperforms the state-of-the-art 2D coronary artery segmentation method.

Key words: coronary arteries segmentation, attention guided, multi-scale fusion, channel-transformer

ID 844

Perceptual-enhanced Conditional Generative Adversarial Networks for Brain Atrophy to Tau Deposition

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Objective: Alzheimer's disease (AD) as a chronic and progressive disease, has become a major medical challenge for the elderly population. The pathogenesis of AD is mainly characterized by the hallmark pathologies amyloid-β and hyperphosphorylated tau. In this study, we propose an end-to-end generative adversarial network (GAN) model to achieve the synthesis of brain tau positron emission tomography (PET) images from existing magnetic resonance imaging (MRI). Our model, perceptual-enhanced conditional GAN, incorporates perceptual loss functions extracted from pre-trained networks to compensate for the shortcomings of traditional pixel-wise loss functions that rely on shallow sub-features, giving the model greater perceptual capabilities to oversee the training process of brain PET synthesis at multiple levels.

Methods: The proposed model is trained with 497 subjects from the ADNI cohort and validated in both an internal data-

set of 199 subjects and an independent external dataset of 61 subjects.

Results: The results show that strong correlations are found in regional uptake which is measured by Standardized Uptake Value Ratio (SUVR) at both cross-region level and cross-individual levels. The synthetic tau PET images achieve a relatively consistent agreement in characterizing the tau deposition state (kappa = 0.7039) and show excellent discrimination between different disease groups.

Conclusion: It was concluded that in the absence of tau PET images, our GAN model maybe provides an effective strategy to achieve multi-modal medical images for joint analysis in AD diagnosis.

Key words: Alzheimer's disease; Medical image synthesis; Magnetic Reso-nance Imaging; Positron Emission Tomography; Generative Adversarial Network.

ID 847

Combined Evaluation of T1 and Diffusion MRI Improves the Noninvasive Prediction of H3K27M Mutation in Brainstem Gliomas

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Objective: Objective: To establish an individualized predictive model to identify patients with brainstem gliomas (BSGs) at high risk of H3K27M mutation with the inclusion of diffusion MRI (dMRI).

Methods: Methods: A cohort of 126 patients with BSGs were respectively included. Local tumor radiomics features were extracted from T1 images, and global brain connectomics features were extracted from dMRI data. A machine learning-based individualized H3K27M mutation prediction model was generated with a nested cross validation strategy. Additionally, two predictive signatures were established using the elastic net method, and simplified logistic models were built using multivariable logistic regression analysis.

Results: Results: 21 radiomics features and 52 topological properties of brain structural connectivity network were selected to construct a machine learning-based H3K27M mutation prediction model, which achieved an accuracy of 92.11% (AUC = 0.9246) in the validation cohort. T1- and dMRI-based signatures were generated and simplified logistic models were built, which achieved an AUC of 0.8348 and 0.8551 in the validation cohort.

Conclusion: Conclusion: dMRI is valuable in prediction of H3K27M mutation in BSGs. Combining multiple MRI sequences and clinical features, the established models have good performance.

Key words: brainstem gliomas, H3K27M, diffusion magnetic resonance imaging, machine learning

ID 874

Background Interference Removal Algorithm for PIV Preprocessing Ba sed on Improved Local Otsu Thresholding

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Objective: Due to light fluctuation, noise interference, voltage change and other reasons, the background of PIV image will have different intensity of noise interference. In this paper, a PIV image background interference removal algorithm based on improved neighborhood Otsu processing is proposed, which solves the problem of large flow field analysis error caused by poor background light removal effect when there is irregular grating and other background light interference with traditional preprocessing only.

Methods: This algorithm is an improved algorithm based on OSTU. It combines the characteristics of PIV image and should have a good removal effect on the background interference of PIV image.This is an effect that other existing PIV image preprocessing algorithms cannot achieve

Results: By testing the images in PIV challenge data set, processing with traditional PIV preprocessing algorithms such as CLAHE, intensity capacity, high-pass, etc., and analyzing the flow field in PIV analysis software such as PIVLab, paraPIV, etc. The results of the flow field are evaluated by SSIM, PSNR. The algorithm proposed in this paper is used in the experimental flow field (aircraft wake vortex) and the synthetic flow field (shear field). Both SSIM and PSNR show obvious advantages (an average increase of more than 50%), indicating the effectiveness of this algorithm in dealing with the background grating type interference of PIV images.

Conclusion: In the case of grating interference, our algorithm has better preprocessing effect on PIV image than other existing algorithms.

Key words: PIV, PIV image preprocessing, Otsu threshold method, moving average threshold

ID 916

Development of the Fetal Brain Structural Connectivity Based on In-utero Diffusion MRI

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Objective: Extensive cortico-cortical connections emerge in the fetal brain during the second-to-third trimester with the rapid development of white matter fiber pathways. However, the early establishment and prenatal development of the brain's structural network are not yet understood.

Methods: In this work, we used in-utero diffusion MRI data of fetuses from 26 to 38 gestational weeks to build brain structural connectivity networks (SCN). Graph theory was adopted to investigate the developmental patterns of fetal brain SCN.

Results: Network analyses revealed increasing global and local efficiency, modularity, and small worldness of the fetal brain during development. We observed the strengthening of short-range cortico-cortical connections and the weakening of long-range connections, reflecting the distinct developmental events of short and long-range fiber pathways during the studied period.

Conclusion: The fetal brain SCN underwent complicated changes during the late-second-to-third trimester. The findings of this study provided valuable information on the early developmental patterns of brain cortico-cortical structural connectivity.

Key words: fetal brain, diffusion MRI, structural connectivity network, normal development

ID 1457

胰腺肿瘤半自动精细勾画方法研究

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目的：自动且精准勾画胰腺肿瘤靶区是辅助医生制定优质放疗方案和确定放疗剂量的根本。然而，患者差异和待勾画的医学图像数量巨大给医生手工勾画带来了很大的挑战。尽管目前自动分割模型被广泛采用以解决这一挑战，但胰腺肿瘤的分割精度仍有待提高。为此，本研究提出了一种按一定 CT 图像层数进行分块预测胰腺肿瘤靶区的方法，设计了一个靶区半自动勾画方案，用于辅助医生精准、快速勾画肿瘤靶区，提高诊治效率。

方法：具体来说，集患者 CT 图像若干层为一个分块，将其和对应的首尾层标签分别作为模型的两个通道，经过 3D Res U-Net 等改进模型的训练，预测出每个分块的勾画轮廓。此外，还引入了联合指标，对每例患者预测结果进行三分类。

结果：在广东省中山大学肿瘤防治中心提供的 11 例病人测试数据集上，本研究对胰腺肿瘤靶区勾画的 DSC 系数为 89.42%±2.89%，NSD 系数为 96.85%±1.90%，HD95 系数为 3.4650±0.7096mm，勾画结果优于现有的大多数方法。

结论：对一例患者靶区平均耗时 4.5 分钟，相比手工勾画平均每 61 分钟一例患者，本研究在减少医生工作量上具备显著优势，在临床应用上有望帮助医生提升工作效率。

关键字：半自动勾画；分块预测；深度学习；胰腺肿瘤

ID 1908

基于光纤式压力传感器的 PET/CT 呼吸信息分析系统研发

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目的：PET/CT 扫描是一种先进的分子影像学技术，主要应用于心脏、肿瘤等重大疾病的早期发现和诊断。为了减少 PET/CT 中患者呼吸运动引起的成像伪影，主流的呼吸控制方法是呼吸门控技术。由于系统存在在线分析的需求，且原始呼吸信号存在体动干扰严重、呼吸频率不稳定等问题，信号分析存在诸多困难。

方法：主要基于光纤型压力传感器，研究并开发呼吸运动信息的实时分析软件系统。本文提出了一种基于傅里叶分解自回归时序模型的呼吸信号降噪算法，提出了奇偶检测和间隔检测的差分极值判断算法，减小了计算复杂度，并保证了低延时和高识别精度，进行了软硬件集成。

结果：与现有传统方法相比，本文方法检出平均延时小于 150ms（现有方法约 300ms）；时相分割相对误差约 1%（现有方法约 5%）。

结论：本研究显著提升了现有呼吸分析方法的分割效率和精度，将有助于提高 PET/CT 扫描的成像质量与效率。

关键字：呼吸门控；PET/CT ； 生理信号处理；时序回归模型

ID 1965

基于影像组学方法的 0-5 岁儿童脑龄预测

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目的：脑龄（BrainAge）是一种用于评价大脑发育或衰老是否正常的生物标志物，儿 童脑龄的精确预测可以用于判断儿童脑发育是否处于正常状态。本研究旨在提出一套基于多 模态磁共振图像和多种机器学习方法进行 0-5 岁儿童脑龄的精确预测。

方法：使用基于两种影像组学特征提取方法——影像组学一阶灰度特征提取及影像组学全特征提取，与五种机器学习建模方法（支持向量机回归 SVR、高斯过程回归 GPR、相关向量回归 RVR、K 邻近回归 KNR、随机森林回归 RFR）。

结果：每种方法所获得的最佳平均绝对误差（MAE）和相关系数 R 方值如下所示：SVR：MAE=230.12d，R=0.68；GPR:MAE=92.72d，R=0.96；RVR：MAE=155.12d，R=0.86；KNR：MAE=185.29d，R=0.78；RFR：MAE=93.19d，R=0.95。

结论：本研究探索了基于影像组学的不同特征提取方法、脑龄预测建模方法、磁共振不同模态图像对脑龄预测精度预测的影响，并对 0-5 岁这一年龄 段的儿童脑龄进行了最佳精度为 MAE=92.72d 的精确预测。

关键字：脑龄；磁共振；机器学习；影像组学

ID 2330

基于 IVOCT 图像的冠状动脉钙化评分系统

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目的：针对 IVOCT 图像的钙化评分对指导临床支架植入手术的选择有很大意义，本文提出一个基于 IVOCT 图像的钙化评分系统，以减少医生工作量及主观误差的引入。

方法：基于 25 个 IVOCT 回撤数据，提出的钙化自动评分系统包含两部分，一是从回撤中检测出钙化位置。将图片在角度方向切割成“patch”，即每个 patch 包含相同数量的 A-Line。具体包含多少 A-Line，我们进行了实验确定。用训练好的 ResNet-18 作为 patch 的分类网络，并在整个回撤上进行测试。二是在检测出的钙化邻域进行钙化分割。由于 OCT 成像各组分灰度值差异不大，采用模糊聚类进行钙化无监督分割，有效避免了手工分割引入的误差。在聚类后，采用条件随机场对结果进行修饰。基于钙化计分标准和分割结果，最终进行钙化评分。

结果：本系统判别一帧 OCT 图像是否有钙化的灵敏度是 0.95；patch 中是否含有钙化的灵敏度是 0.83。无监督分割灵敏度为 0.76，Hausdorff 距离为 44.36。针对四个回撤，系统最终的钙化评分与专家评分一致。

结论：本系统实现了一个对数据标记依赖小、所需数据量少、鲁棒性高的 OCT 钙化自动评分系统，对临床支架植入手术的选择有指导意义。

关键字：IVOCT；钙化评分；模糊聚类；全连接条件场

ID 2454

早期阿尔兹海默痴呆的多模态连接组学变化与评估识别

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目的：阿尔兹海默症是常见的疾病进程漫长的神经退行性疾病，是痴呆的主要病因之一，常使用临床痴呆评定量表进行临床诊断与评估。为了探究痴呆早期中枢神经机制的纵向变化机理，并构建影像学标志物到痴呆量表的客观映射关系。

方法：使用 OASIS 公开数据库的磁共振影像数据构建脑网络的功能连接与结构连接，这些数据包括 133 名健康老化个体、65 名扫描时处于健康状态但在随访中诊断为可疑痴呆的个体以及 39 名扫描时已经处于可疑痴呆状态的被试者，探究连接组学特征的纵向变化机理，进一步使用 455 名被试者连接组学特征构建逻辑回归模型，构建影像与痴呆量表的客观映射。

结果：结果显示潜在痴呆群体的默认模式网络早在认知正常的阶段就已经出现结构功能异常，痴呆早期的逻辑回归 CDR 分类器平均分类准确率约为 85%。

结论：上述发现可能提示着痴呆早期中枢神经系统的潜在变化，并作为临床医生早期痴呆诊断的辅助与参考。

关键字：阿尔兹海默痴呆；多模态磁共振成像；连接组学；临床痴呆评定量表；痴呆早期评估

ID 2705

人工智能在青光眼辅助诊疗领域的研究现状与发展趋势

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目的：青光眼是全球致盲性最大的眼科疾病之一，由于其早期起病隐匿，持续发展，临床医学面临着青光眼早期筛查、诊断和病程预测等一系列重要课题。

方法：近年来，随着人工智能在医学领域的应用日益广泛，基于日益成熟的机器学习和深度学习技术，青光眼辅助诊疗研究不断推进，展现出数字化、智能化的发展趋势。通过对海量医疗数据中关联规则和潜在特征的挖掘和归纳，AI 模型对青光眼的医学判断效率与准确率逐渐提高，一方面降低了患者的临床检查成本，另一方面也促进了医学研究者对青光眼的理解。

结果： AI 在医学图像领域的技术辐射作用，揭示了开拓青光眼医疗干预新手段的潜在可能。

结论： 本文总结了 AI 在青光眼筛查、诊断和病程预测领域的进展，分析当前 AI 青光眼辅助诊疗领域亟需解决的困难与挑战，并展望其应用前景和发展趋势。

关键字： 青光眼；人工智能；筛查；诊断；预测

ID 2946

基于自适应波束合成的无造影超快超声微血流成像

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目的： 显示微细血管结构具有重要的临床价值，例如根据肿瘤供血情况进行良恶性判断、肾脏移植的移植术后观察等。一般基于超快超声平面波发射的无造影微血流成像由于缺乏发射聚焦，存在图像对比度、分辨率差的缺点。本研究提出了一种基于自适应波束合成的无造影微血流成像方法。

方法： 对各个角度精确延时后的回波信号进行基于时间向量的自适应壁滤波，然后对这些数据进行基于协方差矩阵的相位模量相干因子加权的波束合成，最后计算多普勒功率以获取高质量的无造影微血流图像。分别从仿真、人体肾脏和肝脏数据上对该算法进行验证。

结果： 引入自适应的波束合成可以使图像信噪比提高 18.15%~33.72%，噪声对比度提高 .01%~13.45%。

结论： 该技术能显著增强慢速血流的显示，并抑制不相干的噪声成分，对临床的监测具有重大意义。

关键字： 超快超声平面波；无造影微血流；自适应波束合成；壁滤波；协方差矩阵

ID 3051

基于多尺度边界感知的 Transformer 多模态 MRI 脑胶质瘤分割

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目的： 多模态 MRI 脑胶质瘤分割中，肿瘤区域在各模态中表现各异，可能有模糊边界，这使得该任务具有挑战性。

方法： 以 VT-UNet 为框架，Transformer 中引入了多尺度边界感知的模块，提取肿瘤跨模态特征，同时利用各阶段 VT 编码器模块前引入的边界感知模块，提取肿瘤多尺度边界信息并生成特征图。为缓解肿瘤模糊边界问题，利用肿瘤轮廓关键点构建模糊边界热力图，计算其与边界感知模块生成特征的交叉熵损失，监督模型优化。

结果： 本文在 BraTS2021 数据集上进行实验，方法在肿瘤整体、肿瘤核心和增强肿瘤上的 Dice 分数分别为 93.1%、90.5% 和 86.8%，95% 豪斯多夫距离分别为 3.94mm、3.42mm 和 3.04mm。在模糊边界数据上，本文方法的 95% 豪斯多夫距离较 U-Net 及原始 Transformer 有显著提升。

结论： 本方法在模糊边界数据上可以提升弱边界肿瘤的分割精度。

关键字： 脑胶质瘤分割；多模态 MRI；Transformer；边界感知

ID 3413

基于混叠去除的多角度复合矢量血流成像

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目的：动脉狭窄是造成脑梗塞、心肌梗塞等心脑血管疾病的主要原因。血流速度的精确估计对于动脉狭窄疾病筛查和快速诊断起着重要的作用。超声凭借无创、实时成像、价廉等优点，成为最可行的心脑血管疾病筛查手段。传统超声血流速度检测方法仅限于测量血流沿着超声波束方向的速度分量，不能准确测量血流速度。

方法：本文提出了多角度发射复合联合多接收角度方法进行矢量血流成像，并引入交错三重 PRF 算法，有效去除一次混叠与二次混叠，恢复复杂血流场中的真实血流速度。

结果：经仿真与仿体实验验证，多角度复合联合多接收角度方法可以有效提升图像质量和速度估计精度，仿真实验成功将奈奎斯特速度扩展 4.5 倍，降低有效脉冲重复频率（pulse repetition frequency，PRF）。旋转圆盘实验量化评估结果表明，矢量求解算法对于涡流情况同样适用。

结论：矢量求解算法对于涡流情况同样适用，这对于具有复杂血流模式的血管病变筛查以及血流动力学参数研究都具有重要意义。

关键字：矢量血流成像；多角度复合；速度混叠；交错三重 PRF

ID 3438

基于深度学习的血管内超声图像斑块分类方法

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目的：血管内超声技术对冠状动脉血管斑块的分类具有重大意义，但由于血管内超声图像分辨率小、存在伪影与噪声，使得难以对图像进行准确分类。本文提出一种基于 ResNet 与通道注意力机制的血管内超声图像斑块分类方法，以解决冠状动脉斑块的三分类问题。

方法：在 ResNet18 结构的基础上提取血管内超声图像不同大小类别特征，采用 SENet 建模特征通道间信息并进行矫正，在 20MHz 相控阵探头的 S5 型号血管内超声设备上采集的 200 例病人的 1500 张训练集和 500 张验证集上对上述方法进行训练和测试。

结果：模型分类准确率达到 97.16%，训练后损失为 0.0675，优于大部分常用图像分类模型。

结论：该方法在血管内超声图像管腔斑块的分类任务上具有良好分类精度，能够准确进行纤维斑块、钙化斑块、脂质斑块的识别。

关键字：血管内超声图像；深度学习；分类；ResNet ；通道注意力机制

ID 3532

具有 MUSE 的磁共振高分辨率弥散成像方法研究

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目的：磁共振扩散加权序列在肿瘤诊断、中风等级评估和神经研究等方面有着独特的优点，已经作为临床扫描的标准序列。但是传统单激发扩散加权序列的图像畸变大，分辨率受限。为了提高扩散成像的分辨率，将其应用到更多的临床场景中，目前采用多激发扩散成像的方法来实现。

方法：为了提高扩散成像的分辨率，将其应用到更多的临床场景中，目前采用多激发扩散成像的方法来实现。

结果：与传统方法相比，MUSE-DWI 通过结合多激发 DWI 序列和高级重建方法，改进了矩阵的反演条件，拥有更好的信噪比和更高的空间分辨率，进一步提高了成像质量。

结论：基于 MUSE(multiplexed sensitivity-encodingdiffusion-weighted imaging，MUSE-DWI) 的高分辨率扩散成像方法，能够最大限度地降低图像变形、减少磁敏感伪影，提高成像质量。

关键字：磁共振成像 ; 复合灵敏度编码 ; 扩散加权成像

ID 3552

Light-sheet Laser Speckle Imaging for 3D Vascular Visualization

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Objective: In this paper, we report a novel light-sheet laser speckle imaging method that can be used to visualize the three-dimensional blood flow distribution due to its instinctive optical sectioning capability. This method overcomes the poor visibility of the 3D vasculature in traditional laser speckle imaging methods.

Methods: Raw laser speckle images can be analyzed by the temporal laser speckle contrast imaging method. When the raw speckle images are acquired with an ultra-high frame rate, and ultra-low exposure time, the instantaneous speckle intensity will be recorded. The faster the red blood cell moves, the faster the intensity value of the speckle changes. To quantify the degree of change, the K value is calculated, which is the ratio of the standard deviation of the pixel intensity values σ to the mean intensity I in raw images.

Results: For light-sheet laser speckle imaging, these reconstructed 2D images were aligned and combined into a 3D image stack, with each slice mapped to a thin layer of the probed tissue volume. The normal distance between neighboring slices was about 25

Conclusion: In conclusion, we have developed a novel light-sheet laser speckle imaging system that has an excellent optical sectioning ability. The sample can be scanned by the light sheet for acquiring multilayers. The transmission PIV analysis comparison demonstrates that the proposed light-sheet laser speckle imaging has great potential for 3D vasculature reconstruction. It should be possible to achieve an even better axial resolution closer to the lateral resolution by scanning

the same tissue volume with a smaller step size and reduced light sheet thickness.

Key words: laser speckle, 3D, vasculature, light sheet

ID 3553

A Framework for Analysis of Major Depressive Disorder

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Objective: Early detection of Major Depressive Disorder (MDD) remains a significant challenge in the field of mental health. This work proposed an end-to-end deep learning framework designed to extract features from 52 channels of functional near-infrared spectroscopy (fNIRS) and aid in the diagnosis of MDD.

Methods: We began by investigating the performance of various deep learning models as the core model of the framework. Next, we implemented the novel deep learning framework, which employed an optimized model for MDD classification. We compared the performance of deep learning models with and without the framework. In addition, we leveraged a traditional machine learning model, Support Vector Machine, to analyze single fNIRS channel in order to gain a deeper understanding of the impact areas of MDD.

Results: The proposed framework, with convolutional neural network as the core model, achieved the highest classification accuracy of 82.4% on the test set of a large dataset of 374 subjects (including 181 MDD subjects and 193 healthy controls). Moreover, our framework improved the performance of deep learning models by 3.7%. Furthermore, the results from classification accuracy of single channel revealed the crucial role of the dorsolateral prefrontal cortex, pre-motor and supplementary motor cortex, as well as Broca's area in detection of MDD.

Conclusion: With the potential to help detect MDD at an earlier stage, the implementation of deep learning architecture such as the proposed framework into clinical practice could prove invaluable in the treatment of MDD.

Key words: Major depressive disorder, Deep learning, Functional near-infrared spectroscopy, Convolutional neural network.

S03
脑器交互（含脑机接口）与神经工程
Brain-Apparatus Communication and Neural Engineering

ID 357

Effect of Age-related Hearing Loss on Mice Cochlear Structures based on Optical Coherence Tomography

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Objective: With the increasing proportion of the elderly in the population, age-related hearing loss (ARHL) impacts the daily life of seniors and increases society's economic and medical burden. However, the change in the cochlear structures with age is still unknown. The emergency of Optical Coherence Tomography makes it possible to observe the cochlea in vivo. In this article, we aim to observe the changes of cochlear structures with the growth of age and the degeneration of hearing in mice.

Methods: We used Optical Coherence Tomography to obtain the images from mice of different ages, acquired the changes in the thickness of cochlear bone and modiolus, and analyzed the signal intensity of the round window and stria vascularis.

Results: We found that the thickness of the cochlear bone became thicker while the signal intensity became lower with the growth of age and the degeneration of hearing.

Conclusion: These results not only prove the feasibility of OCT which can observe the structural changes of the cochlea but also indicate that age may affect the overall structure of the cochlea, especially stria vascularis, which may deepen our understanding of ARHL.

Key words: age-related hearing loss, optical coherence tomography, cochlear structure, in vivo imaging

ID 413

Alpha Neurofeedback Training Effects on State Anxiety

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Objective: We aimed at testing the effect of one single session of alpha up regulation NF training for high-level state anxiety modulation in healthy individuals, including a sham NF group to assure these goals. We expected both group changes of improvement as measured through Objective changes of D scores and neurophysiological correlates (EEG alpha band power analysis) in the real group.

Methods: A total of 30 right-handed university students， the experiment adopted a single NF training session to explore whether the alpha upregulation NF training was equally appropriate to reduce the high level of state anxiety. The TSST was first used to induce a high level of state anxiety, where heart rate (HR) was measured. Meanwhile, STAI was performed to measure anxiety level before and after TSST. Then NF training, individual state anxiety changes were measured by IAT anxiety before and after training

Results: The results showed that the pre and post-resting alpha power in the real NF group were significantly improved, while sham NF group was not significantly changed. The state anxiety decreased in both groups, while the real NF was not significant and the sham NF showed significantly. Regarding the correlation between alpha power and behavioral data during resting state and training, we found that the difference between alpha power and D score was a negative correlation in both groups, but non-significant.

Conclusion: One single session of alpha upregulation NF training could successfully increase the alpha power but did not show specific effects on state anxiety. Future work can include a larger sample size and better anxiety induction task to examine NF training effects on state anxiety.

Key words: Alpha, neurofeedback training, state anxiety, EEG

ID 594

An Improved Canonical Correlation Analysis for EEG Inter-band Correlation Extraction

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Objective: As the most active and promising research fields of affective computing, emotion recognition based on EEG signal has attracted much attention. Traditional Methods usually pay their attention on single-channel features which reflect time-domain, or frequency-domain of EEG and bi-channel features which reflecting channel-wise relationship across brain regions. However, emotional features which capturing the coupling between the EEG frequency bands was seldom to discuss.

Methods: We proposed a method to extract the inter-bands correlation (IBC) features based on canonical correlation analysis (CCA).

Results: Firstly, we verified the validity of the IBC features through several experiments and found that the more correlated features between the EEG frequency bands contribute more to emotion classification. Then, the IBC features and traditional differential entropy (DE) were fused at the decision-level, which significantly improves the accuracy of emotion recognition on SEED dataset and local CUMULATE dataset.

Conclusion: IBC features is a promising method to promote the emotion recognition accuracy.

Key words: EEG, IBC, CCA, DE, Decision-level fusion

ID 610

Gender modulates Visual Attention to Emotional Faces: An Eye-Tracking Study

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Objective: Autism spectrum disorder (ASD) is a neurodevelopmental disorder with a high prevalence in males. Most studies are based on the sample of male ASD individuals, which may lead to a bias in understanding female ASD individuals. Not only in the diagnostic characteristics, but also in the social cognitive performance, gender differences have been found in the ASD population, but the reason is still unclear. It remains to be studied whether the gender differences in the visual processing of emotional faces are due to the pathology of ASD or to differences in visual processing between males and females.

Methods: we employed eye-tracking technology, designed a dynamic facial emotion discrimination task, and recruited typically developing adults as participants. We calculated the behavioral response accuracy, response time, preference index, and pupil variation as characteristics.

Results: Results showed that the two groups had similar accuracy for facial emotion discrimination, but males spent more time. In addition, males preferred the mouth region during the processing of emotional faces. On the other hand, females preferred to fixate on the eye region, and had greater physiological responses to this region than males.

Conclusion: These findings suggest that males and females differ in their visual processing strategies and sensitivity to emotional faces, which may extend to the ASD population.

Key words: Gender, Facial emotion, Eye movement, Visual attention, Autism spectrum disorder

ID 786

Virtual Reality Game-Based Adaptive Neurofeedback Training for Motor Imagery

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Objective: Motor imagery-based brain-computer interfaces (MI-BCIs) have great application prospects in motor rehabilitation. However, neurofeedback training (NFT) of traditional MI is boring and takes a long time. This study aimed to investigate whether adaptive NFT in virtual reality (VR) scenes could improve MI-BCI performance.

Methods: In this study, we proposed a VR game-based MI-BCI paradigm which contained left and right upper limbs MI tasks. In the course of training, the system could adaptively adjust the game difficulty and dynamic output decoding result according to the training performance of individuals. Six subjects participated in the experiments.

Results: After three days of NFT, the activation of the motor cortex was enhanced. The average accuracy of MI tasks reached 83.52%, with an increase of 10.46%, compared with before training.

Conclusion: The results demonstrate that the adaptive NFT system based on VR games proposed in this study has a good effect on MI performance and is expected to be used in rehabilitation training and treatment for stroke.

Key words: Motor imagery; Virtual reality game; Electroencephalogram; Event-related desynchronization; Neurofeedback Training

ID 880

Effects of Sequence Order on Motor Imagery based on Observing and Delayed Matching Task

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Objective: Motor Imagery (MI) is one of the widely used paradigms for BCI, and its signal is an endogenous EEG signal that is not dependent on external stimuli. The performance of brain computer interfaces (BCI) based on motor imagery is influenced by the way people imagine. Action sequences are the basic units for imitating, learning, and remembering motor behaviors, and it is unclear whether action sequences affect MI-BCI.

Methods: This study proposes a task paradigm with different sequence order to investigate the effect of sequence order on MI by using images and videos to guide people to observe, match and reinforce sequence memory. The MI performance of four subjects is analyzed under different sequence order.

Results: The test results show that different sequence order leads to different MI classification accuracy, with positive sequence acting with 9.69% higher MI classification accuracy than negative sequence ($p<0.05$).

Conclusion: The study shows that the sequence order has a significant effect on MI. It is expected that the study in this paper may provide a new perspective for improving MI- BCI imaging.

Key words: Action observation, Sequence order, Brain-computer interfaces, Motor imagery

ID 962

基于联合约束典型相关分析的大脑精细功能子区划分

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目的：使用功能磁共振成像数据进行基于连接的大脑区域划分会受到老年或者患病人群异质性的影响，特别是在数据需要空间配准到标准模板时，这种影响不可忽略。

方法：本研究提出了一种群组引导的大脑精细功能子区划分模型，能够同时在多个被试的个体空间中，得到目标脑区的子区划分，并保证了群组水平上一致的连接模式。模型是基于联合约束典型相关分析方法，在允许不同个体待划分脑区的数据维数不同的情形下，实现个体化可重叠的功能子区划分。

结果：在仿真数据和真实数据上的大量实验证明了提出的模型与传统方法相比具有优越性。将该模型应用于帕金森病被试和健康对照的功能磁共振数据来估计壳核的子区时，得到的划分结果和连接模式呈现出显著差异。优秀的分类和回归结果证实了该模型在临床应用中的潜力。

结论：本研究为大脑功能区域划分提供了一种新方法，有助于研究帕金森病以及其他大脑相关的疾病。

关键字：大脑连接网络，大脑区域划分，功能磁共振成像，典型相关分析，帕金森病

ID 1155

基于亮度和运动同步调制的新型 SSVEP 脑机接口系统

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目的：基于稳态视觉诱发电位的脑机接口由于其高信息传输率和所需训练少而受到广泛关注。以往基于 SSVEP 的 BCI 系统大多采用固定的视觉闪烁，只有少数研究探讨了移动视觉闪烁对 SSVEP-BCI 的影响。

方法：提出了一种基于亮度和运动同时调制的新型刺激编码方法。采用正弦采样刺激编码方法来编码刺激目标亮度变化的频率和相位。除亮度调制外，刺激目标也同时以不同的频率（即 0、0.2、0.4 和 0.6 Hz）按正弦函数进行左右水平移动。因此，该研究构建了一个 9 目标的 SSVEP-BCI 系统来评估运动调制对 BCI 性能的影响。滤波器组典型相关分析（FBCCA）方法被用来识别刺激目标。

结果：17 名受试者的离线实验结果显示，系统性能随着叠加的水平周期运动频率的增加而下降。在线实验结果显示，叠加的水平周期性运动频率为 0 和 0.2 Hz 时，目标识别准确率分别为 85.00% ± 6.77 % 和 83.15% ± 9.88%。这些结果验证了所提出的系统的可行性。水平运动频率为 0.2 Hz 的系统为受试者提供了最佳的视觉体验。

结论：移动的视觉刺激可以为 SSVEP-BCI 的刺激编码方法提供一个选择方案，可基于本研究所构建的范式开发出更舒适的 BCI 系统。

关键字：脑机接口（BCI）；稳态视觉诱发电位（SSVEP）；移动视觉刺激；亮度调制；运动调制

ID 1162

基于脑电网络判别空间拓扑图的实时情绪识别系统

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目的：基于脑电信号的情绪识别研究已成为情感计算领域的研究热点。为了揭示不同情绪状态下大脑信息加工模式差异、进一步提高情绪识别稳定性。

方法：我们利用情绪 EEG 信号构建不同情绪状态下的脑电网络，并通过监督学习策略挖掘不同情绪状态脑电网络的判别图拓扑特征，从而实现对情绪脑电状态的有效刻画、提升情绪识别性能。基于所提模型，我们构建能实现个体情绪状态实时解码的在线情绪监测系统。

结果：为验证模型的稳定性，我们公开招募 14 名被试开展在线情绪状态解码也监测试验，并得到 84.56% 的在线情绪解码准确率。

结论：所提模型能有效捕获情绪脑电网络的判别图拓扑模式，提高情绪识别性能，这为阵列信号的提取特征提供了一种潜在的解决方案。

关键字：情感计算；情绪识别；EEG ；脑网络；实时情绪解码

ID 1284

多模协变网络的宏观结构和微观转录研究：认知和疾病相关的分子 - 结构 - 功能共变

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目的：人类高级认知功能通常由大脑内在解剖结构和瞬时功能神经活动协同完成，然而，大脑中结构 - 功能回路是如何相互作用以促进高级认知处理仍不清楚。

方法：提出了一种多模协变网络（multimodal covariance network, MCN）构建的新方法，量化大脑结构 - 功能活动的协变耦合，并在两批独立数据集中验证了 MCN 的高度可复制性及在识别认知特异性层级模块方面的能力。

结果：将 MCN 方法应用到各高级认知过程中发现：1）P300 任务下相关子网络的结构 - 功能共变显著增强，揭示了从基线到任务执行切换过程中大脑资源的重配模式；2）MCN 效率高的个体倾向于做出冒险决策，表明大脑可通过配置其结构 - 功能共变而使其利益最大化；3）静息态 MCN 可反映大脑中与年龄变化相关的认知灵活性；4）采用脑网络和转录组学融合模型探究了抑郁患者 MCN 异常模式与脑基因表达的关系，揭示了与抑郁症异常模式相关的基因富集在与突触相关的通路。

结论：以上发现为 MCN 在诸多领域的应用提供完善的神经理论基础。

关键字：多模协变网络；P300 ； 决策； 认知灵活性； 抑郁症

ID 1340

基于 SSVEP 和 sEMG 的无监督 32 目标混合脑机接口拼写系统

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目的：脑机接口旨在大脑与外部环境之间建立直接通道以帮助运动障碍者，拼写系统是其最常见的应用之一。本研究采用高频稳态视觉诱发电位和表面肌电构建混合 BCI。

方法：本研究基于高频 SSVEP 和 sEMG 设计并实现了 32 目标混合 BCI 拼写系统。32 目标被分为 2 组，每组 16 个目标通过 16 个不同的高频视觉刺激（31-34.75 Hz，间隔 0.25 Hz）进行编码。使用 sEMG 信号选择组，并采用 SSVEP 来确定组内目标刺激。采用滤波器组典型相关分析和均方根值法分别检测 SSVEP 和 sEMG。因此该系统允许用户无需校准即可使用。

结果：12 名健康受试的在线结果表明系统的平均准确率达到 93.52%±5.26%，平均信息传输率为 95.50±9.80 bits/min，并且所有的受试者使用该系统成功完成自由拼写任务。

结论：离线和在线试验结果表明所提出的混合 BCI 拼写系统的可行性和实用性，这些结果将为结合 sEMG 和 SSVEP 的混合 BCI 提供基础。

关键字：脑机接口；稳态视觉诱发电位；表面肌电；滤波器组典型相关分析

ID 1373

脑卒中患者皮质肌肉相干的影响因素

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目的：探讨影响卒中患者 CMC 的因素。

方法：首先讨论了 CMC 的机制及其定义公式；其次分别阐述了多种因素对卒中患者 CMC 的影响；最后对当前 CMC 研究存在的问题以及 CMC 的未来发展做了说明。

结果：总结当前对 CMC 研究热点的分类和比较，影响卒中患者 CMC 的因素包括但不限于不同的波段、实验设置 , 卒中部位和时期。

结论：CMC 仍有许多需要我们继续探索和发展的领域。比如，我们已经极大关注了皮层振荡和肌肉活动之间耦合的线性部分，即所谓的皮质肌肉相干性，然而作为运动控制基础的神经元通讯已经被证明是高度非线性的。全面评估皮质肌肉耦合，包括非线性部分，对于理解感觉运动系统内的神经元通讯至关重要。另外，视觉增益对 CMC 的作用是当前一大研究热点，有研究发现年龄对 CMC 的影响取决于提供给受试者的视觉反馈的数量，这表明在未来的研究中，视觉增益应该得到控制。可以预见，未来 CMC 研究有望取得更多的进展，为人类运动控制和学习新动作提供更多的见解，并为治疗神经疾病提供新的途径。

关键字：皮质肌肉相干；脑卒中；影响因素

ID 1456

基于域对抗网络的多类情绪分类迁移学习

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目的：情绪脑机接口已经获得越来越广泛的关注，但是受限于脑电信号采集的困难，当前研究多基于三分类的情绪研究，四分类情绪的研究较少，五分类情绪几乎没有。而多分类情绪识别迁移学习的研究近年来几乎没有，为了填补在多分类情绪识别迁移学习上的空白，本文就基于四分类和五分类情绪的 SEED-IV 和 SEED-V 数据库，研究一种域对抗网络的迁移学习算法

方法：通过构建一个域鉴别器来调整分类网络，使得分类网络能提取源域和目标域的共同特征，在保持对源域分类准确率的情况下，也能对目标域有良好的分类效果。通过增加梯度反转层，网络同时优化分类网络参数和域鉴别器参数，加速网络训练。

结果：本文的方法在 SEED-IV 和 SEED-V 中分别取得了 62.41% 和 71.66% 的平均正确率。

结论：通过对比迁移成分分析，Easy TL 和深度领域混淆算法（DDC），本文的方法在 SEED-IV 和 SEED-V 的平均准确率相较于最优秀的 DDC 提高了 9.15% 和 7.85%。，说明本方法在多分类情绪识别迁移学习中，有最好的效果，对比之前的四种方法提升明显。

关键字：多分类情绪识别；迁移学习；DANN ；MobileNet

ID 1594

一种基于多频通道相关性的运动想象脑机接口通道选择方法

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目的：基于运动想象的脑 - 机接口技术可以从受试者的脑电信号种解码出运动意图，并将其转换为控制信号应用于 BCI 系统。脑电信号采集通常使用较多的脑电通道数量，以提高总体信息量和分类精度。但其中会包含与 MI 任务无关或冗余的通道，影响 BCI 系统的性能。

方法：针对 MI-BCI 系统的通道选择问题，提出一种基于相关性的多频带脑电通道选择方法 (FB-CCS-CSP)，它结合了多频带信号分解滤波和基于相关性的通道选择方法 (CCS) 来选择多频段的最优通道，利用共空间模式 (CSP) 提取各个频段选定通道的 EEG 特征，将特征拼接后训练 SVM 分类器识别分类任务。

结果：与使用 CSP 提取全部脑电信号特征方法相比，FB-CCS-CSP 方法获得了更优的分类准确率 (82% 对比 70%)；与 CCS-CSP 提取全部频段特定通道脑电信号特征方法相比，FB-CCS-CSP 方法也获得了更优的分类准确率（82% 对比 78%），同时使用了更少的通道数量 (29 对比 40)。

结论：所提出的 FB-CCS-CSP 方法可以为进一步个性化 BCI 系统设计，提高 BCI 表现提供了有益工具。

关键字：脑机接口；运动想象；通道选择；

ID 1836

增强现实环境下两种视觉刺激编码的脑机控制方法

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目的：基于视觉诱发的脑机接口（BCI）由于高鲁棒性、训练量小、信息传输率高等优点，得到广泛应用，将其与增强现实（AR）相结合能够提供沉浸、自然的人机交互体验。但已有的 AR-BCI 研究存在自由度控制或动作控制离散的问题，即每种脑电模式控制系统或设备的一个自由度或执行某个固定动作，处于离散自由度控制或离散动作控制。这导致完成一项任务需要用户多次使用脑机接口下达指令，控制过程繁琐，降低用户体验。

方法：设计了一种增强现实环境下两种视觉刺激编码的脑机控制方法，并实现了用该方法控制机械臂进行木块抓取、放置任务。该方法利用编码调制视觉诱发电位（c-VEP）范式、频率调制视觉诱发电位（f-VEP）范式的视觉刺激编码任务信息，通过分类 f-VEP 和 c-VEP 解析出控制任务，并通过有限状态机方法将任务分解为机器指令，以实现脑机协同控制。

结果：5 名被试在线结果表明，f-VEP 的平均分类正确率为 83.6%，信息传输速率为 43.85bits/min；c-VEP 的平均分类正确率为 86.5%，信息传输速率为 45.856bits/min。

结论：实验证明了该方法的可行性，为脑机接口技术的实用化和智能化人机交互提供了新思路和新方法。

关键字：增强现实；频率调制视觉诱发电位；编码调制视觉诱发电位；脑机接口；脑机协同

ID 1981

视觉刺激与同步信号时序的测量及校准

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目的： 1) 阐明串口同步信号与视觉刺激的时序及影响因素；2) 分析串口同步信号精度的影响因素；3) 设计一种高精度校准公式，可利用光标记信号准确计算视觉刺激呈现时刻。

方法： 实验一，PsychToolbox 用于控制视觉刺激和串口同步信号，逻辑分析仪用于采集信号，比较两种信号的时序，并分析 USB 转串口适配器、刷新率、刺激呈现位置的影响。实验二，使用 PsychToolbox 发送串口同步信号，逻辑分析仪采集该信号，统计信号周期并分析 USB 转串口适配器、操作系统、API 函数的影响。实验三，依据 VESA 标准设计校准公式，在显示器上选取 5 点，各点同时显示视觉刺激并被逻辑分析仪采集。任意两点为一组，两点分别作为光标记信号和视觉刺激，计算各组视觉刺激呈现时刻测量值与校准公式计算值的误差。

结果： 1) 串口同步信号超前视觉刺激出现，且刷新率越高，超前时间越小；刺激位置越向右下偏离，超前时间越大。2) 在 Linux 系统、IOPort() 函数下，串口同步信号具有较好的精度。3) 暗化过程作为光标记信号时，所设计的校准公式可推算出准确的视觉刺激呈现时刻。

结论： 所提出方法可用于优化实验设计，对提高反应潜伏期的准确性有一定指导意义。

关键字： 反应潜伏期；同步信号；校准函数；视觉刺激；时序；

ID 2238

经颅磁刺激对老年大鼠工作记忆相关跨脑区网络协同作用的影响

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目的： 经颅磁刺激 (TMS) 因其可以非侵入性地探测和调制大脑皮层兴奋性和功能，已经被广泛的应用于改善大脑认知功能等临床神经调控领域。工作记忆的功能实现需要不同脑区的协同完成，从脑区间信息交流的角度探究不同模式的 TMS 对大脑认知功能的调控作用具有重要的意义。

方法： 分别对老年 Wistar 大鼠实施重复经颅磁刺激（rTMS）及间断性 Theta 节律刺激（iTBS），并设置空白对照组；采集大鼠工作记忆任务中的局部场电位信号 (LFPs)；而后基于定向传递函数的构建脑因果网络；最后通过对比行为学结果差异、各脑区因果网络参数等，探索不同模式 TMS 对老年大鼠工作记忆行为学的影响及脑区内与脑区之间信息协同作用的影响。

结果： rTMS 组和 iTBS 组大鼠执行正确工作记忆任务的平均天数和平均正确率均高于空白对照组，并且相较于 rTMS，iTBS 脉冲串中包含有高频脉冲，对前额叶和海马中的 γ 频段信息交互具有更强的促进作用（$P < 0.05$）。经过刺激后，rTMS 组和 iTBS 组前额叶和海马双向网络连接明显增强，信息流强度和因果流向性得到明显提升（$P < 0.05$）。

结论： rTMS 和 iTBS 均能促进脑区间的信息交流，进而在一定程度上改善大鼠的工作记忆能力。

关键字： 重复经颅磁刺激；间歇性 θ 节律刺激；工作记忆；脑因果网络

ID 2424

基于多尺度原型学习的可解释癫痫发作预测深度学习模型

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目的：癫痫发作预测对提高患者的生活质量至关重要。近年来，许多基于深度学习的方法已经被开发出来解决这个问题，并取得了显著进展。然而，深度学习模型的“黑盒”特性使得临床医生对预测结果不信任，严重限制了其临床应用。因此，在本研究中，我们提出了一种本身可解释的、用于患者特异性癫痫发作预测的深度学习模型 : 多尺度原型学习网络。

方法：该模型试图测量输入与训练过程中学到的原型之间的相似度并作为最终预测的证据，这可以在得到预测结果的同时提供透明的推理过程和决策依据 (例如，输入样本对应的显著原型和相应的相似度得分)。在此基础上，为了捕捉脑电信号的多尺度特征，为不同尺度的原型分配了不同尺寸。

结果：所提出的模型在两个公开癫痫脑电数据集上进行了评估 (CHB-MIT 与 Kaggle 数据集)，在 CHB-MIT 数据集上的灵敏度为 93.8%，误报率为 0.054/h，在 Kaggle 数据集上的灵敏度为 88.6%，误报率为 0.146/h。

结论：本工作是首个开发出本身可解释的、用于癫痫发作预测的深度学习模型的研究，我们的模型能够在提供本身可解释证据的情况下实现当前最先进的癫痫发作预测性能。

关键字：深度学习；可解释性；信号处理；癫痫发作预测；脑电信号

ID 2441

基于鲁棒贝叶斯分布的静 / 动态因果网络分析及其在运动想象脑电的分类应用

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目的：有效网络分析对解释大脑功能机制具有重要影响，但如何推断强噪声下的因果影响仍然是迫切需要解决的挑战。考虑到贝叶斯推论和鲁棒重尾分布对离群值限制的强大能力，在这项工作中，提出了一种新的静 / 动态因果网络估计模型，用于有效网络推理。

方法：为了验证其去噪性能，我们同时进行了仿真实验和真实运动想象脑电信号的分类研究，以考察其对不同噪声情况影响的鲁棒性。仿真实验设计了多种离群值噪声条件 (离群值强度，离群值频率和离群值影响通道数)；此外，将所提出的方法应用于运动想象数据集并基于运动想象数据进行因果网络分析和分类性能对比。

结果：仿真结果表明，本文所提方法相比于其他方法在网络估计上均有显著性地性能提升。此外，所提出的静 / 动态因果脑网络模型所估计网络在分类精度上也优于其他方法。

结论：仿真实验和基于运动想象脑电的真实应用都证明了我们所提的静 / 动态因果脑网络估计模型面对复杂离群值影响下鲁棒捕捉固有网络结构的强大能力。除此之外，本文所提方法也可以为经济领域的数据预测、空中交通的枢纽节点定位提供一种新的参考方案。

关键字：贝叶斯理论；静 / 动态因果脑网络；拉普拉斯分布；离群值噪声；脑电

ID 2519

原位负载 Ag/AgCl 纳米颗粒柔性双网络水凝胶半干电极用于脑电、心电和人体运动的监测

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目的：发展用于脑电、心电和人体运动的多模态健康监测的柔性双网络水凝胶的传感器。

方法：通过在明胶 / 聚（丙烯酰胺 -co- 丙烯酸）双网络水凝胶（Gelatin/P(AM-co-AA)）原位负载 Ag/AgCl 纳米颗粒，构建“电子导体与离子导体一体化”的半干电极，解决了电子导体与离子导体的共性关键问题。

结果：该双网络凝胶表现出优异的机械强度，且对干、湿皮肤均具有良好的粘附性能。凝胶半干电极具有优异的非极化性能，电位漂移低至 1.06 ± 3.19 μV/min。凝胶半干电极作为柔性应变传感器可感知微弱和大应变的人体运动，且能可靠记录心电信号。凝胶半干电极能还可准确捕获预期的神经电生理响应，睁 - 闭眼和 SSVEP 范式两种电极间的平均时域互相关系数分别为 0.919 ± 0.054 和 0.912 ± 0.050。

结论：考虑到快速安装、用户友好、信号可靠等突出优点，凝胶半干电极在脑 - 机接口和可穿戴健康设备中具有广泛的应用前景。

关键字：半干电极；双网络水凝胶；脑电信号；心电信号；运动监测

ID 2522

初级运动皮层的 cTBS 增加了对侧半球皮质肌肉相干性

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目的：经颅磁刺激（TMS）是一种改变大脑皮层活动的非侵入性脑刺激技术，其中连续 theta 爆发式刺激（cTBS）作为一种特殊的 TMS 可有效抑制皮质兴奋性。但 cTBS 对对侧大脑半球皮质肌肉相干性（CMC）的潜在影响机制尚不清楚。

方法：本研究招募了 14 名健康右利手参与者，在其左侧初级运动皮层（M1）发送真 cTBS 或伪 cTBS，并在刺激前后记录左侧手指捏力任务（FPT）期间的脑电图（EEG）和肌电图（EMG）。本研究计算了 C4 通道的 EEG 和左手第一骨间背侧肌（FDI）的 EMG 之间的 CMC，并分析了各组之间的差异。

结果：双因素重复测量方差分析（ANOVA）结果显示，C4-EEG 和 FDI-EMG 之间的 beta 频带 CMC 峰值和 CMC 面积在真 cTBS 后显著增加（CMC 峰值：p = 0.007，CMC 面积：p = 0.024），但伪 cTBS 前后没有显著变化。

结论：cTBS 可以改善对侧半球的 CMC。

关键字：经颅磁刺激；连续性 theta 爆发式刺激；脑电；肌电；皮质 - 肌肉相干

ID 2578

颅内脑电信号的窄带震荡特征和功能连接计算

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目的：颅内脑电具有高时间分辨率和高质量，在脑功能研究和脑疾病诊断方面获得广泛应用。癫痫发作时经常伴随各种症状，同时可观测到颅内脑电的窄带 γ 振荡。基于相位同步的功能连接，反应了脑活动的功能整合，可能解释癫痫及其症状学的基础。考虑到电极采集的信号为宏观神经活动的总和，脑电可含有多个动态频带的同期激活。对于这类复杂信号，常规的相位计算与功能连接评估可能不准确。为了挖掘癫痫的功能整合脑区

方法：本文提出了复杂动态信号的功能连接测量方法：首先，首次提出基于二阶差分峰度的快速检测方法，定位存在窄带 γ 震荡的特异性电极；其次，采用滤波获取子频带信号，通过计算子带信号的相位同步性并融合得到总体的功能连接性。本文通过生成复杂频谱分布的脑源信号并模拟体积传导合成了脑电信号，来对方法进行验证。

结果：NER 特征相比传统的 ER 特征可以更好的评估症状学的发生。仿真实验证实，相比传统的功能连接测度，子带带宽为 20Hz 的融合相位同步方法具有最高的准确性，并在各种复杂情况下可以保持 0.95 以上的准确性。基于这些方法，本文重建了一个症状学网络。

结论：研究将可能为神经信号分析领域，特别是癫痫颅内脑电处理，提供新的工具

关键字：神经信号分析；脑电；功能连接；癫痫；窄带震荡

ID 2660

一种基于生成对抗式并行 CNN 和 Transformer 脑电降噪网络

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目的：目前，基于深度学习的脑电降噪方法已经展现出优于传统方法的降噪性能，然而它们仍然存在以下限制：现有的网络结构在设计时没有充分考虑伪影信号的时序依赖性；以及现有的训练策略忽略了降噪脑电信号与干净脑电信号之间整体的一致性，本文主要针对上述问题展开研究。

方法：提出了一种新的脑电降噪网络，名为 GCTNet。该网络包括生成器和判别器两部分，生成器使用并行卷积神经网络（convolutional neural network,CNN）单元和 Transformer 单元，用于捕获局部和全局的时序依赖性；判别器用于检测和纠正干净脑电信号和生成的降噪脑电信号之间的全局一致性。

结果：为了评估网络性能，在三个公开数据集上进行了验证实验，实验结果表明 GCTNet 在三种评价指标上均显著优于目前最先进的网络。

结论：GCTNet 可以有效地移除 EEG 信号中多种生理伪影和混合伪影，与其他网络的对比结果证实了其优越性。

关键字：深度神经网络；生成对抗网络；脑机接口；脑电降噪；脑电伪影移除

ID 2708

基于动态注意力机制的跨个体脑电情绪解码

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目的：基于脑电的情绪解码能够客观地量化人的情绪状态，在人机交互、情绪障碍预警等领域有着广泛的应用前景。近年来，深度学习相比于传统方法提升了脑电情绪解码的效果，但当前研究对脑电的时空动态特性考虑仍不充分，在跨个体情绪解码中的表现仍有待提高。本文为解决上述问题开展算法研究。

方法：本研究从神经活动的基本生理特性出发，利用深度学习中的注意力机制，提出动态注意力模型提取脑电的时空动态特性。该模型假设大脑中存在多个平行的动态加工过程，在不同时段应赋予每个过程可变的动态权重。

结果：在包含 80 名受试者的 THU-EP 数据集上验证模型。模型在跨个体情绪解码中取得了目前最优的效果，在情绪二分类和九分类中分别达到了 79.4±10.0% 和 63.6±15.1% 的正确率。模型学到的注意力权重变化、脑电时域模式和空域变化模式可能为情绪加工的神经机制提供启发。

结论：提出具有生理可解释性的脑电时空动态特性提取模型，为情绪神经机制研究和情感计算应用提供了新方法。

关键字：脑电；情绪解码；注意力机制；时空动态特性

ID 2786

基于卷积神经网络的体感电刺激诱发 P300 识别

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目的：体感电刺激诱发 P300 是一种新兴的脑机接口范式。但相比视觉刺激，体感电刺激诱发 P300 的识别难度较大。

方法：采用一种集合了多种感觉刺激的 P300 范式，采集了 8 位健康受试者关注体感电刺激时的脑电信号，并设计了基于卷积神经网络的分类器实现体感电刺激诱发 P300 的识别。

结果：结果表明，虽然受试者在该范式下诱发的事件相关电位存在个体差异，但本文设计的分类器不管在多次样本叠加平均还是单次刺激识别时都达到了不错效果，单次刺激下实现 89.95% 的 AUC，而 3 次样本叠加平均时 AUC 为 96.75%。

结论：卷积神经网络在体感电刺激诱发 P300 范式上具有很好识别表现，应用该技术可以促进基于体感电刺激诱发 P300 脑机接口范式的应用。

关键字：事件相关电位；体感电刺激；P300 ；卷积神经网络

ID 2795

216 指令高速率混合脑 - 机接口系统

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目的：脑 - 机接口（Brain-computer interface, BCI）可以实现大脑与外界环境之间的直接交互，而不依赖于正常的外周神经通路。自 1973 年发展至今，BCI 在康复医疗、工业控制等领域展示出了广泛的应用前景。然而，应用场景的快速扩展对 BCI 性能提出更高的要求，亟需开发大指令、高速率、高正确率的高性能 BCI 系统。

方法：设计了基于 P300、运动诱发电位（Motion-onset visual evoked potential, mVEP）和稳态视觉诱发电位（Steady-state visual evoked potential, SSVEP）三种脑电特征的新型混合编码范式，开发了 216 指令高速率 BCI 系统，实现了快速脑 - 控打字应用。

结果：系统在线平均正确率为 85.37%，在线平均信息传输速率（Information transfer rate, ITR）达到 302.83 bits/min。

结论：该研究首次将 BCI 指令数量扩增至 200 以上，是迄今最大指令集的高速率脑 - 机接口系统，在高自由度、高精度控制等领域有较大的应用前景。

关键字：大指令；高速率脑 - 机接口；运动诱发电位；P300 ；稳态视觉诱发电位

ID 3194

基于 360Hz 刷新率的高频 SSVEP 脑机接口系统

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目的：现有的基于稳态视觉诱发电位的脑 - 机接口难以平衡用户体验和系统性能。本研究提出了一种在 360Hz 刷新率显示器上呈现稳定的多目标刺激方法，并使用 55-62.8Hz 频段的刺激开发一个 40 目标的脑 - 机接口字符拼写器，以实现高性能的用户友好型脑 - 机接口系统。

方法：使用实时生成刺激矩阵并渲染的方法，减少计算机负荷，保证刺激呈现的稳定性。随后对 16 名受试者分别进行 40 目标系统的离线和在线实验 , 使用任务判别成分分析算法进行特征提取与分类。

结果：离线和在线实验结果表明该系统在低闪烁感的情况下，平均在线正确率达 88.87%±3.05%，实现了 51.83±2.77 比特 /min 的信息传输速率。

结论：研究结果表明基于屏幕刷新率实现高频多目标编码方法的可行性，对促进视觉脑 - 机接口技术的发展具有重要的理论意义和应用价值。

关键字：脑 - 机接口；稳态视觉诱发电位；高频；刷新率

ID 3217

基于特征对齐和一致性正则化的半监督域自适应癫痫脑电预测

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目的：个体间的差异性对癫痫脑电预测在现实中的发展而言，仍然是一个巨大的挑战。大多数已知的方法只能在病人特异的模式下奏效，而难以实现跨个体的泛化。为克服这一个体间差异性，我们提出了一种半监督域自适应癫痫脑电模型（semi-supervised domain-adaptive seizure prediction model，SSDA-SPM），利用目标病人上少量的带标注数据以及额外的无标注数据来校准模型。

方法：SSDA-SPM 主要由两个无监督的模块组成，分别是特征对齐模块以及一致性正则化模块。特征对齐模块通过全局对齐已知病人和目标病人的特征分布来将已知病人的信息大致迁移至目标病人上。而一致性正则化模块通过将决策边界推向低密度区域来进一步增强模型在目标病人上的辨识性。

结果：所提出的方法在 CHB-MIT 数据集上取得了 88.8% 的灵敏度、0.182/h 的误报率以及 0.849 的 AUC；在 Kaggle 数据集上取得了 75.7% 的灵敏度、0.165/h 的误报率以及 0.763 的 AUC。

结论：实验结果表明我们的方法为提高跨个体癫痫脑电预测的性能提供了一个可靠的方案。

关键字：脑电图；癫痫预测；半监督域适应；特征对齐；一致性正则化

ID 3224

基于双分支交互融合网络的脑电伪迹去除方法

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目的：头皮脑电经常受到各种伪迹的污染。深度学习在脑电去噪中已被初步探索，并被证明比传统方法更有前景。然而，现有深度学习方法专注于从污染信号中重建干净脑电，而忽略对其中存在伪迹的重建。这限制了其去除伪迹的能力。

方法：提出一种双分支交互融合神经网络（EEGIFNet）来处理脑电去噪。EEGIFNet 利用两个分支分别恢复干净的脑电和残留伪迹。在每个分支中，卷积层和双向门控循环单元级联来捕获局部和全局特征。我们还引入交互模块，从对方分支中提取自己分支残留成分，使两个分支相互受益。此外，我们设计了融合模块来自适应融合两个分支的输出，最终重建干净的脑电。

结果：在包括眼电、肌电、心电、电力线干扰和运动伪迹在内的公开数据集上评估所提出的方法。大量实验表明，EEGIFNet 对于不同的伪迹去除和信噪比水平优于目前先进的方法。

结论：所提方法适用于去除脑电信号中的多种伪迹，有助于脑电应用的推广。

关键字：脑电去噪；伪迹去除；双分支网络；交互；融合

ID 3319

基于多任务学习的快速序列视觉呈现脑电图分类研究

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目的：快速序列视觉呈现的脑电图数据存在样本不平衡问题，很大程度上影响了其分类性能。本文提出了一种基于多任务学习的快速序列视觉呈现脑电图分类模型，通过分类任务和超球约束任务的联合学习缓解样本不平衡问题。

方法：首先，建立特征提取共享层，利用卷积神经网络自动提取任务之间的共享参数，深度挖掘任务之间的相关特征；其次，建立特定任务层，利用分类任务和超球约束任务对前一阶段提取的特征进行筛选和优化，并使用损失加权平衡两个任务的损失函数，提高模型泛化性。

结果：利用快速序列视觉呈现公开数据集进行验证，与单任务学习的 EEGNet 模型相比，Multi-task EEGNet 模型 32 个被试平均 AUC 提升了 2.12%。

结论：实验结果表明，本文提出的多任务学习模型能更充分地提取判别特征，有效提升模型分类性能。

关键字：脑电图；快速序列视觉呈现；多任务学习；卷积神经网络

ID 3368

基于脊髓损伤一维局部二值模式与共空间模式结合的特征提取

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目的：脊髓损伤 (SCI) 患者脑电信号 (EEG) 的自动识别可以辅助患者运动功能恢复，提高患者的生活质量。EEG 中的特征提取部分决定了整个识别系统的性能。

方法：本文提出一维局部二值模式 (1D-LBP) 和共同空间模式 (CSP) 特征提取方法融合使用，首先使用 1D-LBP 对 SCI 患者运动想象预处理后的 EEG 信号进行特征提取，生成直方图的形式作为 EEG 信号的特征向量，然后使用 CSP 滤波器对 LBP 处理后的特征进行滤波投影，从而得到 LBP-CSP 特征。

结果：所提出的 LBP-CSP 特征方法大大降低了特征的维度，缩短了训练时间，分类最高准确率达到 95.3%，平均准确率达到 90.0%。

结论：本研究结果对 CNP 患者的神经康复和脑机接口具有重要的临床意义。

关键字：脊髓损伤；运动想象；特征提取；模式识别

ID 3372

用于运动想象识别的基于协同特征选择的时段频带联合优化

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目的：用于运动想象识别的脑机接口是通过解读用户大脑活动和外界交互的设备。本文针对所采集的脑电信号受时变认知因素的影响，每个用户有效的时段和频段不同，提出了训练域和测试域协同特征选择的时频联合优化方法。

方法：首先将时段和频带分别分段构成时频矩阵，对以此为基础获取的独立时频段脑电信号进行特征提取，然后对训练域应用有监督特征选择选取部分效果较好的时段频带，并在此基础上对测试域应用正则化自表达无监督特征选择进一步筛选时段频带，进而获得同时适应于训练域和测试域的联合优化时段频带。

结果：将所提出的方法应用于公共数据集，获得平均分类识别正确率 70.8%，相对于效果最好的对照方法 FBCSP 提升 0.9%。

结论：针对传统特征提取方法仅选择固定时段，忽略了不能产生有效生理现象的低质量脑电信号时段对特征提取的影响，提出“时段 - 频带”分析阵列，通过分析每个“时段 - 频带”所提取的特征对分类性能影响的权重来获取最优时段频带组合，实验验证该方法可以提高所提取的特征质量，进而提高分类识别正确率。

关键字：运动想象；时频优化；共空域模式；特征选择

ID 3493

基于音乐情绪的表征相似性研究

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目的：情绪是一种复杂的认知过程，利用音乐可以唤起强烈的情绪。然而，这些过程的认知机理我们知之甚少，不同的被试对于相同的音乐刺激有着很大的个体差异性，因此在本研究中，我们使用被试间表征相似性（representational similarity analysis，IS-RSA）的方法研究多个被试的共同音乐情绪反应。

方法：采集了 20 个被试的音乐情绪脑电，并收集了这些被试的量表评分。我们将效价作为音乐情绪的行为学指标，分析了积极音乐、消极音乐以及混合音乐情形下的在四种节律（theta、alpha、beta 和 gamma）的脑电反应。

结果：Theta 和 gamma 频段在音乐情绪的被试间一致性起着重要作用，对于 theta 频段主要观察到了前额的活动，对于 gamma 频段主要观察到了额叶、顶叶以及由右颞顶叶的反应。在 theta 频段，积极音乐和消极音乐分别激活了左右额叶的一些区域，显示了左右偏侧性。

结论：以上结果表明尽管被试间存在差异，对于相同类型的音乐，其反应有着一致性。这些结果可以帮助我们理解音乐诱发情绪的相关机制。

关键字：音乐；情绪；脑电；被试间表征相似性

ID 3505

基于偏移鲁棒卷积神经网络的高密度肌电模式识别方法

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目的：基于表面肌电信号的手势识别方法已广泛应用于运动康复、假肢控制等领域。理想环境下，该类方法已取得令人满意的手势识别性能。然而，实际使用时重新穿戴设备导致的电极偏移将显著改变肌电信号表征模式，导致识别性能极大降低。本研究旨在提高电极偏移情况下肌电模式识别性能。

方法：近期研究表明，肌电信号通道间空间模式鲁棒于电极偏移影响，其中卷积神经网络（CNN）因具备强大的空间信息提取能力被广泛采用。然而，已有研究均忽略了 CNN 下采样层存在的混叠效应，使得该模型依旧敏感于电极偏移导致的信号变异。本研究提出一种偏移鲁棒 CNN，该模型舍弃传统下采样层，通过抗混叠滤波器与自适应多相采样方法使得偏移前后的下采样信息保持一致性。具体而言，抗混叠滤波器抑制易导致信号混叠的高频成分，多相采样方法自适应地选择偏移前后关键及稳定信息。

结果：所提方法在公开数据集及实际使用中均优于最先进方法，达到当下最优性能。

结论：该研究为提升肌电手势识别的实用化提供了一种有前景的方案。

关键字：肌电控制；电极偏移；模式识别；抗混叠；深度学习

S04
康复工程—“新理念、新方法、新进展”
Rehabilitation Engineering –“New Ideas, New Methods, New Progress”

ID 690

一种基于高密度表面肌电的实时场景跨用户手势分类的鲁棒工程框架

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目的：密度表面肌电 (HD-sEMG) 在手势识别领域已经得到了广泛应用。然而，大部分手势识别方法仅仅适用于离线场景下的用户个性化模型，而非更接近真实情况下的实时跨用户场景。本研究提出了一种基于迁移学习的实时跨用户手势识别方法，以及一套基于实时场景的完整模型训练和数据测试框架。

方法：选用公开数据库 Hyser (High density Surface Electromyogram Recordings) 验证提出的方法，该数据库包含 20 个被试的高密度表面肌电信号。我们从中选择了 10 种手势样本和休息样本，以 19 个被试的数据预训练模型，第 20 个被试的少数样本用于模型校准。

结果：测试结果显示第 20 个被试实时场景下的动作判断准确率达到 92.36%（对应休息状态误报率为 1.82%）。

结论：这些结果证明了基于高密度表面肌电的实时跨用户手势识别的可行性，为未来基于高密度表面肌电的可穿戴设备在人机交互领域的应用提供了参考。

关键字：实时手势识别；高密度表面肌电；跨用户手势识别；人机交互

ID 785

A Convolutional Neural Network With Narrow Kernel and Dual-view Feature Fusion for sEMG-based Gesture Recognition

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Objective: For gesture recognition based on surface Electromyography (sEMG), Convolutional Neural Network (CNN)-based techniques have made prominent progress to gesture features extract for motor rehabilitation or bionic hand control. However, the performance of traditional CNN algorithms shows limited capability to characterize the time-varying properties and channel independence of sEMG.

Methods: A Narrow Kernel and Dual-view Feature Fusion Convolutional Neural Network (NKDFF-CNN) is proposed. The Narrow Kernel was firstly used to fully extract the temporal features of each channel to protect the channel independence of sEMG. Feature fusion between two views to effectively reduce the number of the model parameters and avoid the over-

fitting phenomenon. Then, shallow and deep features were fused in the decision phase to improve the multi-dimensional characterization of sEMG. Finally, a more powerful Arcface loss function replaced Softmax for gesture classification.

Results: The algorithm was validated experimentally on the Ninapro DB2 dataset using a 200ms window length. The results showed that NKDFF-CNN achieved an average recognition accuracy of 87.96% for 40 subjects, which is 0.94% higher than the best result using other methods.

Conclusion: This algorithm presented in this paper effectively improved the performance of gesture recognition based sEMG and provided a new idea for this research direction.

Key words: surface electromyography (sEMG), gesture recognition, narrow kernel, dual-view, feature fusion

ID 1626

低强度聚焦超声改善抑郁样行为的突触可塑性机制研究

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目的：新型无创调控技术的快速发展为抑郁症的治疗提供了新的选择，低强度聚焦超声刺激（LIFUS）已被证明对抑郁症具有显著的神经调节作用。然而，LIFUS 的不同治疗策略如何影响治疗效果及其机制尚不清楚。本研究从突触可塑性的角度探究了不同 LIFUS 刺激强度对抑郁样行为的影响机制。

方法：建立慢性不可预测应激（chronic unpredictable stress, CUS）抑郁症大鼠模型，在 CUS 后将高 / 低强度（Ispta=500mW/cm2 和 230mW/cm2）的 LIFUS 应用于内侧前额叶皮层（medial prefrontal cortex, mPFC）。

结果：两种强度的 LIFUS 都可以显著改善抑郁样行为，其程度没有显著差异。在机制方面发现，LIFUS 显著改善了海马 vCA1-mPFC 通路中的 θ 振荡同步性、突触功能和结构可塑性。

结论：LIFUS 改善抑郁样行为可能与增强 vCA1-mPFC 通路突触可塑性有关，本研究为应用 LIFUS 治疗抑郁症提供了临床前证据和理论基础。

关键字：抑郁症；低强度聚焦超声；突触可塑性；内侧前额叶皮层；刺激强度

ID 1911

高密度表面肌电揭示帕金森病外周运动单元时空同步的震颤机理

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目的：帕金森病震颤产生的病理生理学机制尚不明确，本研究旨在探寻一种新的观测方法来研究帕金森震颤在外周神经的表现，并据此来联系帕金森震颤产生的机理。

方法：设计了一套基于高密度表面肌电信号和 FastICA 运动单元分解算法的方案，并运用该方案对 3 名帕金森患

者的生理数据进行采集与处理。对分解算法产生的运动单元信号，在时域特征与相干性指标上对结果进行分析。

结果：运动单元时域信号显示出互为拮抗作用的两组肌肉的运动单元与震颤运动相对应，在时间上呈现出节律性规律。并且两组肌肉的运动单元具有一定的相位差异。相干性分析显示三名受试者的肌肉内与肌肉间的运动单元活动均在震颤频率以及一次谐波频率出出现显著相干性。相同被试的相同频率下，肌肉内的相干性呈现高于对应肌肉间的相干性的趋势。利用该方法对帕金森震颤的初步观测表明：帕金森病患者的中枢神经病变导致震颤产生，在外周神经体现为运动的单元活动的同步性。这种同步性反应为 1. 运动的单元以震颤频率为主进行发放；2. 肌肉内与肌肉见的运动的单元在空间上相互同步。

结论：本研究展示的观测方法能克服传统侵入式肌电研究的短板，为研究帕金森病震颤提供了新的方法。

关键字：帕金森震颤；高密度表面肌电；运动单元分解

ID 2005

基于液态金属应变传感器的膀胱液量监测系统研发

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目的：膀胱液量感知对于神经源性膀胱患者的功能恢复至关重要，但目前临床上难以长期实时监测膀胱液量，本研究结合柔性电子技术，设计开发出一款植入式的无线无源的膀胱液量监测系统，既能长期实时监测膀胱液量，又不对使用患者日常生活造成过大干扰。

方法：根据膀胱周围组织环境，基于电阻式应变栅设计出包覆于膀胱表面的柔性液量传感器，在热塑性聚氨酯膜上采用液态金属丝网印刷制备。同时设计制备配套的检测通讯电路和柔性天线，构成可以直接用手机读取膀胱液量的系统。

结果：在离体猪膀胱上实验表明，系统能够正常工作，传感器高敏感线性区理论分辨力可达 0.16~0.17 mL，精确度可达国家工业仪表等级 5.0 级。

结论：依据膀胱外表面形态所设计的液态金属应变传感器，无需缝合即可稳固包覆在膀胱上，测量膀胱在充盈和收缩过程中的表面形变情况，从而反映膀胱内液量。

关键字：柔性传感器；应变传感器；液态金属；膀胱液量

ID 2043

电阻抗断层成像用于评估经颅超声刺激促进脑梗死大鼠康复研究

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目的：利用 EIT 来评估 TUS 对于缺血性卒中的治疗效果并探索 TUS 治疗卒中的机制。

方法：实验组大鼠在 MCAO 之前先进行 EIT 监测 10min 以获得 MCAO 前的正常阻抗，MCAO 后立即进行 EIT 监测 60min，拔掉线栓之后再监测 10min 以获得 MCAO 之后的阻抗，在 MCAO 之后的第 1，2，3 天进行 TUS（频率：1MHz）

并在 1，2，3，5，7 天进行行为学评分（mNSS, 转棒疲劳仪，体重），对照组大鼠不给予 TUS。最后处死大鼠，取出大脑进行 TTC 染色。

结果：结果表明 EIT 能够对大脑缺血区进行成像并且能监测到 MCAO 之后大鼠大脑阻抗的变化，梗死侧阻抗增加 24.11%（$p < 0.05$），全脑阻抗增加 18.64%（$p < 0.05$），TUS 能够促进卒中大鼠运动功能恢复。

结论：在卒中之后连续三天使用 TUS 治疗，对卒中大鼠的运动功能恢复有促进作用，并且 EIT 能够对大鼠大脑缺血灶进行精准的成像，有潜力成为临床上评估卒中后康复效果的一种新技术。

关键字：卒中；经颅超声刺激；电阻抗断层成像

ID 2431

基于复合式纳米发电机的闭环自供电低水平迷走神经刺激系统用于心房颤动治疗

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目的：电活动是人体生命活动的基础，电刺激可以改变神经兴奋和抑制的状态，从而实现疾病的治疗。纳米发电机是一种可将低频机械能转换为电能的新型能源转换器件，并且因为器件结构多样、可柔性化、可纺织、可选择的材料多种多样、输出电压高等优点，获得了研究者的关注。

方法：通过纳米发电机将人体运动的机械能高效的转换为电能并给电刺激器件供电，构建自供能的电子医疗器件，开展了低强度神经电刺激的研究工作。

结果：所构建的神经电刺激装置，具有柔性、便携式、可长期工作、自供电和良好的生物相容性等优点。同时，由于构建的是闭环式的低水平迷走神经电刺激系统，我们的神经电刺激装置没有副作用，达到了实现治疗同时又减少了神经刺激合并症的风险的目的。

结论：我们的研究工作围绕自供能电子医疗器件和神经电刺激治疗，在面向慢性节律性疾病的管理和治疗问题上具有重要的潜力。

关键字：低水平迷走神经刺激；植入式电子医疗器件；纳米发电机；闭环式神经调控；房颤

ID 2457

基于陀螺仪复合纳米发电机的自供电智能训练系统

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目的：将人体运动的机械能转化为电能被认为是便携式电子产品的理想能源供应解决方案。然而，低频人体运动限制了传统能量收集设备的转换效率，难以为便携式电子设备提供可持续的电能。

方法：开发一种基于摩擦纳米发电机（TENG）和电磁发电机（EMG）耦合的健身陀螺仪纳米发电机（fg-NG），它

利用陀螺仪的频率上转换效应将低频手腕运动转换为高频旋转运动。

结果：用手可将 fg-NG 达到 8000 转以上的转速，频率提高了 280 倍。fg-NG 在 220-230 Hz 的频率下连续稳定地输出 17 mA 的电流和 70 V 的电压。

结论：fg-NG 可以持续为温湿度计、智能手环和手机供电。此外，它还可以应用于自供电智能训练系统，可以为用户提供飞轮转速、扭转力矩、运动时间、消耗热量等数据，帮助用户科学训练，显示出其在便携式电子产品和无线物联网设备方面的巨大应用潜力。

关键字：陀螺仪；纳米发电机；便携式电子设备；自供电；智能训练系统

ID 2545

基于深度学习动作估算的人体平衡能力评定研究

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目的：基于深度学习 Keypoint-RCNN 人体动作估算技术，在分析人体关键点轨迹运动的基础上定义人体平衡指标 (以下均简称为「平衡指标」)，并验证平衡指标是否能于「由坐到站」动作过程区分出平衡障碍者和健康人。

方法：将动作「由坐到站」分为三个阶段：起身准备期、起站期和站立期，并且分别建立平衡指标。起身准备期的平衡指标 为该期所耗时间，起站期的平衡指标以模拟人体重心点 (Center of Gravity, COG) 的位移与该期所耗时间共同表示，站立期平衡指标为 COG 位移轨迹的多尺度熵值。使用独立样本 t 检验计算平衡指标在两人群之差异，共招募 13 名平 衡障碍者与 11 名健康者。

结果：与健康对照组相比，平衡障碍人群在起身准备期和起站期平衡指标数值表现明显较差（$p < 0.05$），在站立期，两人群 之间平衡指标没有显著差异。

结论：起身准备期和起站期平衡指标均能够显著区分健康人群和平衡障碍人群，但站立期平衡指标尚需改善。这表明在临床 中使用基于 Keypoint-RCNN 的平衡指标可能有助于在人群中识别出平衡障碍者。

关键字：Keypoint-RCNN ； 平衡评估；平衡指标

ID 2768

基于高密度表面肌电信号的面颈部发音肌群空间激活模式研究

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目的：由于面颈部发音肌群的协调运动，人类能够通过说话进行人际交往和情感表达。基于表面肌电（sEMG）的无声语音识别已被广泛研究。然而，发音过程与面颈部发音肌群 (SAMGs) 活动的关联尚未得到很好的研究。旨在量化面颈部 SAMGs 运动过程中肌肉激活的宏观空间模式。

方法：320 通道高密度（ high-density，HD）电极均匀地放置在面颈部 SAMGs 上。从 HD-sEMG 中提取出 SAMGs 的均方根 (root-mean-square, RMS) 图，用于表征 SAMGs 的激活模式。10 名受试者分别在有声语音和无声语音模式下执行了 14 个元音任务和 15 个辅音任务。

结果：SAMGs 的激活模式存在明显的聚集，并且颈面部左右对称的 SAMGs 激活模式存在较高的相似度。在无声语音模式下，辅音类别的平均分类准确率为为 83.78%，元音类别中的平均分类准确率为 72.64%。

结论：对 SAMGs 空间激活模式量化可有效筛选 sEMG 通道，为基于 sEMG 的无声语音系统实际使用时的电极轮廓设计和通道数优化提供参考。

关键字：高密度表面肌电；发音肌群；无声语音；激活模式

ID 2771

基于 GA-SVM 的脑 - 肌电信号特征融合方法

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目的：针对脑电信号和肌电信号在融合中由于非理想情况下造成的脑 - 肌电信号融合效果差的问题，在信号、通道及特征多方面衡量其重要程度，挑选出对运动模式识别起决定性作用的主导因素，剔除冗余、消极的因素，最终融合主导信息对运动模式识别做出准确可靠的判断。

方法：提出基于 GA-SVM 的脑 - 肌电特征融合方法，以支持向量机的分类结果为自适应度，通过遗传算法搜索脑电和肌电特征的最佳组合因子对脑电信号和肌电信号进行融合。

结果：脑 - 肌电特征融合在手部运动识别任务上相比于单一模式的脑电特征和肌电特征平均分类准确率分别提升了 11.55%、53.11%，在跨个体的手部运动识别任务上相比于等权值的脑 - 肌电特征融合方法平均分类准确率提高了 4.00%。

结论：所提出的方法能够有效地利用脑肌电信号之间的协同互补性，在减少了消极特征对识别精度影响的同时提高了脑 - 肌电融合对运动意图识别的精度。

关键字：脑电信号；表面肌电信号；特征融合；遗传算法 - 支持向量机（GA-SVM）

ID 3056

电触觉反馈重建假肢肘部屈伸感觉的初步研究

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目的：截肢者在使用假肢时，感觉反馈可以帮助他们更好地控制假肢，提高对假肢的信任感。其中肘部的位置感觉和运动感觉反馈可以帮助上臂截肢者改善对假肢的控制，因此对于这方面的感觉反馈需要更深入地研究。

方法：电触觉刺激是常用的提供感觉反馈的方法。本研究设计了一种使用幅度编码角度信息的电触觉刺激方案，我们将肘部的四个角度：0°，45°，90°和 135°，映射到四种双通道刺激模式中；将肘部的六个运动方式，包括三种肘屈运动和三种肘伸运动，映射到六种运动觉反馈模式中。在四名健康被试中测试了该方案的有效性。

结果：四名被试对四种位置觉反馈模式的识别率分别为 91%、63%、68% 和 83%，对六种运动觉反馈模式的识别

率分别为 95%、71%、100%、100%、98% 和 83%。

结论：结果表明，该方法可以有效地通过电触觉刺激为受试者提供肘部屈伸的位置和运动感觉信息。

关键字：假肢；肘关节；感觉反馈；电触觉刺激

ID 3069

基于肌音信号检测的神经肌肉电刺激闭环控制技术研究

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目的：脑卒中后约 80% 的患者遗留明显的肢体运动障碍，其中，手功能运动障碍的康复对于提高患者独立生活能力具有重要意义。在传统的电刺激康复训练中常采用表面肌电信号作为电刺激闭环控制的生理参数，但肌电信号会受到电刺激的干扰。相比之下，肌音信号具有抗电磁干扰强、易于采集等优点，同时可以反映肌肉的活动水平。基于此本文设计了一款电刺激诱发肌音信号检测及四通道电刺激系统。

方法：针对脑卒中患者手功能康复的需求，设计了一款便携式、参数可调的四通道低频电刺激器，并设计肌音信号的实时检测电路和基于 Android 系统的人机交互 APP。并基于本文所设计的硬件与软件平台在 6 位健康受试者身上开展了电刺激实验

结果：初步实验结果表明，根据肌音信号的 RMS 改变电刺激强度，使前臂肌肉收缩所产生的肌音信号保持在预设范围内的控制策略是可行的，实现了神经肌肉电刺激下肌肉收缩水平的监测与闭环反馈控制。

结论：肌音信号可以在脑卒中的肢体运动障碍康复训练中作为表征肌肉收缩水平的指标，在神经肌肉电刺激中可作为检测肌肉活动的反馈控制量；所提出的电刺激反馈控制策略可以使得肌肉的收缩保持在预设水平。

关键字：脑卒中；神经肌肉电刺激；闭环反馈；肌音信号；运动功能障碍康复

ID 3313

结合人工智能与复合式传感器的手势识别手环

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目的：虚拟现实是一项应用广泛的全新技术，要实现虚拟现实，就需要用到人机交互设备。现有的虚拟现实技术通常依赖于相机、数据手套、游戏手柄和其他设备。这些设备要么体积庞大，携带和使用不便，要么普及成本高。因此，开发一种方便、低成本的高精度人机交互设备，将对虚拟现实技术的发展起到积极的推动作用。

方法：设计一种结合自驱动传感器和机器学习技术的手语识别手环。该手环使用基于摩擦纳米发电机与压电纳米发电机的复合式发电机来收集力学信息。当佩带者的皮肤给传感器施加 5N 的力时，复合发电机的输出约为 80mV。复合式发电机的设置使得该手环可以同时收集来自法向与切向的力学信息，丰富了收集到的力学信息，有助于提升识别精度。机器学习上我们采用的是 LDA 模型。

结果：使用者佩带着该手环对 26 个字母的手势识别进行模型训练，反复学习 600 次后，该模型对逐个手势的预测

精度可以达到 92.6%。我们将该智能手环系统应用于实际的手语翻译中，可以实现对语句“Nano biolab”的实时播报。

结论：该手环在手势指令识别、残疾人辅助器具、可穿戴电子器件等领域具有广阔的应用前景。

关键字：虚拟现实；人机交互；机器学习；手势识别；摩擦纳米发电机

ID 3327

一种用于功能性电刺激伪迹去除的多通道空间滤波算法

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燕山大学

目的：针对现有的功能性电刺激去噪方法主要针对恒定参数的功能性电刺激，难以处理变参数下的刺激伪迹的问题，提出并设计一种用于变参数功能性电刺激伪迹去除的算法。

方法：本研究融合格拉姆 - 施密特 (Gram-Schmidt, G-S) 算法和 Grubbs 准则，提出了一种用于多通道肌电中变参数刺激伪迹去除的空间自适应 G-S-G 滤波方法，利用功能性电刺激募集运动单元的同步性和运动神经募集运动单元的异步性，采用通道间信号的相关性，去除相关性较强的刺激伪迹，保留肌电信号。

结果：采用功能性电刺激信号与自愿肌电信号的合成信号进行验证，计算所得结果均方根值与自愿肌电信号的均方根值之间的皮尔逊相关系数均值在 0.87 以上，效果良好。

结论：本算法有效克服了单通道肌电信号预处理时对功能性电刺激频率和幅值的限制，实现了多通道肌电信号中刺激伪迹的自适应去除，对刺激强度较大时引起的伪迹处理也具有良好效果，算法简单，实时性强，使本方法能更好的适用于多通道肌电信号中变参数功能性电刺激伪迹的去除。

关键字：功能性电刺激；伪迹去除；空间滤波

ID 3501

基于无监督深度迁移学习的跨用户手势识别模型的探究

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目的：基于表面肌电的手势识别模型能够帮助用户控制智能电子系统，因此被广泛应用于人机交互领域。然而，由于用户间生理信号的差异性，新用户在使用前一般需要耗费很长时间进行个性化的模型训练，这并不符合实际应用需求。倘若使用已有用户训练的模型直接用于新用户的手势识别任务中，准确度会大幅下降。在此情况下，无监督迁移学习算法可以通过减小用户间数据分布差异，提高模型泛化性能并降低训练成本。

方法：选用公开数据库 Hyser（High density Surface Electromyogram Recordings）验证所提出的方法，探究多种无监督深度迁移学习算法的效果，以及迁移手势种类及样本个数对迁移效果的影响。

结果：迁移效果最好的方法是相关性对齐（CORAL）算法，分类准确率比未使用迁移算法的模型提高了 6.59%。此外，增加手势种类会对迁移效果造成显著影响，而增加每种手势的样本个数则对结果造成的影响较小。

结论：本研究验证了无监督深度迁移模型实现跨用户手势识别任务的可行性，为未来可穿戴设备在人机交互领域的应用提供了参考。

关键字：表面肌电信号；手势识别；无监督迁移学习；深度学习

S05
生物医学传感与可穿戴系统
Biomedical Sensing and Wearable Systems

ID 621

The Love Wave Biosensor for the Detection of the Pneumonia Biomarker Procalcitonin (PCT)

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Objective: Pneumonia is an infection of the pulmonary parenchyma caused by many pathogens, such as bacteria, viruses, mycoplasma, fungi, etc. The early screening of pneumonia is crucial to the treatment for patients. Procalcitonin (PCT) is an acute parameter used to distinguish between bacterial and non-bacterial inflammation. Besides, PCT is clearly correlated with the severity and prognosis of systemic infections such as inflammatory response syndrome, community-acquired pneumonia (CAP), and septic shock (some severe COVID-19 patients will present septic shock symptoms). Exhaled breath condensate (EBC) detection is a promising method for the early diagnosis of lung diseases. Because EBC sampling is non-invasive, rapid and cost-effective. However, biomarker detection in EBC remains a challenge due to extremely low concentrations and complex components. So it is urgent to develop a method to detect potential biomarkers of pneumonia at low concentrations.

Methods: The Love wave sensor, one of the surface acoustic wave (SAW) sensors, has many advantages such as low attenuation, high sensitivity and corrosion resistance in liquids. In this study, we develop an 8-channel automated instrument based on the Love-type surface acoustic wave biosensor for detecting PCT, especially in exhaled breath condensates (EBC) of pneumonia patients. This immunosensor is mainly based on SPA self-assembly layer and the conventional sandwich immunoassay. Besides, the signal is amplified by AuNPs and immunogold staining signal amplification technology.

Results: The preliminary results show that the Love-SAW biosensor has good linearity in detecting PCT (R2=0.9703) from 15.62~500 ng/mL concentration range and the limits of detection (LOD) is 0.85 ng/ml.

Conclusion: This high-throughput instrument based on Love-SAW biosensor is expected to realize the rapid detection of multiple pneumonia biomarkers including PCT, so as to provide provide valuable guidance for the diagnosis and prognosis of pneumonia.

Key words: Surface acoustic wave sensor; Biomarker; PCT; Pneumonia; Exhaled breath condensates

ID 759

A Novel Glutamate Three-electrode System Based on Microelectrode Sensing Technology

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Objective: Glutamate(Glu) plays an important role in brain function. The analysis of variations in Glu in physiological or pathological situations can be done using neuroelectrochemical sensing technology. Since the electrode is susceptible to interference in vivo and H2O2 is difficult to oxidize on carbon materials, it is necessary to improve the stability and sensitivity of the electrode when modifying the electrode.

Methods: By constructing microelectrodes, the three-electrode system can be implanted into the body to achieve electrochemical sensing. The system consists of a glutamate working microelectrode, an Ag/AgCl reference microelectrode, and a Pt pair microelectrode that we fabricated. And this system can be widely used in the detection of biomarkers in small space.

Results: In this work, we first modified Pt nanoparticles and 3-Thiopheneacetic acid(3-TAA) on the surface of carbon fiber microelectrode(CFME) in sequence, and finally fixed glutamate oxidase(GLOD) covalently on the surface of 3-TAA.

Conclusion: So we successfully built the CFME/Pt-PTAA-GLOD sensor which is utilized to detect glutamate, providing a foundation for future neuroscience research.

Key words: Glutamate, 3-Thiopheneacetic Acid, Glutamate Oxidase, Electrochemical Sensor, Carbon Fiber Microelectrode

ID 813

A Novel Electrophoresis Device Combined with Immunosensor for The Detection of Carcinoembryonic Antigen

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Objective: Carcinoembryonic antigen(CEA) is a biomarker highly expressed in cancer patients. The short time, high sensitivity and specificity detection of CEA can greatly help in the early clinical detection and screening of cancer. Electrochemical immunosensors have attracted wide attention in the field of cancer markers detection due to their good stability,excellent selectivity and high sensitivity, but traditional immunosensors generally have the problems of long detection time and high detection limit.

Methods: In this work, we have constructed an electric field-enhanced immunosensor based on the principle electrophoresis principle for the rapid and sensitive detection of CEA. Upon incubation with CEA,the proposed electrophoresis

device imparts the electric field force on CEA, allowing CEA to swim up quickly in the system.

Results: It not only greatly shortens the detection time of CEA, but also further improves the detection sensitivity, and can achieves better results in terms of anti-interference performance.

Conclusion: It has promising applications in the rapid and accurate diagnosis of clinical cancers in the future.

Key words: Electrophoresis device, Glass carbon electrode, Immunosensor, Carcinoembryonic antigen

ID 900

In Silico Investigation of the Effect of Atrial Fibrosis on High-frequency Electrocardiogram

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Objective: Atrial fibrosis plays an important role in the oc_x0002_currence and maintenance of atrial fibrillation (AF). The assess_x0002_ment of atrial fibrosis is of great significance in the prediction, evaluation and treatment of AF. Currently, the development of high-frequency electrocardiogram (ECG) suggests that it may become a new and potential method to assess atrial fibrosis, which is relatively convenient and non-invasive. However, there is little relevant research on this issue.

Methods: We investi_x0002_gated the effect of atrial fibrosis on high-frequency ECG using a two-dimensional (2D) atrial electrophysiological model. The effects of diffusion coefficient, fibrosis density and ion channel remodeling on high-frequency ECG were simulated.

Results: Simulation results demonstrated that the degree of atrial fibrosis (changes in diffusion coefficient and fibrosis density) would lead to a de_x0002_crease in the maximum amplitude of about 30%-63% on high_x0002_frequency ECG, while the ion channel remodeling would limit_x0002_edly affect the maximum amplitude. The more severe the fibro_x0002_sis density or the smaller the diffusion coefficient, the lower the maximum amplitude on high-frequency ECG.

Conclusion: These findings may provide new insights into the assessment of atrial fibrosis by high-frequency ECG.

Key words: High frequency electrocardiogram signal, Atrial fibrosis, Atrial electrophysiology modeling

ID 925

Automatic Analyzer for Urinary Stone Detection in Urine

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Objective: Currently, the world's population is aging and sub-healthy, but due to the stressful life of people or medical pressure (exacerbated by COVID-19), most people are unable to go to the hospital in time for medical checkups to screen for hidden problems. Therefore, we developed an automated analyzer based on the principle of optical detection

sensors for home or community use to help people screen for diseases.

Methods: The analyzer uses non-invasive body fluids, such as urine and saliva, as the detection target, and it can automate the extraction and detection of disease markers in body fluids. The analyzer is also equipped with a unique upper computer operating system, which facilitates human-computer interaction. In this study, a detection protocol and sensing system were developed for urinary stone markers (citric acid and oxalic acid) in urine. The concentration of the target is converted into absorbance at a specific wavelength by nano-sensitive materials, and then the absorbance is quantitatively converted into an electrical signal by a photodiode and transmitted to the upper computer of the analyzer, and a detection report is generated.

Results: The automatic analyzer pre-treatment module can achieve 93.3% and 95.9% recovery of oxalic acid and citric acid in urine, while the detection module has comparable sensitivity and linearity to the microplate reader for the detection of oxalic acid and citric acid standard solutions. And the analyzer can complete the extraction and detection of citric acid and oxalic acid in urine within 20 minutes, and the recovery rate in actual samples can reach more than 90%.

Conclusion: The automatic analyzer can accurately and quickly detect the content of citric acid and oxalic acid in real urine, which has practical value.

Key words: Biomedical sensors and instrument, urinary stone detection, urine pretreatment, nanometer material

ID 927

A U-Sleep Model for Sleep Staging Using Electrocardiography and Respiration Signals

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Objective: Recognizing sleep stages has significant clinical relevance for assessing the physical and mental health of people and for treating sleep-related illnesses. Since manual sleep stage requires experienced clinician to carry out and the process is time-consuming and laborious, the automatic Methods for sleep staging have been widely investigated.

Methods: To perform a five-class (wake, N1, N2, N3 and rapid eye movement) sleep staging task, 255 subjects with polysomnography signals including a single-lead electrocardiography (ECG) signal and single-channel respiration signal from the DCSM dataset is utilized. Notably, ECG and respiration signals are reflecting in heart rate and respiratory rhythm, respectively. The sleep stages are scored in standard 30s-length epochs. This work describes an automatic sleep staging method based on the U-Sleep network, a typical U-Net architecture, which includes three sub-modules: the encoder, the decoder, and the segment classifier.

Results: The subject-independent experiment shows an overall accuracy of 0.641 and F1-score of 0.45 for the five sleep stages on test set by the applied U-sleep network.

Conclusion: Our findings confirm to some extent that ECG and respiratory signals contain comprehensive information for sleep staging.

Key words: ECG; Respiration; U-Sleep model; sleep staging

S07
生物力学与人类健康
Biomechanics in Human Health

ID 176

Metformin-based Carbon Dots: Therapeutic Effects of the Biguanide Functional Groups Chelating Copper ions, Promoting Oxidative Stress and Inhibiting Cell Cycle in Colorectal Cancer

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Objective: Colorectal cancer (CRC) is the most common malignancy-related cause of death worldwide. Elevated levels of plasma copper are closely associated with the prognosis of CRC patients. We hypothesized that plasma copper may be a therapeutic target for treating CRC.

Methods: To examine this hypothesis, we first synthesized metformin-based carbon dots (MFCDs) by hydrothermal method. MFCDs have strong photoluminescence at 460 nm, which is quenched by Cu2+. The photoluminescence intensity of MFCDs shows a high correlation with Cu2+ concentration (0.5–40 μM, limit of detection=0.30 μM). Administration of MFCDs significantly inhibited the growth of CRC xenografts in mice caused by the existence of biguanide functional groups. MFCDs treatment led to the increase of reactive oxygen species and subsequent DNA damage and cell cycle arrest.

Results: We demonstrate that the biguanide functional groups of MFCDs chelate with Cu^{2+}, resulting in the reduction of Cu/Zn-superoxide dismutase and glutathione, which eventually reduces antioxidant capacity and ultimately induces cell apoptosis.

Conclusion: Therefore, MFCDs have the potential to be a novel anti-cancer therapeutic.

Key words: Colorectal cancer, metformin-based carbon dots, biguanide functional groups, copper chelating

ID 267

A New Mathematical Model for Assessment of Bleeding and Thrombotic Risk in Three Different Types of Clinical Ventricular Assist Devices

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Objective: To understand the differences in hemocompatibility of existing VADs and to summarize the causes of blood damage in preparation for the development of highly hemocompatible VADs.

Methods: A new shear-induced thrombosis and bleeding mathematical model was utilized to identify regions at high risk of induced blood damage and assess the bleeding and thrombosis risk in three different types of clinical ventricular assist devices (VADs) (HVAD, Cen-triMag and HeartMate II).

Results: It was found that extracorporeal VADs require a higher pres-sure head to overcome body and pipeline resistance compared to intracorporeal VADs. Centrifugal VADs have a better work ability compared to axial VADs. In vitro VADs are more high-ly blood damaged than in vivo VADs. For bleeding probability, CentriMag > HVAD > HeartMate II. Narrow regions of the VAD (such as the hydrodynamic clearance in HVAD, the side clearance in CentriMag and the blade tip clearance in Heart-Mate II) contribute significantly to device-induced bleeding. For thrombotic potential, CentriMag > HeartMate II > HVAD. The distribution of regions of high thrombotic potential in VADs is similar to the distribution of long residence time re-gions (such as the clearance between rotor and guide cone in HVAD, the back clearance and impeller eye in CentriMag, and the straightener and rotor inlet in HeartMate II). Flow separa-tion regions in VADs resulting in residence time and shear stress pairs also contributed to the risk of bleeding and throm-bosis. Further studies found that the hemocompatibility of VADs was strongly negatively correlated with efficiency (r<-0.80).

Conclusion: This study found that CentriMag > HVAD > HeartMate II in terms of bleeding probability and CentriMag > HeartMate II > HVAD in terms of thrombosis potential. Narrow regions and flow separation regions in VADs contribute to blood damage. The efficiency of VADs is highly correlated with hemocompatibility.

Key words: Ventricular assist devices; Bleeding; Thrombosis; Shear stress; Efficiency

ID 470

Morphological Feature Recognition of Induced ADSCs Based on Deep Learning

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Objective: In order to accurately identify the morphological features of different differentiation stages of induced Adipose Derived Stem Cells (ADSCs) and judge the differentiation types of induced ADSCs.

Methods: a morphological feature recognition method of different differentiation stages of induced ADSCs based on deep learning is proposed. Using the super-resolution image acquisition method of ADSCs differentiation based on stimulated emission depletion imaging, after obtaining the super-resolution images at different stages of inducing ADSCs differentiation, the noise of the obtained image is removed and the image quality is optimized through the ADSCs differentiation image denoising model based on low rank nonlocal sparse representation; The denoised image is taken as the recognition target of the morphological feature recognition method for ADSCs differentiation image based on the improved Visual Geometry Group(VGG-19) convolutional neural network.

Results: Through the improved VGG-19 convolutional neural network and class activation mapping method, the morphological feature recognition and visual display of the recognition results at different stages of inducing ADSCs differentiation are realized.

Conclusion: After testing, this method can accurately identify the morphological features of different differentiation stages of induced ADSCs, and is available.

Key words: Deep learning, Induced ADSCs, Differentiation, Morphological features, Recognition

ID 1138

应变增强的应力松弛调控骨骼肌再生的力学生物学机制研究

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目的：细胞外基质（ECM）的粘弹性通过调节细胞行为和命运，在组织发育和再生中起关键作用。在骨骼肌的发育、成熟过程中，力学拉伸被认为是一种必要的应变刺激。尽管上述两种力学因素很重要，但这些因素是否相互作用，以及它们如何协同调节骨骼肌生成，仍难以确定。

方法：我们测试了正常和患有杜氏肌营养不良症（DMD）的小鼠骨骼肌的力学性能，表征了两者分别加载 5% 和 20% 应变时的应力松弛行为。随后，我们开发了基于胶原大分子的三维水凝胶平台，用于在体外模拟应变增强的应力松弛（SESR）并研究其对肌细胞成肌分化的影响。作为对照，我们设计了双交联、改性胶原水凝胶，以解耦应变和应力松弛的影响。

结果：正常组织中，应变和 ECM 粘弹性的相互作用表现出特殊的粘弹性特征（即 SESR），而在 DMD 小鼠中几乎没有观察到该现象。体外结果表明应变和应力松弛都能促进成肌分化，而当应用 SESR 时，成肌作用更加明显。这种促进作用可能是由整合素 -FAK 信号转导、F-actin 聚合介导的 MRTF 核定位和通过核力学介导的染色质开放驱动的。

结论：本研究首次证实在正常骨骼肌中存在 SESR 现象，并揭示其调控肌生成的潜在机制，这将为肌肉组织再生和细胞治疗开辟新路径。

关键字：力学微环境；应力松弛；肌再生；MRTF 核定位；染色质重塑

ID 1603

步态分析技术在腰椎间盘突出症临床诊断和功能评估中的应用进展

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通过回顾已发表文献，了解步态分析在 LDH 诊断和功能评估中的应用情况，并对临床研究中的不足进行展望。步态分析技术是 LDH 诊断和疗效评估的重要手段，但是目前在设备普适性、肌电测量技术的可行性、纵向研究深度、正常步态数据库的建立四个方面仍存在不足。 针对步态分析系统存在的诸多问题，未来的研究可以将重点放在以下几个方面：①探索深层肌电图的无创测量技术，完善 Anybody 软件中预测肌肉冗余力技术，提高所获取数据的精确性和客观性；②探索不同观测指标的特异性和精确性，拓展便携式可穿戴设备在临床诊疗中的应用；③开展 LDH 不同突出阶段和突出类型的异常步态的纵向研究，为临床提供更具有个性化的治疗方案。④建立健康人群不同年龄阶段的步态数据库，为 LDH 的诊疗评估提供标准化参考。

关键字：步态分析；腰椎间盘突出症；临床诊断；功能评估；综述

ID 2235

跆拳道后横踢动作下运动员膝关节有限元损伤分析

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目的：探索跆拳道后横踢动作下运动员膝关节韧带损伤的生物力学机制。

方法：基于跆拳道专业运动员膝关节 MRI 数据建立膝关节有限元模型，模拟后横踢动作不同时刻下膝关节韧带的生物力学特征，计算韧带应力大小以及应力分布。

结果：进攻腿膝关节前交叉韧带、后交叉韧带、内侧副韧带、外侧副韧带、髌韧带应力峰值分别为 2.22MPa、0.0044MPa、2.15MPa、0.92MPa、0.14MPa；支撑腿腿膝关节前交叉韧带、后交叉韧带、内侧副韧带、外侧副韧带、髌韧带应力峰值分别为 58.95MPa、64.69MPa、15.66MPa、0.22MPa、7.52MPa。

结论：后横踢动作膝关节韧带损伤更多是非接触性损伤。扭转力矩、伸展力矩和自身体重三者的共同作用是造成支撑腿膝关节韧带损伤的主要原因。相较于进攻腿，支撑腿更易发生韧带损伤。

关键字：后横踢；有限元；膝关节；损伤；韧带

ID 2333

基于磁动光学相干弹性成像的组织力学特性评估

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目的：组织的力学特性对于疾病的诊断和疗效评估具有重要价值。

方法：磁动光学相干弹性成像 (Magnetomotive optical coherence elastography, MM-OCE) 的原理是利用外部磁场的激励使组织内的磁性粒子产生动态机械运动，随后通过 OCT 系统检测磁性粒子标记组织的微小振动，从而通过分析振动信息提取能反映组织生物力学特性的参数。本研究搭建了磁动光学相干弹性成像研究平台，主要包括螺线管磁场激励与 SD-OCT 系统采集两个模块，对负载磁纳米颗粒的样品在扫频激励信号下振动响应进行频谱分析，获得组织的机械共振频率，定性表征组织的生物力学特性。

结果：基于该系统测试了明胶仿体和离体猪角膜的力学特性，采用光谱 MM-OCE 方法，硬度越大的明胶仿体其机械共振频率越高，经过多聚甲醛固定的离体猪角膜其共振频率增大。

结论：采用该系统能够检测出生物组织硬度的变化，实现组织生物力学特性定性测量。实验结果验证了这种 MM-OCE 方法评估组织生物力学特性是可行性，可作为评估角膜硬度的一种方法，未来有望眼科临床中得到应用。

关键字：生物医学测量学；光学相干弹性成像；机械共振频率；生物力学特性

ID 2350

亚磁场通过调控成骨细胞的铁代谢和 ROS 水平抑制成骨细胞的分化

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目的：亚磁场通常是指磁感应强度（B）低于地磁场（35-70 μT）的极弱静态磁场环境，磁感应强度 0 < |B| ≤ 5 μT。目前，关于亚磁场的生物学效应研究大多集中在行为和认知层次，对骨骼系统的研究甚少。研究表明，真实空间微重力环境下，长期飞行会引起航天员骨质流失和血清铁过载。因此，本研究的目的是探究亚磁场是否通过调控铁代谢进而介导成骨细胞的生物学行为。

方法：将成骨细胞 MC3T3-E1 置于不同磁场环境下进行培养，利用 CCk-8，ALP 染色，茜素红染色，蛋白质印记（Western Blot）和实时荧光定量 PCR 等技术对成骨细胞的生物学行为进行检测。

结果：结果表明：亚磁场促进成骨细胞的增殖，并增加了细胞增殖期间细胞中的铁含量，这可能与细胞 ROS 水平的升高有关；亚磁场减弱了成骨细胞的分化，在分化早期，成骨细胞中铁含量上升。在亚磁场下，低浓度的 DFO 可逆转亚磁场抑制成骨细胞分化的作用；添加 FAC 可以加强亚磁场抑制成骨的分化及矿化的作用。

结论：亚磁场可通过调控铁代谢介导其对成骨细胞的增殖和分化的调控。该研究有助于开发针对亚磁场的对抗疗法，将为未来载人航天领域航天员的骨骼系统防护，提供理论基础。

关键字：亚磁场；成骨细胞分化；铁代谢，ROS

ID 2365

基于“筋出槽、骨错缝”理论探讨生物力学在手法治疗颈椎病中的研究进展

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基于“筋出槽、骨错缝”理论探讨生物力学在手法治疗颈椎病中的研究进展，通过对“筋出槽、骨错缝”理论的进一步验证和完善，为提升骨伤手法治疗颈椎病的安全性和有效性提供理论依据。 回顾近年来关于颈椎手法生物力学研究进展，从手法运动学和动力学的测量与分析，手法对颈椎内部结构（椎体、椎间盘、韧带、血管）间的生物力学影响两个方面进行综述。“筋出槽、骨错缝”作为颈椎病的核心病机，其理论内涵对手法治疗颈椎病起着指导作用，其本质是筋骨关系的失衡，也是现代生物力学中颈椎的动静力学失衡。“筋出槽、骨错缝”作为颈椎病的核心病机，其理论内涵对手法治疗颈椎病起着指导作用，基于“筋出槽、骨错缝”理论开展手法治疗颈椎病的生物力学研究，是传统医学与现代生物技术的有机融合，是对该理论的进一步验证和完善，有利于促进手法传承与创新，提高手法有效性与安全性，为临床治疗规范化提供更坚实的理论依据与数据支撑。

关键字：筋出槽；骨错缝；颈椎病；中医手法；生物力学；综述

ID 2752

肘部等长收缩过程中大脑皮质激活与肌肉兴奋的映射研究

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目的：本研究旨在探究健康成年人在肘部等长收缩运动任务中大脑脑区激活与外周肌肉收缩之间的作用关系。

方法：招募健康成年受试者 21 名。受试者在视觉反馈调节下完成不同最大自主收缩条件下的肘部等长收缩运动任务。本研究共使用 30 个近红外通道覆盖受试者前额叶皮层、运动皮层和枕叶皮层。同时，表面肌电电极粘贴到受试者的肱二头肌和肱三头肌的腹部。

结果：肌肉收缩运动任务中在较大发力条件下脑区激活程度均显著增强（$P < 0.05$）。对比肱二头肌和肱三头肌在肌肉收缩运动任务中的表面肌电信号发现，在较大发力条件下表面肌电信号的模糊近似熵值均显著高于较小发力条件（$P<0.05$）。肌肉收缩运动任务中脑区激活强度与表面肌电信号相关性分析结果显示，在对侧运动皮层中脑血氧变化与表面肌电信号的模糊近似熵值呈显著正相关（$P < 0.05$）。

结论：运动任务中大脑血流动力学和外周肌肉收缩之间存在显著正相关性，为运动功能康复评估提供了新思路。

关键字：功能性近红外光谱技术；肌电图；脑网络；模糊近似熵；运动任务

ID 2856

基质刚度通过 ANTXR1/Integrin β1 互作调控软骨细胞分泌表型的作用与机制研究

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目的：本研究旨在探究新型细胞膜力学感受分子 ANTXR1 调控软骨细胞分泌功能的作用和机制。

方法：首先构建不同刚度的水凝胶；WB 检测软骨细胞在不同基质刚度下 ANTXR1、Integrin β1、FAK、p-FAK、Collagen II 和 Aggrecan 的表达量；采用荧光共定位和 Co-IP 实验检测不同刚度下 ANTXR1 和 Integrinβ1 的相互作用；最后通过慢病毒下调软骨细胞中 ANTXR1 的表达，检测软骨细胞中 Integrin β1、FAK、p-FAK、Collagen II 和 Aggrecan 的表达量。

结果：随刚度升高 ANTXR1 的表达量降低，而 FAK、p-FAK、Integrinβ1、Aggrecan 的表达量升高，Col II 表达不变；Co-IP 和荧光共定位显示，ANTXR1 和 Integrinβ1 在低刚度条件下存在强相互作用；通过慢病毒下调 ANTXR1 表达后发现，Integrinβ1 的表达量保持不变，但 p-FAK 表达升高，Col II 和 Aggrecan 表达也均升高。

结论：ANTXR1 是软骨生成的负调控分子，通过响应基质刚度变化抑制 Integrinβ1 的功能，干扰其表达可以促进软骨修复。

关键字：细胞外基质刚度；ANTXR1；Integrinβ1；软骨细胞分泌表型

ID 2939

基于磁共振影像和深度学习的端到端器官三维几何重建

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目的：从磁共振影像重建器官的三维几何模型在众多领域都是至关重要的，如生物力学数值模拟、计算机辅助诊断和虚拟手术规划。传统的二维磁共振图像切片分割和复杂的几何修复方法存在着复杂繁琐的手工操作，工作量大，时间长。

方法：在本研究中，我们提出了一种基于深度学习的端到端重建技术来简化这一过程。该技术使用卷积神经网络（CNN）和图卷积神经网络（GCN）的组合来提取图像和三维结构信息，并使用新设计的变形模块来融合这些信息特征，实现从球体模型到任意器官三维几何模型的渐进变形过程。

结果：该技术在重建人体膀胱的三维几何形状的测试任务中取得了良好的定性和定量结果。整个重建过程用时不到 3 秒。

结论：本研究提出的使用深度学习的端到端重建技术大大简化了从磁共振影像重建器官的三维几何模型的过程。该技术有望应用于临床实践，提高诊疗的准确性和效率。

关键字：深度学习；三维几何重建；磁共振影像；卷积神经网络；图卷积神经网络

ID 3061

近视患者角膜生物力学各向异性与眼轴的相关性研究

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目的：探究近视眼患者角膜生物力学性能与眼轴之间的关系。

方法：近视眼患者分为 AL<26mm 组和 AL ≥ 26mm 组，Corvis ST 检测在体角膜应力应变参数 SSI。将角膜基质透镜进行双轴机械拉伸实验，检测角膜力学性能。分别比较应变为 0.03 时角膜组织水平和垂直方向的切线模量，和应力为 0.6 MPa 时各向异性参数，并对 AL 与角膜力学性能之间的相关性进行分析。

结果：与 AL<26mm 相比，AL ≥ 26mm 时，水平和垂直方向弹性模量和 SSI 显著降低。各向异性参数与 AL 呈正相关（r=0.307）。与 AL<26mm 相比，AL ≥ 26mm 的各向异性参数显著增加。AL<26mm 组中，SSI 与 AL 呈负相关（r=-0.380），但在 AL ≥ 26mm 组中无相关性。与 26mm ≤ AL<27mm 组相比，27mm ≤ AL<28mm 组水平方向的弹性模量显著

下降，垂直方向没有差异。AL ≥ 26mm 组水平和垂直方向的弹性模量和 SSI 等角膜生物力学性能显著低于 AL<26mm 组。当 AL ≥ 26mm 时，SSI 不随着 AL 的增加而降低。

结论：近视患者角膜力学性能在水平和垂直方向存在各向异性，且与眼轴长度之间存在一定的相关性，在体测量角膜生物力学参数时应考虑 AL 的影响。

关键字：近视；角膜基质透镜；力学性能；SSI ；各向异性

ID 3094

不同体积骨水泥增强对椎体的生物力学影响

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目的：椎体成形中使用骨水泥的量不足会导致椎体强度恢复不够，使骨折椎体再次塌陷，而骨水泥注射量过多又会造成骨水泥渗漏。目前对于临床中骨水泥的使用量还没有一致的结论。因此，本研究的目的是，评估椎体成形术中骨水泥注射量对椎体的生物力学影响。

方法：建立正常胸腰椎有限元模型、骨质疏松骨折模型及注射不同体积骨水泥（2ml、4ml、6ml）的手术模型，对比 T12 椎体的应力和骨水泥应力。

结果：T12 椎体的皮质骨和松质骨应力均随着骨水泥体积的增加而降低，但是应力降低的趋势会随着骨水泥体积的增加而减缓。术后骨水泥应力也随着骨水泥体积的增加而降低。

结论：使用 4ml 的骨水泥增强椎体，既可以降低椎体应力从而降低椎体再骨折的风险，又能有效降低因注射量过大引起骨水泥渗漏的概率。

关键字：骨质疏松椎体压缩性骨折；骨水泥；椎体成形术；有限元

ID 3177

基于荧光图像的水凝胶几何网格重建方法及其有限元力学模拟

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目的：本研究开发一种基于荧光共聚焦显微图像的水凝胶几何模型 3D 重建方法，有望用于对水凝胶骨架结构进行显微尺度的数值模拟和力学性能仿真。

方法：通过激光共聚焦显微镜获得水凝胶骨架的层状扫描荧光图像。利用 MATLAB 对层状扫描荧光图像进行了处理、分割、重建和优化，生成了可用于有限元模拟的水凝胶体的网格结构，并在 ANSYS 软件中模拟计算了生成模型的压缩模量。

结果：测得 0.5%-2.5%wt 戊二醛交联的明胶水凝胶压缩模量为 409-2094 Pa，利用本研究开发的方法构建的

水凝胶有限元模型仿真计算获得的压缩模量为 392-2080 Pa，实测结果和仿真结果之间误差为 5%。本研究进一步通过在前处理中引入局部自适应阈值算法，以及对 MATLAB 生成的等值面 3D 模型中间件进行拓扑优化，进一步提高计算精度。

结论：本研究开发一种基于荧光共聚焦显微图像的水凝胶几何模型 3D 重建方法，并应用于明胶水凝胶的有限元体网格构建及其压缩模量的计算仿真。初步验证本方法生成的模型准确性较好，计算误差小于 5%，后续将在水凝胶骨架界面几何形状方面进一步优化，扩大可计算的力学参数和计算精度，有望用于细胞与材料界面力的相互作用研究。

关键字：水凝胶；有限元方法；图像分割

ID 3343

骨骼种属鉴定研究进展

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骨骼种属鉴定可区分人类与非人类骨骼，确定是否需要立案侦查，从而节约人力与物力成本，提高办案效率。目前常用的骨骼种属鉴定方法包括形态学、分子生物学、化学、光谱学、微量元素测定及生物力学检测等方法．综述了各种方法的优势与不足，提出应构建一种较为通用和完善的骨骼种属鉴定系统，为法医学鉴定实践提供参考依据。 骨骼种属鉴定可区分人类与非人类骨骼，确定是否需要立案侦查，从而节约人力与物力成本，提高办案效率。目前常用的骨骼种属鉴定方法包括形态学、分子生物学、化学、光谱学、微量元素测定及生物力学检测等方法，本文综述了各种方法的优势与不足，提出应构建一种较为通用和完善的骨骼种属鉴定系统，为法医学鉴定实践提供参考依据。

关键字：法医学；种属鉴定；生物力学；骨骼；研究进展

3537

利用原子力显微镜与全原子分子动力学研究透明质酸与胶原蛋白的相互作用

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目的：胶原蛋白作为人体内非常重要的结构蛋白主要存在于结缔组织中，以不同的趋向特点在组织力学性能以及生理功能上有着极为重要的作用。透明质酸填充在人体的细胞与胶原纤维的空间中，对胶原蛋白所形成的三维结构有着重要的影响。然而目前对于胶原蛋白体与透明质酸之间相互作用的研究较少。

方法：将实验研究与数值仿真相结合。一方面，借助于原子力显微镜，以无端牛皮 I 型胶原蛋白为研究对象，研究透明质酸对胶原纤维体外自组装的影响机制。另一方面，本论文利用全原子分子动力学模拟方法研究了透明质酸对胶原蛋白力学属性的影响机制。创建异三聚体 I 型胶原三螺旋以及透明质酸模型，对处于生理环境下的胶原蛋白以及

胶原蛋白—透明质酸的复合物通过 Steered Molecular Dynamics 进行了力学响应分析。

结果： 原子力显微镜结果得出，透明质酸对原胶原纤维组成胶原纤维及胶原纤维的径向生长皆有促进作用。全原子分子动力学模拟方法研究结果显示，透明质酸吸附到胶原上使胶原的力学性能明显增强；胶原蛋白—透明质酸复合物具有更强的吸水性；透明质酸使胶原蛋白和胶原蛋白之间的结合更加紧密。

结论： 研究结果对组织修复以及再生工程具有重要理论和实验价值。

关键字： I 型胶原蛋白；透明质酸；全原子分子动力学；原子力显微镜；组织修复

S08
类器官与器官芯片
Organoids and Organs-on-Chips

ID 894

Array-based Cerebral Organoids Analysis Strategy to Study Brain Aging Signatures

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Objective: Organoids recapitulate human-specific phenotypes and functions in vivo and have potential in studying development, modeling diseases, and drug screening. Because of the heterogeneity of each organoid, mass samples are required for ideal experiment results. Thus, quick and efficient Methods for processing and phenotypic analysis of batch organoids is urgently needed.

Methods: Here, we propose an integrated strategy to analyze phenotypes in batch organoids combining with array embedding, staining and 2D/3D optical imaging, multiple-organoids can be efficient in situ phenotypic analysis with spatial localization. We prepared cerebral organoid aging models using D-galactose induced and its post-treatment with NGF.

Results: Using this strategy, we analyzed aging hallmarks of drug-treated cerebral organoids through parallel staining and imaging with Live/Dead dyes or aging-specific biomarkers. We can trace-back sample flow and data flow which came from and analyze multiple aging signatures.

Conclusion: This method would have potential to efficiently study organoids or cell spheroids phenotypes in disease models and drug screening.

Key words: Cerebral organoids, parallel imaging, single-cell analysis, aging signatures

ID 1081

络合诱导分辨率增强、具有优越抗菌和血管生成性能的多效小直径血管结构

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目的：研究一种用打印后处理方法制备多效小尺寸人工血管的方法。它能以更便捷的方式来提高同轴打印构建体的分辨率。

方法：将带负电荷的聚乙烯醇（PVA）和海藻酸盐（Alg）互穿网络人工血管浸泡在带正电荷的壳聚糖（CTS）溶液中，通过两者之间的静电相互作用使人工血管发生快速尺寸收缩。

结果：在浸泡过程中 Alg 与 CTS 发生酰胺化反应，在人工血管外表面形成硬壳层，从而改变了人工容器的渗透性。通过离子交联将铜离子引入体系，铜离子与 CTS 的协同作用可以更有效地穿透细菌膜，使细菌内容物流出，对大肠杆菌（E. coil）和金黄色葡萄球菌（S. aureus）表现出极强的杀灭作用。在大鼠背部皮肤移植实验中，铜离子与缺氧诱导因子 -1（HIF-1）相互作用，调控血管内皮生长因子（VEGF）的表达，促进内皮细胞增殖。

结论：该种人工血管表现出优良的血管生成功能和良好的组织相容性，并能通过简单的印刷后处理技术达到打印尺寸的快速收缩。

关键字：打印后处理技术；静电相互作用；抗菌性；促血管再生性；小尺寸人工血管

ID 1611

芯片上生物工程化构建环形大脑类器官

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目的：克服传统大脑类器官存在的培养流程复杂、均一性差和无法进行原位实时观察的局限性。

方法：基于微流控芯片技术设计了一种大脑类器官芯片，用于培养环形大脑类器官。

结果：可在整个培养周期内对环形大脑类器官进行原位培养和实时观察。此外，环形大脑类器官的均一性显著优于传统大脑类器官。免疫荧光染色和 qPCR 结果证实，环形大脑类器官表达与传统大脑类器官相似的多种细胞类型标志物和脑区标志物。

结论：本研究在微流控芯片上通过生物工程方法构建了环形大脑类器官。该方法不仅可在整个培养周期内对环形大脑类器官进行原位培养和实时观察，还可显著提升环形大脑类器官的均一性。我们相信，这种新型环形大脑类器官模型将为大脑发育和疾病的基础研究提供创新平台。

关键字：多能干细胞；生物工程；大脑类器官芯片；均一性；原位成像

ID 1768

一组反映气道类器官向肺泡类器官形态变化的潜在分子标记

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目的：通过不同培养因子建立肺泡类器官的双向培养条件，利用 AI 图像学分析法、免疫染色及蛋白质图谱等多维方法建立一个全面的肺泡类器官验证系统，并建立类器官形态与分子标记的相关性。

方法：采集小鼠肺组织，将消化过滤的肺上皮细胞分为连续“扩增”培养组（EO 组）及“扩增 - 分化”分段培养组（DO 组）。分别在基于气液界面进行体外 3D 类器官培养，通过对类器官形态的观察，AI 影像分析，免疫荧光，qPCR 及蛋白组学分别对两组肺类器官的结构、细胞组成及分子组成进行鉴定。

结果：AI 图像分析量化了表型改变，免疫荧光染色数据表明细胞组成发生了变化，从不同的细胞类型向整体肺泡型细胞转变。 蛋白质组学分析数据表明分子变化伴随着形态变化，并提供了反映用分化培养基处理后形态变化的潜在分子特征。

结论：本研究建立了一个全面的验证系统，并提供了表型特异性分子特征来表征生成的类器官模型。

关键字：支气管肺泡类器官模型；多维分析；AI 图像分析；系统验证系统；分子特征

ID 1941

构建阿尔茨海默病的高通量脑类器官芯片

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目的：为阿尔茨海默病（AD）的病理研究和药物研发提供一种有效的体外模型。该模型需与人体相关性良好，能够模拟人类大脑复杂的生理结构和病理特征，且该模型需为体外脑组织培养提供充足的氧气和养分供应，且能够实现高通量体外培养。

方法：运用流体力学模仿真技术、3D 打印技术等构建了一种新型高通量脑类器官芯片，并使用人诱导的多能干细胞衍生的 3D 脑类器官建立阿尔茨海默病的体外模型。该芯片能够模拟脑组织在体内的低剪切力的三维生长环境，通过模拟血脑屏障渗漏导致血清暴露的情形，诱导正常脑类器官产生 AD 样病理。

结果：构建了新型高通量脑类器官芯片，在芯片上实现了脑类器官的培养，并成功诱导了脑类器官的阿尔茨海默病样病理特征，包括淀粉样蛋白 β 聚集体增加、磷酸化微管相关 tau 蛋白水平升高、突触缺失和神经网络受损。。

结论：这种基于 3D 培养的器官芯片能脑类器官体外培养，并能够模拟阿尔茨海默病的部分病理特征，有望成为阿尔茨海默病的病理研究和药物筛选的有效的高通量体外模型。

关键字：阿尔茨海默病（AD）；器官芯片；人诱导多能干细胞（hiPSC）；脑类器官；疾病模型

ID 2015

高通量细胞自组织构建预血管化的肝脏类器官芯片

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目的：肝脏类器官作为一种人类生理相关的肝脏体外模型系统，近年来为揭示人类肝脏疾病的分子机制和评估药物的肝毒性提供了崭新的工具。人体肝脏中非实质细胞对于维持肝脏的功能和稳态起了重要的作用。然而，现有的主流肝脏类器官培养方法缺乏非实质细胞。基于此，我们研究和开发了一种通过诱导多能干细胞来源的肝脏类器官和内皮细胞、成纤维细胞自组织构建预血管化的肝脏类器官的方法。

方法：首先，通过微加工技术构建了琼脂糖微孔阵列芯片。利用该芯片高通量构建前肠干细胞小球，并将其向肝脏谱系分化。我们研究在无内皮细胞培养基情况，在肝脏分化的不同阶段加入内皮细胞对内皮细胞存活和自组织的影响。进一步，我们研究了不同内皮细胞和成纤维细胞种植量对肝脏类器官自组织和预血管化的影响。

结果：将内皮细胞在类器官分化到肝脏成熟阶段时加入更有利于其存活。此外，成纤维细胞的加入有利于进一步促进内皮细胞的存活率，并促进内皮细胞自组织进入肝脏类器官内部形成预血管化结构。

结论：建立了一种高通量自组织构建预血管化的肝脏类器官的方法，揭示了成纤维细胞能够促进内皮细胞在肝脏类器官内自组织和预血管化。

关键字：肝脏类器官芯片；预血管化；自组织；高通量；人诱导多能干细胞

ID 2023

基于微孔板芯片一步法构建大脑类器官用于研究 Tau fibril 的神经毒性

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目的：人类多能干细胞来源的大脑类器官是模拟大脑发育过程的优良体外模型，可重现人类大脑的特定结构和功能，概括人类大脑发育和神经系统疾病的特征。然而，目前的大脑类器官培养系统缺乏对类器官形态发生和功能成熟的精细调控。

方法：结合微流控芯片技术，开发了一种基于微孔板的大脑类器官芯片，利用重力驱动的双向流体促进氧气供应和营养 / 代谢物质交换，进一步结合免疫荧光和 RT-QPCR 方法研究大脑类器官的成熟性。

结果：该芯片简化了大脑类器官的培养流程和提高大脑类器官的均一性，并促进大脑类器官神经发生和皮层发育。基于该模型，我们进一步研究了神经退行性疾病的特征蛋白 Tau fibril 对大脑类器官的神经毒性作用，发现了 Tau fibril 诱导大脑类器官中的神经元丢失。

结论：建立了一种用于大脑类器官高效培养的孔板芯片系统，该系统为标准化构建大脑类器官和基于大脑类器官的神经疾病研究提供了新思路。

关键字：大脑类器官芯片；人类多能干细胞；神经退行性疾病 ；神经毒性测试；Tau Fibril

S09
纳米医学与工程
MicroNano-Bioengineering

ID 168

磁珠表面修饰氨基苯硼酸调控抗体取向与降低非特异性吸附的研究

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目的：羧基磁性微球是体外诊断中常用的载体，被广泛应用在免疫分析中。目前，它在体外诊断的应用中仍然受限于低灵敏度，高非特异性吸附等问题。本研究对羧基磁性微球进行表面修饰，以调控抗体在磁珠表面取向，改善抗原捕获灵敏度，并建立模型，研究各类表面活性剂对降低磁性微球表面非特异性吸附的效果。

方法：采用氨基苯硼酸修饰磁珠，基于硼酸基团与 IgG 型抗体非活性区域寡糖链的可逆性结合，实现在磁珠表面的良好取向，随后微球表面羧基与抗体氨基形成酰胺键实现固定化，进行抗体取向表征。同时，以牛血清白蛋白包被的磁性微球为模型，构建化学发光法评价 Tween 系列与 Triton 系列对磁珠表面非特异性吸附的改善效果。

结果：证实硼酸基团调控抗体取向的方法实现了抗体取向调节，将抗体活性区域暴露程度提高至 95% 以上。探究表面活性剂对非特异性吸附的改善作用研究结果表明，这两类表面活性剂对非特异性吸附的改善受其疏水链结构的影响，疏水链增长，改善效果降低。

结论：本研究对羧基磁性微球的表面改性，优化了其在体外诊断中检测灵敏度与检测限，后续可应用在各种检测方法中，如化学发光检测。

关键字：抗体取向；磁性微球 ; 表面修饰；表面活性剂；非特异性吸附

ID 386

Design Synthesis and Evaluation of Glycyrrhetinic Acid Functionalized Mesoporous Silica Nanoparticles

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Objective: The purpose of this study was to find a suitable treatment for acute drug-induced liver injury. The use of nanocarriers can improve the therapeutic effect of natural drugs by targeting hepatocytes and higher loads.

Methods: Firstly, a uniformly dispersed three-dimensional dendritic mesoporous silica nanospheres (MSN) was synthe-

sized. Glycyrrhetinic acid (GA) is a hepatocyte targeting group, covalently decorated on the surface of MSN through amide bond, and then loaded with COSM to form drug-loaded nanoparticles COSM@MSN-NH_2-GA. The constructed drug-loaded nano-delivery system was determined by characterization analysis. CCK-8 method was used to evaluate cell viability, and CLSM and FCM were used to observe cell uptake in vitro.

Results: The MSN-NH2-GA nanocarrier was prepared, which was spherical, regular in shape and uniform in particle size of about 150 nm. The successful modification of glycyrrhetinic acid makes the surface charge of nanoparticles close to electrical neutrality and improves biocompatibility. Nitrogen adsorption experiments showed that MSN-NH2-GA had a suitable specific surface area and pore volume, which provided a basis for high drug loading (28.36 % ± 1.00). In vitro cell experiments showed that COSM@MSN-NH2-GA significantly enhanced the uptake of hepatocellular carcinoma (LO2) cells and improved the therapeutic effect of acetaminophen (APAP) -induced drug-induced liver injury through a specific GA receptor-mediated endocytosis mechanism, and reduced AST and ALT indicators.

Conclusion: This study demonstrated for the first time that the formulation and delivery scheme using natural drug COSM and nanocarrier MSN have a protective effect on APAP-induced hepatocyte injury. This result provides a potential nano-delivery scheme for targeted therapy of acute drug-induced liver injury.

Key words: Chitosan oligosaccharide; Mesoporous silica; Drug-induced liver injury; Acetaminophen; Glycyrrhetinic acid modification

ID 1837

变构 DNA 在肿瘤相关分子识别中的应用研究

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目的：肿瘤定点的药物释放是提高抗肿瘤治疗准确性和有效性的关键环节。

方法：利用 DNA 结构的精确可控性和良好的生物相容性，并嵌入酸性 pH 响应序列和端粒酶 RNA 序列为释药开关，构建了一种在肿瘤微环境中控释免疫佐剂 R848 和化疗药物铂的 DNA 纳米载体系统，从而极化肿瘤相关巨噬细胞和诱导肿瘤免疫原性细胞死亡。

结果：该载药系统在特异性的双响应下，释放 R848 和化疗药物铂，进一步发挥协同作用，将促肿瘤的 M2 型肿瘤相关巨噬细胞极化为抗肿瘤的 M1 型肿瘤相关巨噬细胞，并诱导免疫原性细胞死亡，重塑免疫抑制微环境，并且在乳腺癌肺转移肿瘤模型中取得了令人满意的治疗效果。同时在体内外深入地证明了其作用机制。

结论：所建立的方法减轻了单独使用游离药物带来的毒副作用，体现了 DNA 纳米结构作为免疫治疗载体的优势，为抗肿瘤治疗提供了一个具有潜力的平台。

关键字：DNA 纳米结构；巨噬细胞；免疫微环境

ID 1871

CXCR4 拮抗多肽修饰的金纳米棒靶向内质网光热免疫治疗三阴性乳腺癌

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目的：利用三阴性乳腺癌细胞（TNBC）高表达 CXCR4 这一特性，将可特异性拮抗 CXCR4 的多肽 E5 修饰金纳米棒（AuNRs），构建靶向 TNBC 的光热治疗系统（AuNRs-E5），在光热杀伤肿瘤细胞的同时诱导细胞内质网应激引发细胞发生免疫原性死亡（ICD），对荷瘤小鼠进行光热免疫治疗。

方法：用紫外 - 可见 - 近红外分光光度计，透射电子显微镜和 X 射线光电子能谱等对 AuNRs-E5 的理化性质进行表征；使用流式细胞术和 Elisa 试剂盒检测 ICD 相关指标；通过免疫荧光染色观察肿瘤免疫微环境的组成。

结果：AuNRs-E5 可特异性靶向 4T1 细胞的内质网，并通过光热免疫作用杀伤 4T1。在 TNBC 小鼠模型上，AuNRs-E5 组在激光照射下，会诱导小鼠体内肿瘤免疫微环境中的巨噬细胞从 M2 表型转换为 M1 表型，诱导机体产生特异性免疫反应，抑制肿瘤在肝和肺中的转移，小鼠总生存期和对照组的 24 天相比延长到 100 天以上。

结论：AuNRs-E5 光热免疫治疗是一种具有巨大潜力的有效治疗肿瘤的策略，有望用于治疗包括 TNBC 在内的 CXCR4 高表达的各种癌症。

关键字：金纳米棒；CXCR4 ；光热疗法；免疫原性死亡；三阴性乳腺癌

S10
组织工程与再生医学
Tissue Engineering and Regenerative Medicine

ID 288

A Matrix-targeted Cartilage Repair with a Molecular Machine that Drives Glycosaminoglycan Assembly

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Objective: Globally, over 500 million people suffer from osteoarthritis (OA), the most common arthritis featured by an irreversible loss of glycosaminoglycans (GAGs) at joint surfaces. GAGs are key extracellular matrix (ECM) components that maintain cartilage structure and function. However, they cannot be efficiently regenerated or directly manipulated by current tissue/cell engineering approaches. Molecular machines can conduct molecular-level tasks to modify biological processes. Inspired by this concept, we hypothesized that the highly anionic GAG molecules could complex with cationic biomaterials via electrostatic interactions for hyaline cartilage regeneration.

Methods: We identified a model polymer hexadimethrine bromide (HDMBr) that uniquely enriched GAGs in a human mesenchymal stem cell chondrogenesis. After confirming its function, we investigated the molecular mechanisms that drove GAG enrichment in both extracellular and intracellular space. Furthermore, we applied HDMBr in two therapeutic models for cartilage repair.

Results: HDMBr anchored pericellular GAGs to create a chondrogenic niche and up-regulated the formation of vesicles for matrix secretion. Notably, HDMBr bound chondroitin sulfate (CS), the major component of cartilage GAG, and acted like a molecular machine to softly promote the assembly of CS-rich condensates by electrostatic and hydrogen bonds. Taken together, HDMBr drove a productive GAG secretion with increased carriers (vesicles) and a higher transport efficiency (highly concentrated GAGs). In one therapeutic model, HDMBr suppressed GAG loss at the surface of human OA cartilage explants and enriched GAGs in OA chondrocyte-derived tissues. In another model of large-size osteochondral defects in rabbits, HDMBr enabled the formation of GAG-rich hyaline-like cartilage and a superior articular architecture.

Conclusion: We proposed a new cost-effective GAG-targeted strategy for cartilage repair, indicating that readily accessible ECM components (GAGs) could be recognized as therapeutic targets for high-efficacy tissue regeneration. This study also provides insights on how to manipulate cell-material interactions via synthetic molecules acting in the intracellular space.

Key words: hyaline cartilage regeneration, glycosaminoglycan, cationic polymers, molecular machines, cell-material interactions

ID 457

快速组织黏附性细胞涂层提高细胞疗法移植率及其在骨关节炎中的应用

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目的：细胞移植是影响细胞治疗效果的关键因素之一。然而，大多数注射的干细胞不能在短时间内锚定在损伤的微环境上，这些悬浮的细胞将失巢凋亡，导致细胞治疗中细胞率利用率低。

方法：本研究用组织粘合剂涂层 (TAC) 改造了脂肪来源的间充质干细胞 (ADSCs) 的表面，该涂层能使细胞在 1 分钟内锚定在目标区域。该组织粘合剂涂层由邻硝基苯基与生物素 - 链霉亲和素 - 生物素放大系统。

结果：在紫外光照射下，邻硝基苯基转化为邻硝基苯甲醛，并与组织表面的氨基交联，导致细胞快速锚定在目标位点。这种工程细胞可以快速地固定在细胞难以粘附的软骨表面。修饰后的细胞活力和分化能力未受影响。组织黏附性干细胞在关节腔内定植存活增强，停留时间延长。同时，TAC-ADSCs 在兔软骨缺损模型和小鼠 OA 模型中表现出较 ADSCs 更好的治疗效果。

结论：该表面改性的方法安全、操作简单，为提高细胞治疗效率提供了一种新的方法。

关键字：细胞涂层；组织黏附性；细胞疗法；骨关节炎

ID 691

以形状记忆功能材料为基础的多通道导管用于周围神经再生

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目的：因机械损伤、生理病变及医疗操作不当等因素造成的周围神经损伤事件时有发生，临床上主要表现为感觉和运动功能的障碍，症状严重或处理不当时甚至可能导致残疾。目前治疗周围神经损伤的主要方法包括机体自愈、自体和异体神经移植、植入生物材料替代品等。其中，短距离周围神经损伤后可以通过机体自身逐渐愈合，当出现大于 5 mm 的长距离神经损伤时，已无法依靠机体自身的能力愈合，需借助生物工程支架辅助神经损伤修复。

方法：利用静电纺丝技术，制备出四组以形状记忆材料 PLMC 为基础的神经导管，并进行材料表征和 SCs 的增殖验证。

结果：明胶、氧化石墨烯和还原氧化石墨的添加，对神经导管的形状记忆性能没有显著影响，四组导管能满足神经再生的力学需求；其中，PLMC/Gel-GO 和 PLMC/Gel-RGO 组显著促进 SCs 的增殖，有望用于周围神经的损伤修复。

结论：共混后的纳米纤维仍保持良好的形状记忆性能，且 PLMC/Gel-GO 和 PLMC/Gel-RGO 组显著促进 SCs 的增殖。因此，负载 GO 或 RGO 的形状记忆三通道神经导管有望用于周围神经的损伤后修复。

关键字：静电纺丝；形状记忆；周围神经再生；氧化石墨烯；还原氧化石墨烯

ID 809

负载 VEGF 募集肽的多功能纳米纤维敷料用于感染型创面修复研究

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目的：制备一种用于感染型创面治疗的多功能纳米纤维膜敷料，通过抑菌、抗炎、抗氧化的方式加速创面再生。

方法：通过静电纺丝技术制备纳米纤维膜敷料，使用金黄色葡萄球菌制备 SD 大鼠感染模型。

结果：BP 作为一种可募集内源性 VEGF 的 12 个氨基酸短肽，可通过募集体内的 VEGF，实现在创伤部位的高 VGEF 浓度效应，进而促进组织损伤部位的血管再生。OEO（牛至精油）作为一种中草药精油，具有抗菌、抗炎、促进胶原沉积等生物学功能，被广泛应用在组织工程修复领域中。基于 BP 和 OEO 的生物学效应，将其通过静电纺丝技术共纺制备为纳米纤维膜敷料，具有促进血管再生和抗菌抗炎等功能，被应用在感染型创面中具有良好的创面再生修复效果，表明该纳米纤维膜敷料在感染型创面再生中具有广阔的应用前景。

结论：基于 BP 和 OEO 的生物学效应，将其通过静电纺丝技术共纺制备为纳米纤维膜敷料，具有促进血管再生和抗菌抗炎等功能，被应用在感染型创面中具有良好的创面再生修复效果，表明该纳米纤维膜敷料在感染型创面再生中具有广阔的应用前景。

关键字：纳米纤维；静电纺丝；敷料；创面修复

ID 929

Bioengineering Human Brain Organoid with Blood-Brain Barrier on a Microfluidic Microplate

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Objective: The blood-brain barrier (BBB) is a highly selective tissue barrier that modulates molecular exchange between brain blood and parenchyma. Here, we report a novel brain model incorporating human pluripotent stem cell (hPSC) derived brain organoid with a functional BBB in a microfluidic microplate. We expect that this in vitro brain model can be used to investigate the transport efficiency of neurotherapeutic drugs through the BBB and simultaneously evaluate their neurotoxicity.

Methods: Brain organoids were added to the upper chamber of the bilayer BBB chip for dynamic culture to establish the BBB-brain organoid chip model. The culture medium of the upper and lower chambers was respectively replaced by neural maturation medium and conditioned medium every day for 7 days.

Results: We successfully developed a human neurophysiologically relevant brain model integrated functional BBB with brain organoid. We observed the changes in organoid morphology and cell types by in situ imaging and qPCR analysis and identified the barrier function by TEER and permeability assays. Notably, TEER and permeability assays showed that the BBB-brain organoid model improved and maintained the resistance and tissue barrier function better than the monolayer BBB model.

Conclusion: Overall, we designed and manufactured a microfluidic microplate-based brain model integrated functional

BBB with brain organoid. We optimized a conditioned medium that could sustain long-term homeostasis of functions and phenotypes for both the bioengineered BBB and brain organoid. We expect that this novel model will find broad application in neurological drug discovery and mechanistic studies.

Key words: brain organoid on a chip, blood-brain barrier, dynamic coculture, human pluripotent stem cells, brain parenchyma

ID 1205

法拉第波差分生物组装肝脏类器官和含内皮细胞凝胶微球构建仿生肝小叶模型

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目的：声学组装是一种新兴的生物制造策略，能够以动态可调的方式构建细胞紧密排列的组织和器官微结构。然而，同时组装不同类型的细胞形成具有特定空间排列的异质细胞微结构仍然是一个的挑战。为了解决这一问题，在本研究中，我们开发了一种声学差分组装方法。

方法：该方法根据组装单元固有的物理属性（即尺度和浮力密度），将含有不同类型细胞的组装单元差分定位到法拉第波的节点或反节点区域形成互补样结构，或者差分定位到节点（或反节点）的中心或者边缘形成三明治样结构。

结果：利用该方法，将人肝脏类器官和内皮细胞差分组装成六边形由中心向外边缘发射的互补样结构，从而模拟人肝小叶中肝血窦和肝锁的解剖特征。对所构建的肝小叶模型进行了 6 天培养和功能表征。结果显示，肝小叶模型的白蛋白分泌量为 130.9 ng/mL，尿素合成量为 4.8 mg/dL。

结论：声学差分组装技术填补了原有声学组装技术缺乏对异种细胞空间差分定位能力的局限性，有利于构建具有特定异质细胞空间排列的人体微组织。因此，其在组织工程和再生医学研究中有着广泛的应用前景。

关键字：生物制造；生物组装；法拉第波声学差分生物组装；肝脏类器官；肝小叶模型

ID 1542

基于微加工气体声匹配层的体超声波任意图案化生物组装技术用于构建肝小叶模型

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目的：构建具有肝脏合成和分泌功能的肝小叶模型，从而服务于组织工程与再生医学研究。

方法：利用微加工气体声匹配层调制声场的声压分布，并通过数值模拟和微粒实验研究了最佳的微加工气体匹配层条件，能够使气体声匹配层上方形成最小的声压，实现了对其上方微粒和细胞的任意图案化组装。

结果：数值模拟和微粒实验研究了最佳的微加工气体匹配层条件（薄膜厚度为 20 μm；空腔高度为 60 μm；空腔间距为 400 μm），将 HUVEC 球体和 HepG2 细胞进行差分组装形成肝小叶结构，免疫荧光和 ELISA 结果表明构建的肝小叶模型具有肝脏合成和分泌功能。

结论：所提出的微加工气体声匹配层体超声波任意图案生物组装技术可以实现微粒和生物物体的复杂和非周期性图案组装，并用于构建具有空间定义的人类相关的体外组织模型，这可能会促进它在基础医学研究、药物筛选和再生医学中的广泛应用。

关键字：生物制造；体超声波生物组装；微加工气体声匹配层；任意图案化；肝小叶模型

ID 1793

丝素蛋白和丝胶蛋白差异性调控干细胞旁分泌和再生功能的多组学分析研究

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目的：丝素蛋白（SF）和丝胶蛋白（SS）是构成蚕丝的两种主要蛋白，在再生医学领域得到广泛应用。然而，它们与干细胞的生化相互作用尚不清楚。本研究旨在利用多组学技术，在分子水平上揭示由 SF 和 SS 介导的间充质干细胞（MSCs）的行为响应及调控机制。

方法：首先全面评估了 SF 和 SS 溶液对 MSCs 的行为影响，并结合 RNA 测序和蛋白组学分析，研究了 SF/SS 与 MSCs 的生化相互作用。根据组学结果，进一步探索 SF/SS 诱导的 MSCs 的旁分泌因子对多种皮肤驻留细胞的功能影响。最后，通过构建一种支持 MSCs-SF/SS 相互作用的水凝胶系统，在体内验证了这些旁分泌因子对皮肤再生的作用。

结果：SF 和 SS 分别通过激活整合素 /PI3K/Akt 和糖酵解信号通路，诱导 MSCs 广泛但不同的细胞反应，并显著增强其旁分泌功能。SF/SS 诱导的 MSCs 旁分泌信号可调节皮肤伤口微环境中的成纤维细胞、内皮细胞和巨噬细胞的行为和功能，有效促进皮肤修复和再生。相对而言，SF 较 SS 具有更优异的免疫调节作用。

结论：所进行的研究为细胞与 SF 和 SS 的相互作用提供了全面可靠的见解，有利于未来基于蚕丝的组织工程和干细胞治疗的发展。

关键字：蚕丝；MSCs ；多组学；旁分泌信号；皮肤再生

ID 2010

微振动环境中基质应力传递调控细胞骨向分化研究

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目的：研究发现微振动机械刺激主要是通过流体剪切应力和基质应力传递这两种方式共同作用于细胞，但目前在微振动调控细胞生物响应性的研究中尚无针对单因素基质应力传递调控细胞生物学行为的报道。

方法：通过考察微振动环境下，间充质干细胞在基质硬度低于 40kPa 的海藻酸钠（SA）水凝胶 3D 基质中的增殖、凋亡、碱性磷酸酶（ALP）合成、细胞骨架蛋白合成、活性氧表达、成骨基因表达及 ERK1/2 通路磷酸化的情况，探讨基质应力传递对细胞生物学行为的调控作用。

结果：微振动机械刺激显著促进了 SA 水凝胶 3D 基质中细胞的增殖活性，并在加力早期显著增强了细胞的力学适

应性和活性氧表达，上调了 ALP 和细胞骨架蛋白合成，促进了成骨相关基因表达和 ERK1/2 磷酸化。

结论：通过构建低粘度海藻酸钠水凝胶 3D 细胞培养体系，在排除流体剪切应力和基质材料特性对细胞骨向分化影响的条件下，证实基质应力传递可以作为一种独立于流体剪切应力和基质材料特性之外的因素调控细胞骨向分化，并且 ERK1/2 信号通路磷酸化在这种调控作用中发挥了重要作用，显著增强增殖活性，显著性成骨。

关键字：微振动；基质应力传递；成骨分化；海藻酸钠水凝胶

ID 2011

电信号波形调控力场外驱耦合磷酸钙生物陶瓷构建具有快速成骨性能的功能化组织工程骨

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目的：设计具有生物功能适应性的骨移植物是一项极具挑战的任务。基于微振动机械场驱动耦合 Ca/P 陶瓷优化成骨微环境和细胞功能活性的策略能够显著提升移植物的骨再生能力。而这种耦合作用增强构建体功能的精确调控方式和机制目前还有待深入理解。

方法：探究电信号波形调控在这种耦合作用中对构建体成骨发育进程的干预效应及其信号通路调控机制。

结果：体外实验结果表明，电信号波形调控的微振动力场驱动耦合在 HA 陶瓷的钙磷溶解 - 再沉积中以及细胞钙通道和整合素通道激活中发挥了关键的作用，并因此进一步影响了功能化组织工程骨的时序性成骨潜力。动物实验结果首次报道了方波电信号驱动组骨构建体在裸鼠皮下植入仅仅 2 周后即有明显的新骨形成。

结论：电信号波形调控的力场驱动耦合策略是一种全新的无添加和无侵入式的促快速成骨调控方式，能更安全、准确、可靠地赋予骨构建体高效骨再生功能，为利用电信号波形驱动微振动外场构建具有快速成骨性能的组织工程骨构建体的机理研究和临床应用提供了有价值的研究数据和结果。

关键字：电信号波形；微振动；钙磷陶瓷；外驱力场耦合；组织工程骨构建体

ID 2440

自供电辅助剂增强药物药效学

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目的：表皮生长因子 (EGF) 常用于各类伤口治疗，主要通过与 EGF 受体 (EGFR) 的结合发挥作用。但在实际应用中，EGF 存在难以被皮肤吸收、稳定性低和受体易脱敏等问题。针对上述药效学挑战，本研究开发一种自供电经皮药物递送系统用于皮肤伤口修复。

方法：通过将摩擦纳米发电机（TENG）与微针递药贴片结合，以微创的方式实施 EGF 的递送并进行电刺激治疗。

结果：该方法可以显著提高药物的通透性和利用率；TENG 产生的电刺激加快了 GSH 分子运动速度，减少了 EGF 的还原；此外自供电刺激可上调 EGFR 的表达，以补偿长期使用药物导致的受体减少，并改善 EGF 的疗效。

结论：本研究展现了自供电辅助剂在改善药物药效学方面的前景，为人类克服经典药物的耐受性提供了一种潜在的解决方案。

关键字：电辅助剂；电刺激治疗；微针；药物递送；伤口愈合

ID 2798

法拉第波生物组装构建微血管化的骨肉瘤组织

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目的：利用法拉第波生物组装技术构建骨肉瘤血管化模型，服务于肿瘤研究。

方法：将 Saos2 细胞与 HUVEC 在琼脂糖微孔阵列中孵育 48 h 形成细胞球。收获细胞球混入水凝胶后注入组装腔室内，使用法拉第波组装仪快速组装图案化样本而后交联。后续进行 2 天的维持培养与 14 天的分化培养。

结果：具有核壳结构的 3D 细胞球体在声学组装图案组中融合形成了明显的条带组织，并且在冰冻切片中观察到内皮细胞沿着条带方向呈现血管样结构。在 PCR 水平上图案组相较随机组表达了更高的成血管与成骨分化相关基因表达，并且 ALP 染色也验证了图案组融合条带具有更强的成骨分化效果。

结论：通过法拉第波生物组装技术确定了 SaoS2/HUVEC 细胞球融合后的形状并提高了局部的细胞球密度。融合的细胞球条带组织为球体中心的 HUVEC 生长、迁移、连接提供了基础，进而在融合组织内部形成了自发的微血管样结构，并进一步提高了组织的成骨分化效果。我们相信该技术可以用于构建骨肉瘤血管化模型，并服务于未来骨肉瘤的药物筛选及临床治疗。

关键字：生物制造；法拉第波生物组装；骨肉瘤组织；微血管化；成骨分化

ID 2909

声学组装 hiPSC 来源的神经干细胞构建大脑皮层微组织模型

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目的：大脑皮层相关神经疾病的机制研究和临床前神经药物的开发需要人类生理相关和临床相关的大脑皮层模型。然而，现有的二维神经细胞培养模型缺乏体内神经微环境，且动物模型与人类大脑皮层在发育和进化时间上存在许多显著差异。

方法：基于反向工程仿生制造原理开发了一种大脑皮层微组织。具体而言，我们利用声学组装技术组装 hiPSC 来源的神经干细胞形成神经微组织，并对其继续进行后期分化和培养。

结果：构建的神经微组织具有人类大脑皮层的结构和生理特征，包括六层神经元结构、400 微米层间间距、层间突触连接以及电生理信号的表达。

结论：为大脑皮层提供了一个高保真的人类相关体外组织型模型，该模型将有助于在探索神经退行性疾病的机制和候选神经保护剂方面的广泛应用。

关键字：声学组装；反向工程仿生制造；大脑皮层微组织；人类相关组织模型

ID 3359

具有“终身”微环境炎症智能响应性纤维用于心血管组织修复

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目的：快速的基质重塑和持久的抗炎反应对于修复心血管系统损伤至关重要。虽然先前有很多心血管领域的研究者对心血管组织的再生和功能恢复进行了广泛且深入的研究，但新血管组织再生方面通过聚合物支架进行血管或心肌的修复并未得到较好的效果。如何构建长效改善炎症微环境的支架用于心血管组织修复亟待解决。

方法：通过本体共聚技术，合成了丹酚酸 A (SA) 嵌段的具有生物活性的可生物降解聚氨酯（PCHU-D），并通过静电纺技术将其纺制成纳米纤维毡和纳米纤维管（DINN）。

结果：用于大鼠心肌和腹主动脉修复结果显示，在炎症刺激下，SA 可以从可从纳米纤维中缓慢且持久释放。相关动物实验结果也显示 DINN 能够有效抑制炎症细胞的迁移和趋化、增加血管生成基因的表达，从而促进心肌梗死后心肌功能的恢复。最重要的是随着移植周期延长，组成 DINN 的 PCHU-D 的结构被破坏，能够持续释放 SA，促进后续细胞浸润和组织重塑。体内移植实验结果还表明，这种长效缓释 SA 的抗炎症的纳米纤维 DINN 能够快速重塑内皮组织。

结论：DINN 可能是一种有效的治疗心脏组织损伤的生物活性基质。

关键字：丹酚酸 A；本体共聚；生物活性聚氨酯；生态位；心血管组织

ID 3488

具光热及抗菌功能的没食子酸改性生物玻璃促进糖尿病感染伤口修复的作用和机制研究

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目的：糖尿病感染伤口的修复受到多种因素阻碍，包括易发细菌感染、持续的炎症反应、血管难以重建等。因此，迫切需要研发可以调节糖尿病伤口的复杂生理特征，促进其伤口愈合的新型生物材料系统。

方法：提出一种溶剂热辅助的小分子改性无机材料的方法，成功制备了新型没食子酸（GA）改性的生物玻璃（BG）基生物材料。

结果：与传统生物玻璃相比，没食子酸改性生物玻璃 (GA@BG) 的光吸收性质发生了显著改变，颜色由白色变为黑色或深灰色，从而赋予生物玻璃良好的近红外光吸收和光热性能。此外，体外生物学实验结果表明 GA@BG 不仅可以促进血管内皮细胞的迁移和血管生成，还具有优异的光热增强的抗菌性能。

结论：本研究成果不仅为糖尿病感染伤口的治疗提供了一种新型的多功能生物材料，而且为无机生物材料的改性和功能化提供了新思路。

关键字：皮肤再生；生物玻璃；没食子酸；光热治疗；抗感染；有机 - 无机复合物

S11
生物材料产业化及临床应用
Industrialized Development and Clinical Application of Biomaterials

ID 164

Biomimetic Activator of Sonodynamic Ferroptosis Amplifies Inherent Peroxidation for Improving the Treatment of Breast Cancer

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Objective: Ferroptosis is a novel type of non-apoptotic cell death, and has been gradually emerging as an important anticancer treatment. However, its therapeutic efficacy has been impaired by low intracellular levels of reactive oxygen species (ROS) and long-chain polyunsaturated fatty acids, significantly limiting its therapeutic potential. Herein, we present an ingenious multimodal strategy to improve ferroptosis, in which a state-of-art engineered erythrocyte, termed as sonodynamic amplified ferroptosis erythrocyte (SAFE), is developed for simultaneously activating ferroptosis and oxygen-riched sonodynamic therapy (SDT).

Methods: SAFE was composed of iRGD peptide and red blood cell membrane (RBCM) hybrid camouflaged nanocomplex of hemoglobin (Hb), perfluorocarbon (PFC), DGLA and Verteporfin (Vp). It has been reported that low intracellular ROS levels always minimize ferroptosis effect, which might be overcome by the oxidative cascade reaction strategy. Vp is a medication used for photodynamic therapy, and has been identified as an effective sonosensitizer to eliminate abnormal tissues. However, SDT always suffers from the undesirable impediment of local hypoxia in tumors, leading to therapeutic resistance. We therefore developed a PFC based oxygen supply system, in which oxygen-riched PFC could be stabilized by Hb. Hb/PFC complex not only relieved tumor hypoxia and enhanced the sonodynamic effects, but rendered cancer cells sensitive to ROS.

Results: We identified that SAFE, along with ultrasound stimulation, could not only substantially supply oxygen to overcome tumor hypoxia associated therapeutic resistance, but effectively trigger ferroptosis through synergistic effects of DGLA and SDT, which eventually improved anticancer activity. In vivo studies revealed that SAFE selectively accumulated and penetrated in tumor tissues after intravenous administration, and induced desired anticancer effects under mild ultrasound stimulation, resulting in effective tumor elimination with minimal invasiveness, which significantly prolonged the survival of tumor bearing mice.

Conclusion: In summary, we present a novel multimodal ferroptosis therapy driven by oxygen-riched sonodynamic peroxidation of lipids, significantly advancing synergistic cancer treatment.

Key words: biomimetic strategy, synergistic cancer therapy, sonodynamic effects, lipid peroxidation, ferroptosis

ID 1440

家蚕蛹虫草海宁株生产及抗肝癌作用研究

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目的：探索具有高附加值蛹虫草（Cordyceps militaris）的生产及应用。

方法：以家蚕蛹虫草（海宁株）（C. militaris (HN)）为试材，摸索其子实体原料生产并分析比较所含虫草素、N6-（2- 羟乙基）腺苷、麦角甾醇类化合物（DI）三种药用质量鉴定指标，进一步深入研究 DI 抗肝癌作用机理。

结果：本研究实现了家蚕蛹虫草（海宁株）子实体原料的生产；其虫草素、N6-（2- 羟乙基）腺苷、DI 三个成分的含量均高于市场随机采购的 2 种蛹虫草；同时，发现 DI 能抑制人肝癌细胞（HepG2）生长过程中甘油醛 -3- 磷酸脱氢酶（GAPDH）含量升高和 3β 羟基 -5- 类固醇脱氢酶（3βH-5SD）含量降低；DI 对小鼠的最大给药量为 7.80g/kg。

结论：家蚕蛹虫草（海宁株）具有高药用附加值，本研究建立了其子实体原料生产方法。同时，从分子水平上初步验证了 DI 的抗肝癌作用与 GAPDH 的关系，首次发现 DI 抗肝癌作用与 3βH-5SD 有关，这为进一步研究肝癌诊断提供一个新的物质基础。

关键字：蛹虫草；肝癌；麦角甾醇；虫草素 ;N6-（2- 羟乙基）腺苷；3β 羟基 -5- 类固醇脱氢酶；甘油醛 -3- 磷酸脱氢酶

ID 1595

聚醚醚酮复合材料治疗骨坏死的实验研究

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目的：探讨聚醚醚酮 (PEEK) 改性材料的生物相容性、抗菌性和对兔骨坏死的疗效，从而为骨坏死的修复和治疗开发理想的骨移植物。

方法：利用 PEEK 表面磺化、聚多巴胺嫁接生物活性因子的表面改性技术，复合活性物质缓慢释放，制作改性锚钉。设置 PEEK 材料为对照组，骨形成肽（BFP）改性和血管内皮生长因子（VEGF）改性材料分别为 BFP 组和 VEGF 组，进行体外细胞实验、动物实验及抑菌实验，探究材料成骨活性。

结果：VEGF 组细胞黏附数量相较于 BFP 组更多。CCK-8：BFP 组和 VEGF 组 OD 值均高于对照组，且 VEGF 组高于 BFP 组。碱性磷酸酶活性：BFP 组和 VEGF 组 OD 值均高于对照组。抗拔出：VEGF 组抗拔出力高于 BFP 组及对照组。Micro-CT 及 HE：VEGF 组及 BFP 组锚钉周围骨质增生明显，VEGF 组优于 BFP 组。免疫荧光染色：两组改性材料成骨蛋白 OCN 及成血管蛋白 CD31 表达均显著上调，BFP 组 OCN 表达更强，而 VEGF 组 CD31 表达最强。

结论：三组材料均有良好的生物相容性，但通过持续释放 BFP 及 VEGF，两组复合材料能显著促进成骨细胞增殖分化、成骨基因的表达及骨和血管的再生。尤其以 VEGF 组效果优于 BFP 组。

关键字：聚醚醚酮；骨形成肽；血管内皮生长因子；骨坏死

S12
数智融合创新，赋能智慧医院发展
Integration and Innovation of Big Data and Artificial Intelligence Empowers the Development of Smart Hospital

ID 99

A Predictive Model for Clinical Health Risk Using Multimodal Electronic Health Record Data

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Objective: To develop a deep learning model to predict in-hospital mortality and decompensation risk using time series data and clinical notes in electronic health records (EHR) to improve the shortage of ICU resources and the quality of clinical monitoring.

Methods: A retrospective study was conducted by using the patient records in MIMIC-III. Variables, including demographics, laboratory tests, and vital signs data, were extracted using the general MIMIC-III preprocessing pipeline. In addition, clinical notes are extracted to provide extra information for risk prediction. A deep learning model was proposed to process multimodal EHR data, which integrated the time series prediction module and the text feature extraction module. The area under the receiver operating characteristic (AUROC) and the area under the precision-recall curve (AUPRC) were used to evaluate the performance. The model was compared with other clinical risk prediction models.

Results: In in-hospital mortality risk prediction, all models with text information obtained AUPRC > 0.52 and AUROC > 0.85, while those only using time series information had AUPRC and AUROC of about 0.37 and 0.79, respectively. In decompensation risk prediction, all models combined with text information obtained AUPRC > 0.34 and AUROC > 0.90, while those of models only using time series information were between 0.19-0.30 and 0.84-0.90, respectively. Our proposed model surpasses other models in performance metrics, reaching AUPRC of 0.6068 and AUROC of 0.9130 in the in-hospital mortality prediction task. The decompensation risk prediction task obtained the AUPRC of 0.3885 and AUROC of 0.9661.

Conclusion: We developed a deep learning model to predict risk with multimodal data as input. Compared with the baseline model, the proposed model obtained the highest value on the metrics of two clinical tasks. Our model is expected to help medical staff identify high-risk patients, improve the quality of nursing care and provide more reasonable scheduling of medical resources.

Key words: Electronic health records, Mortality prediction, Decompensation prediction, Deep learning

ID 348

融合人工规则与自动数据特征的动态信息提取及临床风险预测

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目的：临床上经常需要连续观测患者生理信息，对患者进行风险评估预测。从时间序列临床数据中提取有效动态信息，是临床风险预测的一个重要环节。现有时序特征提取方法存在人工设计统计规则困难、时序特征有效性不高等问题。

方法：本文提出整合人工规则和自动数据特征的动态信息提取方法，通过序列网络算法从有标签数据中自动提取序列网络特征，并汇聚人工统计规则，再将所有特征应用于分类器，实现临床风险预测。

结果：在脓毒症早期预测数据集上的实验结果显示，人工统计规则特征较为简单时，融合自动网络特征能够提升预测 AUROC 值 0.037-0.050。样本数量比例大于 25% 时，融合网络特征总是具备性能提升作用。

结论：该方法降低了对人工设计统计规则的要求，能够有效捕捉动态特征信息，具有较优预测性能。可扩展到更多疾病应用，为连续观测患者数据的动态信息提取提供一种有用工具。

关键字：临床风险预测；动态信息；人工规则；自动提取特征

ID 387

A Multifuctional Image Processing Tool for CT Data Standardization

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Objective: As one of the most commonly used imaging examinations in clinical practice, CT images have been widely sued in computer-aided diagnosis and disease-related studies. Due to the diverse content and format of the original CT data, it is usually necessary to conduct standardized operations on CT data before image processing or deep learning, which is called data preprocessing. The complexity of CT data makes preprocessing often time-consuming and labor-intensive especially for multi-cohort studies of multiple sequence CT images, and the results directly affect the subsequent algorithms.

Methods: This study establishes a universal CT data standardization process and tool that can greatly improve the efficiency of preprocessing. The established pipeline includes de-privacy, format conversion, data check, denoising, resampling and registration.

Results: The standardization process we built in the tool is applicable to the preprocessing of most studies.

Conclusion: We integrate a variety of common algorithms to extend the user's choice at the same time.

Key words: CT, Standardization, Preprocessing

ID 390

基于真实世界的儿童肿瘤住院病例挖掘

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目的：挖掘真实世界中儿童肿瘤的病种分布及影响其医疗费用的关键因素。

方法：收集某三甲医院 2016 年 1 月 1 日—2022 年 10 月 31 日儿童肿瘤病案首页 381 份，采用力引导布局算法绘制儿童肿瘤病种分布图谱，决策树算法寻找住院费用影响因素。

结果：儿童肿瘤恶性肿瘤以白血病为主，多与重度贫血、扁桃体炎、急性支气管炎、上呼吸道感染、噬血细胞综合征等疾病共同出现；良性肿瘤以血管瘤为主，多与癫痫、颅内感染、脑萎缩、脱水等疾病共同出现；住院费用可分为 4 个组别，影响其住院费用的主要因素为住院天数，其次分别为是否手术、年龄和入院途径。

结论：数据挖掘是分析病案首页信息的有效方法，通过完善儿童肿瘤临床路径以缩短住院日，可有效减少儿童肿瘤患者住院费用。

关键字：真实世界；儿童肿瘤；病案首页；可视化；数据挖掘

ID 428

Effect of Schroth Exercise on Pulmonary Function and Exercise Capacity in Patients with Severe Adolescent Idiopathic Scoliosis

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Objective: This study aimed to investigate the effect of Schroth exercise on pulmonary function and exercise capacity in patients with severe adolescent idiopathic scoliosis (AIS).

Methods: Forty subjects with severe AIS were assigned to the Schroth exercise and aerobic exercise groups and then received the corresponding intervention. Pulmonary function and exercise capacity were evaluated at baseline and 12-week follow-up visits.

Results: Pulmonary function：After 12 weeks of intervention, the pulmonary function parameters of all subjects were significantly improved ($p<0.05$). According to the inter-group comparison, the parameters, including FEV1/FVC, MIP, MPE, and PEF, were significantly higher in the Schroth group than in the aerobic group after 12 weeks ($p<0.05$).

Exercise capacity：After 12-week exercise, the walking distance, Borg score, and respiratory rate of all subjects were significantly improved ($p<0.05$), as shown in Table 3. Besides, Borg score and respiratory rate were significantly lower in the Schroth group than in the aerobic group at the 12-week follow-up visit ($p<0.05$).

Conclusion: Schroth exercise offered better improvement of pulmonary function and exercise capacity in patients with severe AIS than aerobic exercise.

Key words: Schroth exercise; Adolescent idiopathic scoliosis; Pulmonary function; Exercise capacity

ID 971

医疗器械不良事件的监测、分析及管理现状

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目的：医疗器械不良事件的监测、分析及管理水平是衡量医疗器械生产、使用单位管理、技术能力的重要指标之一，也是衡量一个国家整体医疗水平的重要环节。本文总结分析了中美两国在医疗器械不良事件的监测工作的差异和目前对于医疗器械不良事件的分析、处置和管理方法。同时指出了其中可能可以改进的地方。医疗器械不良事件的监测、分析及管理水平是衡量医疗器械生产、使用单位管理、技术能力的重要指标之一，也是衡量一个国家整体医疗水平的重要环节。本文总结分析了中美两国在医疗器械不良事件的监测工作的差异和目前对于医疗器械不良事件的分析、处置和管理方法。同时指出了其中可能可以改进之处。

关键字：医疗器械不良事件；监测；分析方法；管理

ID 1185

回波时间依赖的多中心扩散磁共振信号校正方法

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目的：对于多中心合作采集的扩散磁共振成像（Magnetic Resonance Imaging，MRI）数据而言，序列中回波时间（Echo Time，TE）的差异将降低扩散模型中定量测量值的一致性。然而不同型号 MRI 设备之间软硬件性能存在差异，使扩散成像在采集参数上无法保持完全一致。为降低扩散测量模型对 TE 的依赖性进行本研究。

方法：提出了一种扩散信号建模方法，将多成分 T2 引入扩散模型的多成分假设中，从而可将不同 TE 采集的扩散数据校正至同一 TE 下。

结果：此方法可用于多中心不同设备间的扩散数据校正中，降低扩散图像和多种扩散模型参数中的测量差异。

结论：此方法对扩散信号、多种扩散模型参数的中心间差异都有较好的校正效果。

关键字：磁共振成像；扩散成像；多中心；扩散模型

ID 1460

基于结构一致性对比学习的跨模态医学图像生成模型

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目的：跨模态医学图像生成可以解决医学影像诊断和治疗中的一些实际问题，例如缺乏某种模态的数据、缺乏高质量的图像数据等，并大大减少不同模态数据的采集成本和患者的扫描时间。现有研究缺乏对内容和结构信息的深度

挖掘，且无法有效利用来自不同网络层的丰富的特征表示，导致跨模态医学图像生成质量无法用于临床。

方法：提出了一种基于结构一致性对比学习的跨模态医学图像生成模型，将对比学习和循环残差卷积神经网络引入到生成对抗网络中，通过在鉴别网络的中间层和高层使用对比学习同时学习高层语义的内容信息和数据增强的不变性；在生成器端加入循环残差卷积神经网络，不增加参数的情况下，增加感受野，关注输入图像的结构信息，增强鉴别器的性能的同时提高生成器的表达能力。

结果：在开放访问数据集 BraTS 2018 上的实验表明，提出的方法与其他方法相比达到了最先进的性能。其中，PSNR 增加了 0.6，SSIM 提高了 1%，MAE 降低了 0.3%。

结论：提出的高质量跨模态医学图像生成模型提升了跨模态图像的生成质量，为将来临床应用、诊断和治疗提供了一种通用、可行的解决方案。

关键字：跨模态生成；医学图像；GAN ；对比学习；循环残差卷积神经网络

ID 2066

基于文本嵌入和 LightGBM 的静脉血栓栓塞症预测模型研究

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目的：静脉血栓栓塞症（VTE）是一种致死率高的血管类疾病，可以由影像学检查或问卷检查诊断。然而，影像学检查是在栓塞发生以后才会去检测，问卷准确率和效率不足。针对 VTE 的前瞻性自动化预测工具开发非常必要。而以往开发的机器学习 VTE 预测模型存在对诊断文本信息的忽视，同时使用的机器模型模型也有改进空间。所以本研究期望通过引入自然语言处理和更先进的机器学习模型提出更准确的 VTE 预测模型。

方法：使用来自南昌大学第一附属第一医院信息处提供的住院患者信息。数据集 3:1 比例的随机分层方法划分为训练集和测试集。对生理生化指标做了预处理。利用 FastText 或者 MacBERT 对诊断文本进行文本嵌入化处理；最后，以 LightGBM 算法 VTE 预测模型。尝试使用了 smote 算法处理不平衡问题，进行了特征重要度统计。

结果：在 2796 个患者构成测试集上模型的 AUC 达到 0.82，F1 值 51.0% 和 F2 值 61.9%，高于以往基于机器学习的 VTE 模型在本数据集上的结果。

结论：引入的文本模态特征提高了分类模型性能，LightGBM 比其他分类模型更适用于 VTE 预测场景。对于探索医疗电子病历辅助诊断的发展具有借鉴意义。

关键字：静脉血栓栓塞症；机器学习；自然语言处理；辅助诊断

ID 2124

基于图神经网络的住院心衰患者急性肾损伤发生风险预测

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目的：利用医学知识指导深度学习模型的构建，在疾病的诊断预测方面取得了较好的效果。然而，这些基于递归神经网络的研究仅利用了来自知识图谱的信息，未能利用可能重要的全局图结构特征。

方法：提出了一种基于图神经网络的临床风险预测方法，在医学知识图谱引导下，以图结构重建患者电子病历数据生成个体化患者图谱，融合医学知识和电子病历数据，构建心力衰竭患者急性肾损伤发生风险预测模型。

结果：基于真实世界电子病历数据的实验结果表明，提出的方法在心力衰竭患者急性肾损伤风险预测方面优于其他基准模型，准确性达 0.791，F1 值达 0.602。模型的临床实用性分析结果提示该模型具有重要的临床使用价值。

结论：本研究可以为基于电子病历数据的临床风险预测模型构建提供新的思路。

关键字：图神经网络；知识图谱；心力衰竭；急性肾损伤；风险预测模型

ID 2237

基于活动轮廓正则化弱监督深度学习的 CT 图像脂肪与肌肉组织自动分割方法

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目的：身体脂肪和肌肉含量与癌症治疗、慢性病、代谢疾病等非常相关，CT 图像可以准确测量腹部不同脂肪和肌肉含量。

方法：提出一个活动轮廓正则化的弱监督 CT 图像脂肪与肌肉组织分割方法，利用少量标注图像对全腹部 CT 进行分割。具体地，构建一个二维分割网络和三维分割网络，分别用于伪标签数据的生成和三维分割模型学习。并且，引入活动轮廓正则化损失，提高分割区域的边界光滑性和形状正则性。

结果：所提出方法在 40 个 CT 图像上训练，在 20 个 CT 图像上测试。在测试集的 L3 横断面图像上，皮下脂肪、内脏脂肪和骨骼肌组织的分割结果的 DSC 达到 0.9 以上，各个组织面积与真实值的 Spearman 相关系数分别为 0.997，0.988 和 0.814，具有良好的一致性。

结论：所提出方法可以准确地测量脂肪和肌肉含量，具有临床应用潜力。

关键字：CT 图像；弱监督学习；活动轮廓模型；深度学习；脂肪测量

ID 2352

语义引导的层级疾病预测

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目的：疾病预测有助于早期疾病预防，能够帮助医生进行全面诊断、制定合理的治疗方案和处方管理、降低医疗成本等。一个优秀的预测模型，除了准确的预测性能，更需要有良好的可解释性与鲁棒性。本文的目的在于构建一个具有良好预测准确性、可解释性与鲁棒性的疾病预测模型，以辅助医疗，提高诊断的准确率并制定合理的诊疗计划。

方法：提出语义引导的层级疾病预测模型，采用层级分类实现由粗粒度到细粒度的准确预测，通过词嵌入方法提升模型的可解释性，并将现有的医学理论融入学习过程中，以增强模型的鲁棒性。

结果：在真实世界数据集 MIMIC-III 与 MIMIC-IV 上进行实验论证，对比现有的疾病预测方法，实验结果证实了语义引导的层级疾病预测方法具有更好的性能。

结论：所提出的语义引导的层级分类网络，通过层级分类实现由粗粒度到细粒度的精准预测，利用语义嵌入将医学知识融入预测模型中，以提高模型的可解释性与鲁棒性。在两个真实世界数据集上的实验结果证实了该算法具有良好的性能。

关键字：疾病预测；语义引导；层级分类

ID 2529

基于深度自编码器网络的结肠癌通路异常评估方法

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目的：现有的通路异常评估方法对于同一样本的评估结果稳定性不佳，因此需要研究具有稳定性的通路异常评估方法用于结肠癌的通路异常评估，进而辅助临床更好的进行临床诊疗。

方法：基于公开数据集的正常结肠组织的基因表达数据与每个通路的拓扑学结构信息，训练可以有效表征正常结肠组织通路情况的深度自编码器网络，然后对公开数据集中的结肠癌组织样本进行评估，基于重构误差、通路的拓扑学结构信息和支持向量数据描述算法，得到被检测样本的通路异常评估结果。

结果：基于 308 例 GTEx 的正常结肠组织完成了 202 个 KEGG 通路的深度自编码器网络的训练，并将这些网络用于 286 例 TCGA 原发结肠癌组织和 41 例 TCGA 癌旁正常组织的通路异常评估。评估结果在保留 6 位小数的情况下，不会受到干扰数据的影响。

结论：所提出的可以稳定对结肠癌患者进行通路异常评估的通路异常评估方法，评估结果可以用于结肠癌的预后、亚型识别、生物标志物发现等多项研究。

关键字：通路异常评估；深度自编码器网络；结肠癌

ID 2935

基于电子病历数据的上市后药物因果性评价研究

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目的：真实世界的数据可能是一种评估上市后药物安全性和有效性的新方法，但对于如何使用真实世界数据进行药物评估还没有通用的方法或框架。本文的主要目的是构建一个基于电子病历数据的上市后药物治疗效果的因果性评估框架。

方法：针对每一种药评估的药物，通过从电子病历数据中为其自动生成不同的实验组和对照组队列，大规模重复随机临床试验，并使用嵌入了 Super Learner 的目标最大似然估计方法来估计药物的平均治疗效果。使用十年间的真实世界电子病历数据来验证该框架，并将药物性肝损伤作为测试案例。

结果：评估了 641 种非复方药物与药物性肝损伤之间的因果关系，发现 12 种药物的平均治疗效应及 95% 置信区间具有统计学意义。其中有 6 种药物与肝毒性之间的关系是没有记录在既往研究或公开知识库中的。

结论：研究结果在一定程度上证明了提出框架的有效性，可以为临床药物使用、药物警戒和药物发现提供新的见解。

关键字：电子病历；药物监测；因果评估；目标最大似然估计；Super Learner

ID 3055

基于多任务学习的肝细胞癌早期复发预测

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目的：探索肿瘤分割任务对基于术前 CT 影像预测肝细胞癌早期复发的作用并建立多任务早期复发预测模型

方法：回顾性分析 2012 年到 2016 年之间接受部分肝切除术的 142 例肝细胞癌患者数据。将预处理后的 CT 图像输入到融合注意力机制的端到端多任务早期复发预测模型，得到肝细胞癌早期复发预测概率与肿瘤分割结果。该模型通过构建在线类激活图引入肿瘤分割分支，有效挖掘肿瘤分割与肝细胞癌早期复发预测间的相关性，采用多任务学习策略训练模型，通过融合注意力机制进行自适应特征优化，增强网络的特征学习能力，从而提升模型的预测精度。

结果：在多任务框架下，肝细胞癌早期复发预测精度达到 75.24%，相比单任务提高了 5.7%，病灶分割的 Dice 达到 74.32%，验证了多任务学习与注意力机制的有效性。

结论：肿瘤分割任务能够帮助多任务预测模型提高肝细胞癌早期复发预测精度。

关键字：多任务学习；早期复发预测；肿瘤分割；肝细胞癌

ID 3151

面向院前急救任务的个性化语音增强算法

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目的：基于语音识别的智能辅助技术对于院前急救服务有着巨大的吸引力，但截止目前成功实施的案例并不多，这很大程度上是由于院前急救服务涉及到多样的复杂环境，面临着各种不确定的声学干扰，导致语音识别的准确度无法得到保障。一般的语音增强 / 降噪技术可一定程度上缓解此问题，但通常此类算法也仅支持有限的使用环境，无法满足急救服务的需求。

方法：本研究尝试利用目标用户（即急救医师）的先验信息来指导语音增强，从而实现对多场景中复杂声学干扰的抑制，且在多人对话并有重叠语音可能的情况下，实现仅提取急救医师语音内容的定向语音识别。

结果：通过在真实急救任务录音数据集上的测试，我们的方法可有效提升语音识别准确率与语音质量，字识别错误率从初始的 22.5% 下降到了 14.2%。

结论：结果表明，我们的方法有望推动语音辅助技术在急救领域的落地应用，从而节省急救医师的工作量，解放双手，为病人提供更高质量的急救服务。

关键字：院前急救；语音识别；语音增强；个性化语音增强

ID 3222

基于两级图卷积神经网络的肝癌微坏死预后模型

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目的：原发病理性坏死是肝细胞癌有效的预后指标，我们希望通过肝癌病理微坏死切片预测肝癌患者的生存。

方法：提出了一种基于两级 GCN 的预后模型，第一级 GCN 模拟病理学家的视角，对肝癌坏死组织分布进行全面评估，以分析患者的生存情况。它引入图卷积神经网络构建坏死组织和肿瘤组织为图节点的空间地图，旨在挖掘病理切片中坏死组织之间的上下文信息。第二级 GCN 在第一级 GCN 的基础上构建了以患者影像特征为节点的图网络，每个节点均代表一个患者的病理切片信息，节点与节点之间的边由患者临床非影像信息构建而成。

结果：所提出方法的比基线模型性能高出 4.45%

结论：坏死图网络的结果表明通过图卷积引入额外的坏死标签可以提高生存预测模型的性能。患者图网络的提出则给了图卷积网络对融合影像和非影像数据的更多可能性。

关键字：肝细胞癌；GCN ； 预后；计算病理学

ID 3284

基于数字病理图像的肝癌微坏死识别及预后分析系统

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目的：数字病理图像中的微坏死在包括肝癌在内的多种癌症中与患者预后较差相关，使用深度学习**方法：**进一步探究病理微坏死在肝癌患者的预后分析中的作用。在此基础上，开发基于数字病理图像的肝癌微坏死识 别及预后分析系统辅助医生对肝癌患者的疾病进展做出判断和研究。

方法：收集两组肝癌数字病理图像数据集 建立数据集，训练图卷积神经网络模型从肝癌患者的数字病理图像中提取出病理微坏死的空间关系，使用金字塔 形的分层存储结构将肝癌的数字病理图像微坏死识别结果可视化展示。

结果：训练的图卷积神经网络模型的一 致性指数在内部数据集上为 0.6888，在外部数据集上为 0.6075，开发的系统实现了微坏死识别结果的可视化。

结论：基于图卷积的肝癌预后模型能够基于肝癌患者数字病理图像输出肝癌患者的预后生存评分，辅助医生对 肝癌患者的预后分析，基于数字病理图像的肝癌微坏死识别及预后分析系统使复杂模型的使用更简单直观。

关键字：肝癌；图卷积神经网络；病理微坏死；预后

ID 3426

融合病理图像和临床特征的脑胶质瘤的生存结果预测

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目的：脑胶质瘤是颅内高发的一种肿瘤，对其生存结果预测具有重要的临床意义和现实价值。目前关于脑胶质瘤的生存结果预测研究大多基于基因表达数据或者病理图像进行。但大多数方法仅仅利用单个模态数据，且基因获取成本较高。本文研究了基于病理图像和临床数据的多模态融合方法用于脑胶质瘤生存结果预测。

方法：首先利用深度卷积神经网络和图卷积神经网络分别对病理图像提取图像的深度特征和图特征，并构建了临床特征子集。然后，设计了基于浅层卷积神经网络的图像和临床特征融合预测模型。本方法在两个 TCGA 脑胶质瘤数据集上进行了训练与测试。

结果：融合图像深度特征和临床特征的融合预测模型的 c-Index 达到 0.81, 优于病理图像模型和临床特征模型。

结论：通过融合病理图像和临床特征可以有效地提高生存结果预测的准确性。

关键字：多模态融合；病理图像；临床数据；软投票；生存结果预测

ID 3431

基于相近医疗术语的患者队列快速构建方法

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目的：队列研究是一种研究复杂性疾病病因的重要方法。本探究提出一种基于相近医学术语的患者队列快速构建方法。可根据用户指定的筛选逻辑，对拥有相近医学术语特征的数据进行概念的聚合筛选。

方法：采用 KMP 匹配算法、bitmap 算法，提升构建患者队列的速度。

结果：模拟大规模医疗数据对所提出方法进行验证，当数据集中数据条数为十万级时，本文提出的方法队列构建耗时是常规方法的 40%-70%；数据条数为百万级时，队列构建耗时为常规方法的 30%-60%。

结论：所提出方法利用相近医疗术语概念 ID 连续性的特点，结合相应算法，通过语句解析、队列筛选与聚合的方式使得用户可以更快、更稳定的获取医疗研究所需队列，极大地节省了时间，为之后的研究提供了便利。

关键字：相近医疗术语；队列构建；聚合筛选；医学研究

ID 3450

基于 OMOP-CDM 扩展的生物医学信息融合分析通用数据模型

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目的：破译疾病和衰老是科学家一直以来的目标，但其复杂性促使精准医疗成为趋势。过去的数年间，生物医学研究正式进入了大数据时代，其根本原因是电子健康记录（Electronic Health Record，EHR）系统的日益普及和人类基因或分子图谱的快速积累。整合多组学数据（如基因组、蛋白组和代谢组等）与 EHR 数据成为精准医疗的重要突破口，但数据类型、来源多样化以及高异质性带来了前所未有的困难。因此，构建可支持生物医学融合分析的通用数据模型迫在眉睫。

方法：本研究基于 OMOP-CDM 模型，扩展临床类数据表以丰富患者信息，创建了多组学数据表以便于多层次集成，构造了存储统计分析、建模参数和结果的基础表以支持融合分析。

结果：构建的通用数据模型通过 GitHub 免费提供给社区，便于用户进行定制化修改及应用（https://github.com/RCHDS-Zhejianglab/CDM-for-biomedical-information-fusion-analysis.git）。

结论：本研究构建的通用数据模型可促进多模态、多中心临床与多组学数据的融合分析，为精准医疗的发展提供支撑。

关键字：生物医学信息；融合分析；数据模型；OMOP-CDM；精准医疗

ID 3509

基于少数样本学习的全科未分化疾病辅助诊断模型

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目的：目前临床治疗中的未分化疾病诊断问题面临着医疗资源过度浪费，诊疗效果不明显等问题，利用医院中的大量医疗数据信息，用少数样本学习的方法进行全科未分化疾病的辅助诊断模型研究，

方法：使用了自然语言处理中的少数样本学习领域的预训练模型方法，在预训练模型的基础上提出词义依存编码层和特征融合层，提取语义编码向量和词义依存向量进行注意力机制融合，来提升模型在样本量较小时的表现。

结果：通过实验论证本文所提模型的整体精确率达 65.04%，召回率达 37.58%，F1 得分达 47.64%，证明该模型在实际诊断中具有一定的参考意义。

结论：本研究在全科未分化疾病辅助诊断问题上开展小样本学习的方法研究，通过采取预训练模型的研究思想来优化样本量不足时的模型效果，在预训练模型的基础上提出词义依存编码层和特征融合层，提取语义编码向量和词义依存向量进行注意力机制融合，通过实验证明该模型在实际诊断中具有一定的参考意义。由于数据问题，该模型只针对 16 类别的疾病进行实验分析，说服力不足；另外由于研究时间有限，模型内部没有考虑到疾病（标签）与疾病（标签）的间接关联关系，在以后的工作中将继续展开该部分的研究。

关键字：未分化疾病；少数样本学习；预训练模型；辅助诊断模型

ID 3545

基于电子病历知识图谱的跨科室多疾病辅助诊断模型

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目的：基于电子病历知识图谱理论和构建方法探寻跨科室多疾病可解释性诊断的方法。

方法：基于之江实验室多中心智能医学信息平台，收集某三甲医院 11 个科室或系统共计 107 种疾病的入院患者资料，其中 70% 的数据随机用于训练电子病历知识图谱，其余的用于测试。通过知识建模、图谱构建和诊断推理构建了电子病历知识图谱并验证了其在跨科室多疾病诊断上的表现。

结果：共收集 179743 名患者结构化和非结构化临床数据，构建了包含 592 万节点，1150 万条三元组关系的电子病历知识图谱，在 107 种疾病上归一化折现累积收益（NDCG@3）总体为 0.836，并可对每个病人提出的定量和可解释的推理路径。

结论：研究结果充分证明了方法的有效性，该框架在跨科室的多疾病诊断方面显示出良好的潜力，为多疾病可解释性的临床决策提供了启示。

关键字：知识图谱；疾病诊断；知识推理；元路径；可解释性

S13
第五届医工韶光创新分会场
The 5th Medical Engineering Shaoguang Innovation Session

ID 424

Deep Learning-based Intelligent Aided Diagnosis System For Ophthalmic Ultrasound Images

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Objective: Design a deep learning-based intelligent aided diagnostic system for ophthalmic ultrasound images to provide aided analysis for intelligent clinical diagnosis of posterior ocular segment diseases.

Methods: The InceptionV3-Xception fusion model is established by using two pre-trained network models—InceptionV3 and Xception—in series to achieve multi-level feature extraction and fusion, and a classifier more suitable for the multi-classification recognition task of ophthalmic ultrasound images is designed to classify 3402 ophthalmic ultrasound images. The accuracy, macro-average precision, macro-average sensitivity, macro-average F1 value, subject working feature curves, and area under the curve are used as model evaluation metrics, and the credibility of the model is assessed by testing the decision basis of the model using a gradient-weighted class activation mapping method. Complete the human-computer interaction interface development of the ophthalmic ultrasound image intelligent assisted diagnosis system based on PyQt toolkit.

Results: The accuracy, precision, sensitivity, and area under the subject working feature curve of the InceptionV3-Xception fusion model on the test set reached 0.9673, 0.9521, 0.9528, and 0.9988, respectively, and the model decision basis was consistent with the clinical diagnosis basis of ophthalmologists. The auxiliary diagnosis system has a concise interface, simple operation, and can realize intelligent recognition of ophthalmic ultrasound images and interpretable analysis of thermograms, and has good reliability and portability.

Conclusion: The deep learning-based intelligent aided diagnosis system for ophthalmic ultrasound images can quickly and accurately identify six types of ophthalmic ultrasound images, which is beneficial to the intelligent development of ophthalmic clinical diagnosis.

Key words: posterior ocular segment diseases, ultrasound images, migration learning, feature fusion, PyQt

ID 972

基于 ConvNeXt 网络的新冠肺炎 X 射线图像诊断方法

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目的：医学人工智能方法可以帮助早期发现新冠肺炎肺部 X 射线图像异常并帮助监测疾病的进展，从而有可能降低死亡率。

方法：通过设计主干网络 ConvNeXt，聚合注意力模块与长短期记忆网络加关注全局与局部信息的交互性。实验对公开访问的 COVID-19 Radiography Database 数据集图像分类，另外选用 Chest X-ray 数据集进一步验证 GlstNet 网络泛化能力，采用 Score-CAM 算法验证该方法的有效性。

结果：GlstNet 网络在 COVID-19 Radiography Database 数据集三分类实验中相较于基础模型 ConvNeXt 在准确率、精确率、召回率上分别提高了 1.60%，1.23%，1.76%。其中准确率、精确率、召回率、特异度分别提高到 95.6%，96.03%，95.76%，97.53%，在 Chest X-ray 数据集上 GlstNet 与主流算法的性能比较，准确率，精确率，召回率分别达到 97.20%，97.03%，97.60%

结论：聚合注意力模块（CGMB），LSTM 网络与 ConvNeXt 可以较好地配合，有效地利用胸部 X 射线图像诊断新冠肺炎患者，具有较好的泛化性能。

关键字：X 射线图像；新冠肺炎；注意力机制；长短期记忆网络

ID 1021

精确预测 ICU 中急性呼吸窘迫综合征的动态机器学习算法

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目的：在主要的观察性研究中，ARDS 疾病有着较高的发病率与死亡率，对潜在 ARDS 患者进行早期临床干预能够有效预防 ARDS 疾病发生。

方法：建立并评估了一种动态 ARDS 发病预测模型，使用 1-8 小时不同时间长度的 ICU 常规无创数据实时预测患者未来 1-4 小时的 ARDS 发病概率。从 2001 年至 2012 年在马萨诸塞州波士顿的贝丝以色列女执事医疗中心重症监护室提取需要 ICU 护理 29395 名住院患者的规范化数据并进行流程化处理。每小时计算患者 21 个无创参数，25 个实验室参数，通过随机森林机器学习方法预测未来 1-4 小时的中重度 ARDS 发病概率，并列出重要的预警因素。

结果：基于无创参数的预警模型 AUC 值在 0.925 至 0.966 范围内，增加实验室参数（对模型性能提升幅度在 0.005 至 0.015 之间。模型预警阳性患者比预警阴性患者具有更高的死亡率以及更长的 ICU 住院时长。

结论：研究证明了利用机器学习方法开发一个动态预警 ARDS 发病模型的可行性。该方法依赖于 ICU 患者在监护过程中收集的常规无创数据，从临床管理系统中提取规范化数据进行流程化处理。当这个模型仅有无创参数其性能仍可匹敌基于全集参数的算法。

关键字：动态预警系统；机器学习；急性呼吸窘迫综合征；电子病历；临床无创监测

ID 1174

基于 Transformer 的多模态电子病历数据融合架构研究

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目的：建立允许缺失模态的多模态电子病历数据融合模型，并对其融合性能和模态缺失下的鲁棒性进行评估。

方法：建立图像、文本和结构化数据三个模态的嵌入表征网络，将不同模态的数据嵌入为相同的向量形式。基于 Transformer 架构中的注意力单元，搭建三模态融合框架。通过引入多元损失函数，提升融合框架在模态缺失下的鲁棒性。对 MIMIC IV 公开数据集中的 X 线片图像、影像学报告文本和实验室检查等结构化数据进行三模态融合，在 14 标签分类任务上评估融合模型的性能。

结果：设计的三模态融合架构在 14 标签分类任务上平均 ROC 曲线下面积（AUROC）达到 0.914，超过仅涉及单模态的模型（0.732，0.835）和图文双模态融合模型（0.870）。在分别缺失单一模态的情况下，平均 AUROC 下降 0.002、0.099 及 0.003。

结论：本研究提出的三模态融合架构可以有效融合三模态数据，提升模型分类性能，且在模态缺失情况下也有良好的鲁棒性。

关键字：跨模态注意力；多模态融合；电子病历；模态缺失

ID 1486

基于人工智能的围术期困难气道预警及解决方案系统研究

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目的：建立基于人工智能的围术期困难气道预警及解决方案。

方法：（1）预警系统：在拟全身麻醉下行择期手术的患者中采集面部图像及语音数据，使用 ResNet18，ECAPA 等深度学习算法结合困难气道真实标签构建评估模型。（2）解决方案：（1）基于空洞卷积和特征融合的 YOLOv3 网络和多路二氧化碳浓度信号定位算法研发多模态气管插管辅助装置，并在困难气道人体模型上进行验证。

结果：（1）基于面部图像及语音特征的困难气道评估模型最佳曲线下面积分别为 0.751 和 0.778。（2）多模态气管插管辅助装置在人体模型中的插管成功率为 90%。

结论：基于人工智能的预警及解决方案有效地辅助困难气道评估及气管插管操作，有望优化困难气道管理流程，降低围术期气道相关并发症及死亡率。

关键字：困难气道；人工智能；面部图像；语音特征；多模态

ID 2407

一种新型智能艾灸机器人的设计与应用

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目的：针对艾灸机器人存在的施灸模式单一、施灸过程中穴位偏离等问题，设计一种可模仿医师施灸手法施灸以及跟踪施灸穴位的新型智能艾灸机器人。

方法：首先，针对施灸模式单一的问题，引入了灸法示教回放功能，艾灸机器人可通过示教的方式记录医师施灸手法，该施灸手法可在之后进行回放，以满足对身体穴位多样化灵活施灸的需求。然后，针对施灸过程中施灸穴位可能偏移的问题，对施灸时的目标穴位点粘贴色块并采用 OpenMV 视觉模块识别并定位目标色块中心点，尽可能保证艾灸机器人施灸位置正对目标穴位，以降低施灸过程中穴位偏离对艾灸疗效的影响。

结果：灸法示教功能可以有效模仿医师施灸手法并进行回放施灸；OpenMV 视觉模块能够有效识别和定位目标色块中心点，当目标施灸穴位在一定距离内移动时艾灸机器人可实现对目标色块位置的跟踪。

结论：本研究将机器人示教与计算机视觉技术引入到艾灸机器人中，解决了艾灸机器人存在的施灸模式单一、施灸时穴位发生移动难以保证艾灸疗效的问题，丰富了艾灸机器人的功能，进一步提高了艾灸机器人的使用性能。

关键字：艾灸治疗；艾灸机器人；灸法示教回放；穴位跟踪

ID 2450

基于对比预测编码的脑卒中患者脑电信号自监督表征学习

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目的：随着人工智能的快速发展，深度学习网络已广泛应用于基于运动想象（Motor Imagery，MI）的脑机接口（Brain Computer Interface，BCI）。脑卒中患者在脑电信号（Electroencephalogram，EEG）采集过程中容易疲劳，实验对受试者的认知和身体限制有很高的要求。因此，如何学习有效的特征表示对于 MI-BCI 系统非常重要。

方法：本文提出了一种基于改进 s 变换（Modified s-transform, MST）的对比预测编码（Contrastive Predict Coding, CPC）框架，以生成 MST-CPC 特征表示。MST 用于获取时间频率特征，以提高 MI 任务识别的解码性能。EEG2Image 用于将多通道一维 EEG 转换为二维 EEG 地形图。高级特征表示由 CPC 生成，CPC 由编码器和自回归模型组成。最后，通过特征可视化和分类性能评估验证了生成特征的有效性。

结果：基于 43 名受试者，MI 的平均分类准确率为 89%。

结论：该模型有助于为中风患者提供有效的康复训练，促进运动功能恢复。

关键字：脑卒中；脑电信号；EEG2Image ；改进 S 变换；对比学习

ID 2677

基于远程交互式系统的帕金森病运动症状自动分析

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目的：针对帕金森病患者运动症状的长期评估与追踪对疾病的干预和治疗有重要意义，但也往往给患者及其家庭带来很大的经济负担，并受制于医疗资源的可及性。随着远程医疗和人工智能技术的发展与应用，基于移动端智能应用程序对患者运动症状进行自动采集与分析，为这一问题提供了可能的解决方案。

方法：结合计算机视觉与机器学习方法，通过建立远程交互式运动视频采集系统，获取了 27 名帕金森病患者自主采集的多项运动评估任务视频，提出了针对帕金森病运动迟缓与步态障碍的运动症状特征提取与自动分析方法。

结果：提出的针对帕金森病运动迟缓与步态障碍的运动症状特征提取与自动分析方法，达到了接近 90% 的动作检测准确率，相关运动特征与专家评分呈现出较强的相关性。

结论：该系统与方法可为患者提供高效率、低成本的病情日常监测与长期追踪工具，辅助临床诊疗。

关键字：帕金森病；远程医疗；交互式系统；计算机视觉；运动症状分析

ID 2734

基于位姿反馈的机器人辅助脊柱穿刺手术误差补偿

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目的：为避免脊柱微创穿刺过程中损伤目标附近的关键组织，需确保穿刺针准确到达靶点。然而穿刺针尖端存在斜角且相较于组织自身刚性不足，刺入组织后发生弯曲，无法准确到达靶点。故本研究旨在实现机器人辅助穿刺手术针体被动弯曲下的精准置针。

方法：首先搭建基于磁定位穿刺针的机器人辅助置针系统，并构建系统坐标传递关系。为应对针体被动弯曲，将整体穿刺过程迭代步进，每步穿刺后基于针尖位姿信息调整针尾进行针尖位姿补偿。

结果：针体以与竖直方向夹角 0°，30° 与 45° 插入模体，直接穿刺误差分别为 3.63mm，12.37mm 和 15.57mm，位姿补偿方法误差分别为 0.68mm，1.55mm 和 2.48mm。

结论：所提出的方法降低了穿刺手术误差，提高了手术的精准性和稳定性，推动医学手术的智能化发展，实现智慧医疗。

关键字：穿刺手术；针体弯曲；电磁定位；位姿补偿

ID 2915

人工智能赋能北京冬奥应急医疗保障平台的应用与展望

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目的：紧紧围绕冬奥会医疗保障中的重点和难点问题，以人工智能为关键科技赋能元素，重点论述冬奥会医疗保障中的智慧化保障关键技术、智能救治装备和平台体系以及发展趋势展望。

方法：通过对“科技冬奥”所引领的人工智能科技创新元素进行分析论述，深入探讨智慧应急医疗体系的特征与发展趋势，并针对如何进一步加强智慧应急医疗保障提出了建议和技术方案。

结果：通过三年多的攻关，联合中国人民解放军总医院的专家，综合运用 5G、物联网和人工智能大数据等技术，构建起一套面向 2022 年北京冬奥会应急医学诊疗保障体系。另外，还设计研发了赛场闭环园区设置的智能应急方舱和 5G 救护车。

结论：基于现有架构和冬奥保障应用的经验，未来更应加强人工智能技术在其中的应用，而人工智能技术的助力也必将会进一步构建并完善人工智能的应急救治医疗保障的闭环应用体系；同时，应大力发展“人机协作”的智慧应急医疗保障体系建设，以实现人机完美协同结合，促进其在更广泛的智慧医疗服务保障领域中提供技术支撑，以期为我国的区域雪上运动、户外运动项目的发展提供更多的更完善的医疗保障支撑手段和智慧急救诊疗技术方案。

关键字：人工智能；应急救治；智慧医疗保障；后冬奥；智能救治装备

ID 3026

基于医学电子病历表型自动标注算法和机器学习算法构建疾病诊断模型

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目的：本研究旨在开发一种基于医学电子病历表型表征自动标注算法的机器学习诊断模型。通过自动标注将临床电子病历中的自由文本转化为结构化、标准化的形式，自动提取电子病历中疾病相关特征，用于训练机器学习模型进行疾病诊断预测。

方法：在电子病历深度表型表征语义信息模型自动标注算法 PhenoSSU 的帮助下，将中文电子病历转换成结构化和标准化的形式，从中提取出“概念 - 属性 - 取值”形式的语义单元，形成特征矩阵用于机器学习模型训练。通过随机森林模型，实现中文电子病历的自动化诊断。

结果：在华为云比赛提供的 11068 份电子病历诊断数据集上使用五折交叉评估方法测试，五折宏平均精确率为

83.88%，宏平均召回率为 81.39%，宏平均 F1 分值为 0.8241。

结论：本研究实现了一种基于医学语义信息模型自动标注算法的机器学习诊断模型，通过它可一定程度的实现从电子病历文本到诊断的自动化过程，为人工智能结合自然语言处理辅助诊断提供新的思路。

关键字：机器学习，自然语言处理算法，医学信息学

ID 3036

利用预训练语言模型实现的常见疾病智能诊断方法

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目的：电子病历中蕴含着大量的医学专业知识和诊疗经验。本研究希望通过借助机器学习和深度学习方法，实现对电子病历知识和经验的特征话提取，进而通过对临床真是数据的学习，实现常见疾病的智能化诊断。

方法：利用预训练语言模型对电子病历数据进行编码，从而实现病历数据的向量化表示。后面利用深度神经网络分类模型，初步实现了常见疾病的只能预测，并在真实世界数据集上取得当前最好水平。

结果：取得最优表现的方法是基于 MacBERT 预训练语言模型的方法，其准确度为 0.667，召会率为 0.7157，F1-score 为 0.6905。

结论：所提出的基于预训练语言模型方法的疾病预测方法在真实世界病历数据集中取得了当前最有的表现效果。进一步证明了深度学习方法和预语言模型在疾病预测以及知能诊断应用方面的潜力。

关键字：深度学习；预训练语言模型；疾病诊断；文本表示

ID 3365

一种具有人机相容性的指关节康复外骨骼机构设计与验证

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目的：针对目前连杆型指关节康复外骨骼机构设计中普遍存在两个问题：①掌指关节和指间关节末端关节轨迹未被考虑；②欠驱动构型无确定轨迹，全驱动构型轨迹限制过强；提出了一种融合指关节关联性的伪欠驱动外骨骼机构设计方法。

方法：首先根据手部生理解剖抽象出肌骨构型（ MSC），基于 MSC 构建了人机融合构型（HMC）的基础形式，采用结合邻接矩阵的二连杆单元插入法综合出 15 种自由度为 3 的 HMC 构型，并利用复用因子优选出控制性最佳构型。然后，设计了自适应角度采集设备并拟合出 2 个指关节关联性函数，将关联性函数引入到优选构型的拉式方程组中，并将名义自由度数量超过广义拉氏坐标数量的欠驱动构型定义为伪欠驱动机构。最后，通过粒子群算法优化了尺度参数

结果：样机实验结果显示，指关节康复外骨骼样机具有伪欠驱动构型特点，具备良好的关节关联性和人机相容性，能够较好地拟合三关节末端的轨迹，验证了设计方法的有效性。

结论：所设计的算法具备良好的关节关联性和人机相容性，能够较好地拟合三关节末端的轨迹，验证了设计方法的有效性。

关键字：外骨骼机构；伪欠驱动；人机融合；指关节关联性；复用因子

ID 3392

基于时间相干低频电刺激的无线电能传输系统研究

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目的：针对脑卒中的康复疗法中迷走神经刺激系统能量耗尽问题，研究具有神经刺激功能的体外无线发射线圈结构的模型优化方法

方法：拟将迷走神经电磁调控与磁耦合谐振式无线电能传输技术相结合，基于时间相干方法，建立电磁耦合模型结构，进行有限元仿真，并借助鼠笼系统验证实验。

结果：发射端接入 10V 电压，得到电极的接收电流为 2.5mA，所提出的无线电能传输系统在接收线圈中能够产生使神经兴奋的电信号，频率范围为 10-40Hz，幅值可达 2.5mA，频率和幅值均能满足迷走神经电刺激所需要 30hz 以及 0.8mA 的要求。

结论：该平台通过差频包络方式对电场进行叠加，产生的包络线频率远小于传输工作频率，可达到高频传输电能低频神经电刺激的作用，即开展动物实验时无需头台侧降频电路部分，可减小头台尺寸及重量，大幅降低头台对大鼠的影响。可为临床迷走神经刺激系统能量耗尽问题提供支持方案。

关键字：无线电能传输；时间相干；迷走神经电刺激

ID 3394

基于可解释集成机器学习方法的前列腺癌风险因素预测模型

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目的：为前列腺癌筛查和早期诊治提供准确及时的科学依据。

方法：对国家临床医学科学数据中心（301 医院）的前列腺肿瘤患者相关生化和病理资料进行数据清洗，建立集成和非集成学习模型对前列腺癌发生风险因子进行预测，将表现最好的模型在数据集上进行预测，评估模型效能。最后使用 SHAP 方法进行全局性和局部性特征分析，提出可供早期筛查和诊治的临床截断值。

结果：集成机器学习模型效果显著优于非集成学习模型，表现最好的 LightGBM 预测准确率为 71%，F1 值为 73%，AUC 值为 0.78。SHAP 对特征进行解释时发现 f/tPSA、P、tPSA、CKMB、LDL-C 和 CK6 种指标对前列腺癌的发生有重要影响。最终模型为包括游离前列腺特异性抗原比例（f/tPSA）在内的 6 个重要特征提供了准确的截断值以供参考：f/tPSA>0.12, P>1.15, tPSA>18, CKMB>12, LDL-C>3.2 and CK>73。

结论：利用集成学习方法可以显著提升模型的预测能力，添加可解释性模型可以从全局和局部角度对实验结果进

行不同层次的深入分析。

关键字： 前列腺癌；风险因素；集成机器学习；SHAP

ID 3441

基于 CNN-Transform 深度学习技术的 1 型糖尿病多参数血糖预测算法

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目的： 提出了一种结合 CNN 和 Transformer 模型的深度学习框架，利用患者的历史数据来进行血糖预测。

方法： 将患者过去的血糖值、碳水化合物的摄入量、胰岛素的注射量作为输入，分别在 15min、30min、60min 的时间范围内对患者的血糖值进行预测。模型使用 CNN 网络对输入的数据进行特征提取，再由 Transformer 模型进行对提取到的特征进行训练以获得血糖预测模型。在这项工作中，为 UVA/Padova 模拟器的 10 名成年 1 型糖尿病患者建立了个性化的 transformer 模型。

结果： 在 15min/30min/60min 的预测时长上，平均绝对百分误差分别达到了 2.41% /2.89%/ 3.19%(RMSE=6.75/10.51/15.98)。

结论： 多参数患者个性化的 CNN—Transformer 模型相对与其它血糖预测模型有较高的精度。

关键字： 血糖预测；一型糖尿病；CNN-Transformer ；深度学习

ID 3512

基于深度学习的乳腺纤维腺瘤超声图像病灶分割的两种新型方法

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目的： 利用人工神经网络提高计算机辅助分割超声图像中乳腺纤维瘤边界的准确率

方法： 构建了两个新型高效的神经网络，从临床上收集并制作了两套乳腺超声图像数据集用于训练以及测试。第一个网络模型效仿人的学习模式，将大规模知识转化为碎片知识进行学习。输入的图像首先被分割成若干碎片，接着，引入上下文信息交互机制来提取这些强关联数据，提高分割精度。第二个模型将网络与临床医生的诊断思维相结合，引导模型效仿医师的临床诊断办法对超声图像进行特征学习，以获得更优结果。

结果： 人脑学习模式指导的网络模型在包含 600 张超声图像的数据集上的 Dice 相似性系数上被证明优于其他方法，而且降低了推理时间。同时，临床先验知识指导的神经网络在包含 1016 张超声图像的数据集上的分割表现相比于其他模型同样更好。

结论： 我们提出的两种学习模型通过更加直接的、效仿人脑思维方式的学习模式得到了更加准确的病灶分割性能 , 优秀的学习模式是提高神经网络性能的关键。

关键字： 深度学习；医学图像分割；乳腺纤维瘤；超声影像

ID 3529

基于机器学习模型的代谢综合征预测

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目的：探索机器学习技术在代谢综合征预测中的应用效果，并研究将模型应用到分布不同的目标人群时的表现。

方法：使用 NHANES 数据集并基于 IDF 标准和定义诊断了 MetS，将数据集重新采样并分为三个不同的子集。使用 NHANES 中的生化指标数据，通过多种机器学习模型来预测代谢综合征。

结果：总数据集上的各模型测试表现均较为良好，AUROC 值分别为 0.94（LightGBM），0.93（Random Forest）和 0.92（Logistic Regression），而所有模型在匹配过后的子集上的表现均有所下降，LightGBM 和 Random Forest 模型相较于 Logistic Regression 具有更大的下降幅度。

结论：应用机器学习技术可以在 NHANES 数据集上以较高的准确率对代谢综合征进行预测，然而及机器学习模型在外推到分布不同的人群时依然存在挑战。

关键字：机器学习；代谢综合征

S14
生物医学光子学分会 2023 学术年会
2023Annual Meeting for Biomedical Photonics

ID 378

A 980 nm Absorbing Aggregation-Induced Emission Luminogen for NIR-II Imaging-Guided Synergistic Photo-Immunotherapy Against Advanced Pancreatic Cancer

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Objective: To address urgent tasks in the treatment of advanced deep-seated tumors, we developed a 980 nm absorbing agent with aggregation-induced emission (AIE) tendency, namely TPE-BT-BBTD, which simultaneously possesses the longest absorption wavelength among all the reported AIE molecules.

Methods: The functionality of deep near-infrared-II fluorescence imaging (NIR-II FLI) and outstanding photothermal performance was well tailored for advanced pancreatic cancer treatment.

Results: With the covalent attachment of αPD-L1 antibody, αPD-L1@TPE-BT-BBTD nanoparticles showed precise tumor targeting and excellent immunosuppression reversal ability. Following local photothermal therapy, immunogenic tumor vaccination was induced to trigger the infiltration of cytotoxic T lymphocytes (CTLs) in tumors. With the decreased $FoxP3^+$ Treg cells and M2-like macrophages that reversed by αPD-L1, CTLs activity was further enhanced with more production of granzyme B (GrB), which much accurately led to tumor apoptosis and effectively suppressed spontaneous metastases.

Conclusion: Overall, αPD-L1@TPE-BT-BBTD nanoparticles based NIR-II FLI-mediated photo-immunotherapy was able to significantly improve the controlling of primary tumor and metastasis in the treatment of advanced deep-seated tumors.

Key words: aggregation-induced emission, photo-immunotherapy, NIR-II imaging, immunosuppression reversal, pancreatic cancer

ID 532

Rapid Virus Detection Using Recombinase Polymerase Amplification Assisted by Computational Amplicon-Complex Spectrum

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Objective: The detection of respiratory viruses is crucial in the setting of the SARS-CoV-2 outbreak. Recombinase polymerase amplification technology speeds up nucleic acid detection compared to the conventional polymerase chain reaction, and requires no professional operations. The integration, cost, and convenience issues with recombinase polymerase amplification detection limits its wide application.

Methods: In this study, we used the polar GelRed dye's computational absorption spectrum to probe the amplicon. After bonding with DNA, GelRed molecules can transform into polar electric dipoles attributing to the asymmetry structure. Following centrifugal vibration, electrostatic contact resulted in the precipitation of dipoles. The supernatant's absorbance spectra changed once the precipitation was removed. The remaining GelRed molecule in the amplified product can be assessed to determine its composition.

Results: Based on this principle, we confirmed the viability of the suggested method, and also concentrated the GelRed dye. Finally, we tested the effectiveness of this technique using the synthetic Influenza A template and primer. 100 copies/μL of the template was the lowest concentration that can be detected. It was linearly correlated with the template concentration logarithm.

Conclusion: This technique has offered a workable, practical, and affordable detection strategy for the quick pathogen identification.

Key words: recombinase polymerase amplification, virus detection, computational spectrum, nucleic acid detection

ID 892

Recent Advances of Intact Organ Embedding Methods for High-Precision 3D Imaging

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Objective: The complete and accurate three-dimensional reconstruction of the fine structure of the nervous system is of great significance for the systematic understanding of the working mechanism of organs and the pathogenesis of diseases. Fluores-cence micro-optical sectioning tomography (fMOST) enables multi-scale brain-wide imaging, and several embedding tech-niques for intact organs have been developed. In this review, we will describe the whole organ embedding techniques and its application in neuronal imaging in detail. Firstly, the intact organs embedding method is introduced. Secondly, the research progresses of embedding techniques in high-precision 3D continuous imaging is systematically summarized. Finally, the chal-lenges and possible solutions of the whole organ embedding method in 3D tissue imaging are proposed.

ID 928

Neuromodulation with Submillimeter Spatial Precision by Optoacoustic Fiber Emitter

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Objective: New techniques to non-invasively modulate neural activities with high precision are constantly being sought in neuroscience. Ultrasound is a promising neuromodulation modality due to its non-invasive potential. However, conventional piezo-based ultrasound neuromodulation using a transducer usually have a spatial resolution of more than a few millimeters, limiting research on specific brain area or neural circuits. Here, a spatially confined optoacoustic emitter is developed for high-precision neuromodulation, allowing neurons to be activated at submillimeter spatial precision.

Methods: By designing a candle soot-PDMS layered optoacoustic fiber tip (CPOF) with a diameter of 350 μm, we demonstrate the generation of local ultrasound waves with a peak frequency of 3.5 MHz.

Results: The ultrasound generated by CPOF can directly activate cortical neurons in culture within a radius of 450 μm around the fiber tip, generating intracellular calcium transients.

Conclusion: The CPOF promises to be a novel technique for high-precision neural stimulation and for investigating the mechanism of neurostimulation.

Key words: optoacoustic neuromodulation, high spatial resolution, calcium imaging, cortical neuron, optoacoustic fiber

ID 2316

使用光刺激进行神经操控的最新进展

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目的：本综述主要介绍了近期光操控研究涉及的原理与实验结果。

方法：伴随着光学方法在脑科学中的广泛应用，大脑原理的研究被显著推动，其中光操控神经集成活动对于理解脑功能和疾病具有重要意义。神经系统错综复杂，但通过单光子与双光子照明配合细胞中表达光感蛋白使用，可以实现对目标神经元不同层次的操控，如单光子在可见波段对神经活动的激活、抑制和在紫外波段驱动目标细胞的转化，双光子除调控与转化外还具有的消融功能等，以实现对神经环路间复杂关系的清晰刻画。

结果：在此方法的基础上，研究团队们使用数字微镜阵列（Digital Micromirror Device, DMD）、空间光调制器（Spatial Light Modulator, SLM）、声光偏转器（Acousto-optic Deflectors，AODs）等器件，改进硬件、算法等诸多方面，在不同的方法下实现了对光刺激各指标的提升。

结论：这些研究所提出的刺激精度高、模式响应速度快和刺激范围广的光操控系统，将为脑科学提供更有力的工具。

关键字：脑神经操控；光刺激；单 / 双光子；空间光调制器

S15
第五届医学免疫与临床应用（SFICA）分会场
The 5th Summit Forum on Immunology and Clinical Application

ID 963

肿瘤代谢产物乳酸通过调节 Treg 细胞 MOESIN 乳酸化修饰和增强 TGF-β 信号传导促进肿瘤发生发展

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目的：探究肿瘤代谢产物乳酸对 Treg 代谢和功能的影响并且在蛋白质修饰层面解析其机制

方法：泛乳酸化分析、分子互作三维结构分析、流式分选、Seahorse 细胞代谢实验、慢病毒转染等

结果：在体外乳酸可提高 Treg 功能和稳定性，而降低乳酸浓度会减少 Treg 的诱导水平，增加抗肿瘤免疫力并降低小鼠的肿瘤生长速度。从机制上讲，乳酸通过 MOESIN 的 Lys72 位点乳酸化修饰增强 MOESIN 与 TGF-βRI 的相互作用以及下游的 SMAD3 信号。抗 PD-1 和乳酸脱氢酶抑制剂联合治疗具有比单独使用抗 PD-1 更强的抗肿瘤作用。抗 PD-1 治疗有反应的原发性肝癌个体的 Treg 中 MOESIN Lys72 乳酸化水平低于无反应个体。因此，我们认为乳酸是通过乳酸化修饰增强肿瘤微环境中 Treg 功能和稳定性的必需小分子。

结论：MOESIN 蛋白在赖氨酸 72 位点发生了乳酸化修饰后增强了与 TGF-β 受体的结合，从而促进了 TGF-β 信号通路的传导，提升了 FOXP3 的表达和 Treg 的功能

关键字：乳酸；Treg；MOESIN；乳酸化；代谢

S17
医学检验工程——医工协同 融合创新
Medical Laboratory Engineering：Medicine and Industry, Fusion and Innovation

ID 729

A Novel Poly(3-hexylthiophene) Microelectrode for Ascorbic Acid Monitoring During Brain Cytotoxic Edema

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Objective: Neuroelectrochemical sensing technology offers unique benefits for neuroscience research,being able to target measurements of marker changes during physiological or pathological processes. Changes in many physiological processes are often very microscopic or invisible, so there is a need for a method to directly monitor the markers of interest in these processes. Thus, microelectrodes are beginning to fill this gap.

Methods: In this paper, we introduce poly(3-hexylthiophene) (P3HT) and nitrogen-doped multiwalled carbon nanotubes (N-MWCNTs) to construct a composite membrane-modified carbon fiber (CF) microelectrode (CFME/P3HT-N-MWCNTs) to detect ascorbic acid (AA).

Results: We apply CFME/P3HT-N-MWCNTs to monitor the AA of intercellular fluid, we achieve the observation of the cellular mechanical process of brain cytotoxic edema at the electrochemical level.

Conclusion: Our study can apply a new in vivo electrochemical sensing technology to construct in vivo implanted microelectrodes and monitor key biomarkers. Thanks to this research approach, we will explore the molecular basis of biomechanic-related diseases and discover some underlying mechanisms.

Key words: Microelectrodes, Neuroscience, Brain Cytotoxic Edema, Ascorbic Acid, Poly 3-hexylthiophene.

S18
健康感知评估干预与融合创新
Integrated Innovation of Health Perception Assessment and Intervention

ID 410

Radar Translator: Contactless Eyeblink Detection Assisting Basic Daily Intension Voice for the Paralyzed Aphasia Patient Using Bio-Radar

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Objective: In order to assist the paralysis aphasia patients (PAP) to 'speaking out' their intension in daily life for smooth communication with their families and care workers, a contactless, all-the-clock and privacy-preserving bio-radar-based 'eye-language' translator is first proposed.

Methods: The radar was newly exploited to non-contact capture the number of human eyelid blink behavior based on two key physiological features, and corresponding eyeblink recognition results were subsequently used to realize the eye-blink-to-voice translation for the PAP's intension expression combined with text-to-speech technology.

Results: Quantitative investigation on the system performance over three key factors indicates that this translator could identify blink behavior accurately and stably. Moreover, during comprehensive functional testing experiments, eyeblink-to-voice translation tasks of 39 life scenarios were successfully realized.

Conclusion: Consequently, it can be demonstrated that this bio-radar based translator can effectively recognize eyeblink and help PAP patients actively express their basic extension in a voice way, which is promising to improve the PAP's life quality and nursing level.

Key words: Bio-radar, paralysis aphasia patient, eye blink, eye-language

ID 859

An Explainable Assessment for Depression Detection using Frontal EEG

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Objective: Depression is a common mental disease that seriously threatens human physical and mental health. Finding effective and useful biomarkers to early recognize depression has become an urgent trend. This study's purpose is to evaluate the complexity of electroencephalogram (EEG) sub-bands and provide an explainable for multi-classification of depression.

Methods: At first, Higuchi's fractal dimension (HFD) and sample entropy (SEn) were extracted from the frontal EEG sub-bands and statistically analyzed. Second, the performance of various classifiers in recognizing three depression states was

verified. Finally, the features' importance on the model output was assessed and quantified.

Results: The results exhibited the increased complexity in depression compared with healthy controls, and increases with the deepening of depression. The best classification accuracy of 90.5% in discriminating three groups. Furthermore, the top 10 features with the highest impact are dominated by high-frequency features, both the overall output impact and single category output impact.

Conclusion: The results suggest an interpretable quantitative assessment for the identification of depression, which might help in future depressive state prediction.

Key words: depression recognition, EEG, complexity analysis, sample entropy.

ID 2030

竞技跆拳道旋风踢动作时下肢运动生物力学特征分析

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目的：探索竞技跆拳道运动员在使用电子护具时旋风踢技术动作的下肢运动生物力学特征。

方法：采用三维运动捕捉、三维力台和 Deado 电子护具等设备，采集 12 名竞技跆拳道运动员旋风踢动作下肢关节的运动学和动力学数据，用 V3D 软件计算关节角度、角速度、净力矩，击打速度和地反力等参数。

结果：运动学：进攻腿髋 / 膝关节屈曲角度峰值为 33.17/-120.5°、屈曲角速度峰值为 7.07 /12.67 rad/s、伸展角速度峰值为 -4.82 /22.19 rad/s，踝关节跖屈 / 内旋角度峰值为 75.85/20.40°、跖屈 / 内旋角速度峰值为 14.57 /7.09 rad/s，击打线速度峰值 X、Y、Z 轴分别为 7.01/10.87/6.27m/s；动力学：进攻腿髋 / 膝关节伸展力矩峰值为 -2.84 /-1.94 N · m/kg，踝关节跖屈 / 内旋力矩峰值为 2.71 /0.34 N · m/kg，地反力峰值 X、Y、Z 分别为 0.19/0.2/2.62BW。

结论：相比前横踢，旋风踢技术具有更高的击打速度和更优的下肢关节力学表现；在进攻方向上踝关节的运动学和动力学表现优于旋转方向；在进攻腿离地前足底与地面的相互作用力对转体和腾空具有一定影响。

关键字：跆拳道；旋风踢；电子护具；运动学；动力学

ID 2349

中医诊断装备在临床部分疾病中的应用

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目的：通过检索近十年中医诊断装备在临床上的应用文献，分析中医诊断装备在使用过程中存在的问题与局限，以期更好地研发相关设备。本研究以 CNKI 为数据来源，运用专业检索文献，时间范围设定为 2012 年 1 月 1 日至 2022

年 12 月 31 日。将符合纳入标准的参考文献以内科、外科、妇科、儿科的类别进行归纳整理。 检索到 2000 篇相关文献，经过人工筛选出红外仪、舌象仪、脉诊仪及其他设备在临床各科疾病中的应用。 中医诊断装备在临床诊断上目前已取得部分成果。随着 5G 时代的到来，人工智能、大数据、多源信息融合技术、生化检测技术等技术突飞猛进，客观化的中医诊断装备的应用将得到进一步扩大，之后中医装备的研究将趋向于利用更加高效、准确、完善的相关技术进行疾病的辅助诊断。

关键字： 红外仪；舌象仪；脉诊仪；临床疾病

ID 2551

基于卷积神经网络的心理疲劳状态识别方法

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目的： 新时代生活节奏加快，人们生活压力逐渐增大，不同的压力对人们会产生一定的影响，若压力长期累积或程度过大，容易引起人们的心理疲劳。心理疲劳不仅降低了人们的工作效率，更危险的是对疲劳的忽视可能诱发各种抑郁和慢性病。因此，识别人们的心理疲劳状态并及时预警干预可有助于降低危害的发生，对健康生活有着重要的意义。

方法： 考虑到卷积神经网络在自动特征提取和分类精度方面的优势，本研究提出了基于卷积神经网络（CNN）的心电信号心理疲劳状态识别方法。该方法通过一维卷积神经网络模型的卷积层，对输入的心电节拍提取局部特征，并通过池化层是从局部特征中提取关键特征，舍弃冗余特征，最后通过全连接层是对提取的关键信息进行整合，实现了心理疲劳状态的识别。

结果： 基于心理疲劳诱发实验采集被试的心电数据进行方法测试。实验结果表明，与支持向量机相比，所提出的方法提高了心理疲劳识别的精度，具有更好的识别效果。

结论： CNN 算法能够有效地识别心理疲劳，为心理疲劳状态的干预与心理健康等提供了可能性。

关键字： 心理疲劳；心电信号；卷积神经网络

ID 2878

心肺运动试验结合动态血糖监测指导 2 型糖尿病患者个体化精准运动中的疗效

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目的： 探索心肺运动试验（CPET）结合动态血糖监测（CGMS）在指导 2 型糖尿病（T2DM）患者个体化精准运动整体方案强化管控 1 周后（简称强化管控）的效果

方法： 选取 2019 年至 2022 年由我们团队强化管控的 T2DM 患者 28 例，签署知情同意书后完成 CPET，根据 CPET、连续功能学检测结果制定以个体化适度运动强度为核心的整体管理方案，同时佩戴 CGMS 9-14d，强化管控 1 周后，分析管控前 1 天与管控后第 1 天血糖谱参数，包括日内平均血糖水平（24h MBG）、最大血糖波动幅度（LAGE）、

平均血糖波动幅度（MAGE）及血糖波动系数（SDBG）等水平指标

结果： 管控前患者 24h MBG、LAGE、MAGE 及 SDBG 分别为（9.1±2.77, 7.7±3.12, 7.6±3.03, 1.8±0.98）mmol/L；强化管控后上述指标分别为（7.3±1.81，2.7±1.22，5.5±1.99，1.4±0.68）mmol/L，均显著降低（P<0.05）

结论： CPET 能安全客观定量地评估和指导制定个体化精准运动强度，并通过结合 CGMS，在个体化精准运动整体方案强化管控 1 周能安全有效逆转 T2DM 患者血糖异常指标

关键字： 心肺运动试验；2 型糖尿病；个体化精准运动整体方案；动态血糖监测

ID 3001

基于运动手环的老年人实时运动功能分析

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目的： 随着年龄的增长，老年人因自然衰老、疾病或意外损伤等原因导致运动功能衰退、运动障碍或者失能的风险不断增加。便捷易用、高性价比的运动功能实时评估与长期监测方案对维护老年人运动健康、应对老龄化挑战有重要意义。目前，老年人运动功能评估仍主要依赖临床资源，无法实现规模化、及时性的运动健康评估。

方法： 提出了一种基于姿态解算、机器学习和临床专家知识的实时动作姿态识别和运动功能精细化分析方法。基于 65 名老年人的运动手环数据，提出了实时动作姿态和运动状态识别模型。

结果： 准确率达到 92%，提取的运动功能精细化分析指标与临床评估指标具有高度一致性。

结论： 基于普通运动手环能够实现实时的动作姿态识别与运动功能评估，为老年人日常运动功能监测提供了有效途径，并可应用到其他运动功能障碍患者的诊疗辅助与康复训练中。

关键字： 老年人运动功能；动作姿态识别；运动功能评估；运动手环

ID 3071

基于迁移学习的机械通气呼吸音识别与吸痰时机判断

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目的： 使用呼吸机进行机械通气的过程中，建立人工气道会降低患者的分泌物排出能力，容易造成痰液淤积。目前临床上主要依赖医生对呼吸音进行听诊，来判断患者的吸痰需求，需要研究吸痰时机的自主判断方法。

方法： 提出基于迁移学习的呼吸音特征识别与吸痰时机自主判断方法。使用电子听诊器采集临床机械通气患者在吸痰前、后的主气道呼吸音，以前者表征需要吸痰时机，对其进行高通滤波和小波软阈值滤波进行噪声去除，提取对数梅尔频谱图，然后使用在 Audioset 数据集上预训练的 VGGish 模型提取对数梅尔频谱图的特征向量，最后使用支持向量机对特征向量进行分类，自主判断是否需要吸痰。

结果： 实验结果对需要吸痰的呼吸音识别的特异性、敏感性和准确率分别为 90.35%、93.1% 和 90.96%，证明了

方法的可行性。

结论：本研究探索利用呼吸音对机械通气患者的吸痰需求进行识别，证明了迁移学习用于呼吸音的可行性。下一步将收集更多临床数据，对模型进行迭代，并将该模型部署到呼吸机上，以提升呼吸机的智能性。

关键字：机械通气；呼吸音；迁移学习；吸痰时机判断

ID 3178

中医五藏是生物进化的重演

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目的：为中医五藏的相生关系提供生物学依据

方法：通过将与生命活动相关的生物进化现象与中医五藏进行对比。

结果：前生命的化学进化阶段为原始生命的形成提供了物质基础，相当于中医脾藏为人体生命活动提供的营养物质；光合作用提供的氧气和能量是生物进化的前提，相当于中医肺藏主气功能是人体生命活动和新陈代谢正常运行的前提；无脊椎动物具有的传递遗传信息的生殖能力和维持自身形态结构稳定的能力，此时动物的生活效率低下，相当于中医的肾藏；神经系统使动物的生命活动协调有序和对外界环境的适应提高，相当于中医的肝藏的疏泄和藏血功能；大脑和心理进化机制的出现，相当于中医的心藏的藏神功能。

结论：与生物进化相关的五个藏之间存在相生关系，中医五藏是生物进化的重演。

关键字：五藏；生物进化；五行相生

ID 3318

基于实体和关系论中西医结合

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目的：从实体与关系的角度出发探讨中西医结合。

方法：从哲学角度出发，明确实体与关系的哲学内涵，以及西医学与实体中心论、中医学与关系中心论的理论基础，并进一步从中医、西医在生理、病理、治疗的具体方面的不同表现，阐述中西医各自的优势、劣势之所在；总结中医、西医诊疗知识的特点以及当前中西医结合存在的问题，为进一步寻求中西医结合的方式方法提供理论基础。

结果：中西医在生理、病理、治疗方面存在形态与功能、辨病与辨证、治病与治人的结合方式，并可归结于实体与功能的结合；中西医诊疗数据存在碎片化、隐形化的特点而形成了两座“知识孤岛”，知识图谱因具有知识语义化、数据易关联、易扩充的特性的特点而可成为联系孤岛的桥梁。

结论：可从实体与关系的角度，以知识图谱为桥梁，促进中西医结合。

关键字：中西医结合；实体；关系

ID 3320

基于脉诊客观化的脉象系统研究综述

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目的：中医脉诊有着几千年的发展历史，也是中医诊断中最具有特色和辨别能力的诊断方法之一，脉搏传感器、脉象信号系统是现代脉诊客观化历程中重要的组成部分，脉搏传感器的仪器精密程度影响和脉象信号的检测质量都可能使脉诊分析结果产生误差。脉诊仪是当今中医药研究发展接轨现代化科技的直接手段，脉搏传感器的单一研究并不能解决目前面临的客观化标准无法统一的问题，对此开展进一步分析。

方法：以典型种类的脉搏传感器结合脉象信号系统的采集工具与方法，从脉搏信号分析的数字化信息、特征提取、脉象识别和脉象信息系统的种类与区别展开研究。

结果：重点介绍了脉象信息分析系统中脉搏信号分析和脉象信号采集系统的种类与差别。

结论：提出脉诊多维度研究、脉搏信号侧重点不同的问题，以期为脉诊客观化提供新的思路。

关键字：脉诊客观化；脉诊；脉搏传感器；脉象信号系统；脉搏信号分析

ID 3333

连续型气管插管机器人参数化设计与路径规划

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目的：气管插管是救治呼吸困难的常用方法之一，但救治呼吸道传染病患者会极大增加医护人员感染风险，而且院外急救现场常因插管不及时错失急救时机，所以亟需一种可远程实施气管插管的智能装备。

方法：基于 CT 影像对矢状面和横截面内气管插管路径的几何参数进行测量与分析，以此作为机器人设计依据。根据影像特征设计连续型机器人的多节段弯曲结构，表征几何变量，并 3D 打印机器人样机。采用两个相切圆弧对气管插管路径进行拟合和参数化，制定分阶段插管策略。

结果：统计了气管插管时气道的主要几何尺寸作为机器人设计依据，多节段连续型气管插管机器人可以满足插管过程中适应气道结构变化的自由度要求，插管过程可分为五个阶段进行路径规划。

结论：连续型气管插管机器人可以实现远程插管功能，为呼吸道传染病患者救治和院外应急救援提供新的智能治疗设备。

关键字：气管插管；连续型机器人；参数设计；插管策略

ID 3491

易筋经特定动作“卧虎式”治疗非特异性下背痛的运动学相关分析

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目的：通过表面肌电、三维步态分析对易筋经特定动作“卧虎式”改善非特异性下背痛异常动作模式机制进行探索，并为后继的建模打下理论基础。

方法：收集易筋经特定动作“卧虎式”治疗非特异性下背痛的相关表面肌电图信号、三维步态分析数据等进行相关分析，以阐述易筋经“卧虎式”训练治疗非特异性下背痛的作用机理。

结果：1.NSLBP 患者腰部 L5-S1 多裂肌 sEMG 信号与治疗前相比有显著增加（P <0.05）；2. 患者治疗后步幅、步频、步速、髋屈曲最大角度、膝屈曲最大角度均显著增加（P <0.05）；支撑相、摆动相、踝跖曲最大角度均显著降低（P <0.05）。

结论：易筋经特定动作“卧虎式”治疗非特异性下背痛前后的相关表面肌电图信号、三维步态分析数据得到有效改善，其治疗效果的运动学机制可能通过改善非特异性下背痛异常动作模式而获得。

关键字：易筋经；三维步态分析；表面肌电图

ID 3522

基于深度耳像学习的耳穴识别及辅助定位应用

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目的：耳穴疗法是一种特色的中医外治技术，但因为人耳郭形态具有较大的个体差异，导致不同人耳郭穴位的定位和分区也具有较大的差异性，影响了临床穴位使用的精准性和治疗的效果。因此，如何实现不同人耳郭形态下穴位定位，是耳穴疗法普及应用所必须解决的难题。

方法：基于深度图像学习的耳郭分区识别算法，通过对左右耳各 500 张耳郭 32 个生理性特征点和耳穴分区划分的 59 个标志点的标注。在 AAM 基础上，通过归一化和主成分分析构建耳郭形状模型算法和纹理模型算法进行深度学习和训练，获取训练图片的形状和纹理特征。并进一步利用逆和成算法，通过对已有的耳郭形状和纹理模型变化方向进行改变，在最优求解多次迭代后获取一个和目标图像最相符的特征模型，从而更精准的实现对目标图片中耳郭 91 个特征点的搜索识别。并在已获得的耳郭 91 个特征点的基础上，通过增加相邻特征点之间的差值运算，重构耳郭穴位定位与分区的划分。

结果：通过耳穴专业人员对 100 张耳像图片的智能耳穴定位和分区效果检验，识别达到了 92.6% 的符合度。

结论：本研究实现耳像图片的智能化耳穴定位和识别，并在此基础上开发了测试应用程序，获得 2000 多人次的识别应用，是图像技术在智慧中医方面的应用尝试。

关键字：智慧中医；耳穴；穴位识别；耳像；深度学习