

基于功能磁共振成像针灸镇痛的神经理控机制的研究进展



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【摘要】 本文基于功能磁共振成像 (functional magnetic resonance imaging, fMRI) 技术探讨针灸镇痛的神经理控机制。研究表明, 不同针刺和艾灸手法对脑功能调控存在差异。针刺疗效与行针手法、穴位组合、刺激强度等因素密切相关, 而其中枢镇痛机制涉及大脑局部核团功能连接的变化。特殊针刺 (如电针、火针等) 在特定疾病的治疗中表现出独特的中枢神经调控效果。艾灸 (包括普通灸法、特殊灸法和热敏灸) 同样通过调节脑区神经活动发挥镇痛作用, 但与针刺的中枢镇痛机制存在差异。尽管 fMRI 技术为针灸神经调控机制的研究提供了技术支持, 但目前研究仍存在样本量小、实验设计不统一、缺乏病理对照组等局限性。未来研究需建立统一规范的操作规程, 扩大样本量, 并结合临床实际治疗方案, 深入探讨针灸镇痛的神经理控机制, 为针灸学的发展提供更坚实的科学依据。

【关键词】 功能磁共振成像; 神经调控; 针法; 灸法

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Research progress on the neuromodulation mechanisms of acupuncture and moxibustion analgesia based on functional magnetic resonance imaging

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【Abstract】 To investigate the differences in brain effects induced by acupuncture therapy based on functional magnetic resonance imaging (fMRI) technology, this study demonstrated that different acupuncture and moxibustion techniques had distinct regulatory effects on brain regions. The therapeutic efficacy of acupuncture was closely related to needling techniques, acupoint

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combinations, and stimulation intensity. Its central analgesic mechanism involved changes in the functional connectivity of local brain nuclei. Special acupuncture techniques (such as electroacupuncture and fire needle) exhibited unique central nervous system regulatory effects in the treatment of specific diseases. Moxibustion (including common moxibustion, special moxibustion, and heat-sensitive moxibustion) also exerted analgesic effects by regulating brain neural activity, with differences from the central analgesic mechanisms of acupuncture. Although fMRI technology has provided technical support for the study of acupuncture neuroregulation mechanisms, the research at that time still had limitations, as including small sample sizes, non-uniform experimental designs, and the lack of pathological control groups. Future research was suggested to establish unified and standardized operating procedures, expand sample sizes, and integrate clinical treatment plans to further explore the neuroregulatory mechanisms of acupuncture analgesia, thereby providing a more solid scientific basis for the development of acupuncture.

【Keywords】 Functional magnetic resonance imaging; Neuromodulation; Acupuncture; Moxibustion

针灸学是以经络学说为理论基础,以腧穴为导向,历经数千年的经验积累,通过针刺、艾灸或结合不同的手法进行疾病的治疗^[1-2]。作为一种用针或艾灸刺激身体某些穴位的传统治疗方法,针灸通过调节疼痛感知和相关大脑区域和网络来缓解疼痛^[3],并以“低创伤、多靶点、整体调节”的特点在临床治疗中得到广泛应用^[4]。神经调控机制是全球医学界关注和研究的焦点,针灸镇痛的神经理控机制更是被视为针灸学科领域的核心问题^[5-8]。功能磁共振成像(functional magnetic resonance imaging, fMRI)的主要分析指标包括局部一致性(regional homogeneity, ReHo)、低频振幅(amplitude of low-frequency fluctuation, ALFF)及功能连接(functional connectivity, FC)等^[9]。该技术能够较直接地反映脑功能区的基础状态和变化,具有无创、可视、高时空分辨率、无辐射及形态与功能同步成像等优势,且操作简易稳定,已成为针灸学科的一种新型“望诊”手段。在针灸镇痛神经调控机制方面的研究中,fMRI已崭露头角并取得了一定成果,为深入研究针灸神经调控机制提供了技术手段^[10-14]。目前,我们对针灸镇痛潜在神经调控机制的理解仍较欠缺,如针灸应用过程中的fMRI信号变化规律、针灸调节大脑活动和功能连接的方式,及其与针灸疗效相关的个体差异性的关联仍然未明确。阐明针灸镇痛神经调控的潜在作用机制,将有助于开发更有效的干预措施。因此,本文将以国内外相关研究为依据,基于fMRI技术综合阐述不同针灸手法镇痛治疗的神经调控特点,深度剖析针灸镇痛的神经理控

作用机制,以期为今后针灸脑效应研究提供系统的理论参考。

1 疼痛的神经调控机制

疼痛作为继脉搏、血压、呼吸、体温之后的第五生命体征,分为急性疼痛和慢性疼痛,也是各种疾病最常见的症状之一,属于一种多维度的复合感觉^[15]。fMRI能直观地揭示复杂的脑网络系统,结合疼痛的复合性,从认知、感觉、情绪等多维度开展研究,从而揭示疼痛相关脑区或核团活动的变化,以及各脑区间功能连接组的改变等。有研究发现,疼痛信号在传输过程中会导致中枢神经的各级痛觉神经元进入高敏化,使上传的疼痛信号不断被放大,进而导致疼痛感加强和脑功能区重塑^[16]。因此,在痛觉信息上传及处理的各个阶段,相关脑区之间会不断发生相互作用。现代影像学进一步发现,脑内其他很多皮层和皮层下区域也参与痛觉信息的加工和处理,如前额叶和杏仁核等^[17-21]。这些疼痛相关脑区并非单纯地处理痛觉单一信息,而是可以同时对接痛觉的多种信息进行整合加工。例如,岛叶既可以编码伤害性和非伤害性温度刺激的强度^[22-23]和位置信息^[24-25],也参与形成疼痛的情绪反应^[26-28]。

2 针刺镇痛的神经理控机制

2.1 普通毫针针刺的中枢镇痛机制

针刺作为临床常用的治疗手段之一,其毫针刺法以直刺法、斜刺法或平刺法刺入穴位后直接留针或配合捻转、提插等补泻手法后再留针。研

究表明, 针刺可以诱导内源性阿片类物质的释放^[2]。针刺后肠易激综合征患者小脑、左侧舌回、左侧枕中回、右侧海马体、右侧枕上回等区域 FC 变化显著, 这表示针刺后大脑局部核团功能连接的变化与患者疼痛症状的改善密切相关。

现代研究表明, 针灸功效的发挥依赖于中枢神经系统的调控^[29-30]。不同行针手法、穴位组合及刺激强度等产生的脑区响应存在差异^[31], 进而影响其针刺镇痛疗效。徐佐宇等采用平补平泻的手法直刺受试者右侧大钟穴且不留针, 结合 fMRI 技术分析后发现, 所获得的激活脑区主要位于双侧小脑前叶、右侧颞极、左侧脑干、左侧苍白球、右侧额中回、左侧额上回, 这些针刺大钟穴激活的脑区与足跟痛、腰痛等在脑内对应的躯体感觉中枢一致^[5]。赵彦琳等的研究发现, 对腰椎间盘突出患者针刺治疗后可有效改善其下肢放射痛症状, 进一步结合 fMRI 技术分析发现, 患者双侧楔前叶、双侧额内侧回、扣带回等区域 FC 显著降低。针刺镇痛疗效还与治疗时间和次数相关^[32]。有研究表明, 针灸治疗的最佳留针时间为 15~45 min^[33]。赖淑华等对腰椎间盘突出患者行毫针刺法并配合捻转手法治疗, 结合 fMRI 技术分析发现患者枕上回、踞状回、楔叶等区域 ALFF 增高, 且随着治疗次数的增加, 镇痛效果也显著增加^[34]。

2.2 特殊针刺的中枢镇痛机制

特殊针刺将传统毫针刺法与电、火、特殊针具相结合, 在特定疾病的治疗中往往能发挥出独特的疗效。闫立平等^[8]在用电针刺刺激受试者右侧曲池穴, 并结合 fMRI 技术分析, 发现所获得的脑激活区包括同侧初级躯体运动区、辅助运动区、双侧感觉区、以及这些感觉的高级整合区; 这些区域是重要的痛觉为内脏调节中枢, 为曲池穴治疗疼痛性疾病和胃肠道疾病等提供了理论支撑, 但是该研究的受试者均为健康在校大学生, 缺乏病理性数据对照。俞燕丽等^[35]的研究发现薄氏腹针可有效改善卒中后患者的认知功能障碍, 并改善其肢体麻木疼痛等症状, 表明局部脑区 ALFF 增高与卒中后认知功能障碍程度密切相关, 而薄氏腹针可调节多个脑区的神经活动, 如颞下回、左侧颞中回、左侧小脑后叶、左侧顶上小叶、左侧额下回、左侧枕下回的 ALFF 值显著降低^[35]。陈鹏等的研究发现火针点刺抑郁症患者的颅底穴

可以有效改善其认知和情绪等相关指标的评分, 结合 fMRI 技术进一步分析发现其小脑、顶叶、颞叶、额叶的 ALFF 均出现显著变化^[36]。何永强等的研究发现, 头针联合肩三针可有效缓解中风患者的上肢疼痛症状, fMRI 结果显示在肩三针的基础上加上头针治疗后, 病灶侧中央后回和枕叶的激活状态更为显著^[37]。上述研究表明特殊针刺在镇痛治疗中可引起中枢神经系统 FC 和局部脑区的改变, 然而特殊针刺的 fMRI 研究普遍存在研究设计不够严谨、样本量偏小, 以及缺乏针刺与正常对照组的问题。

3 艾灸镇痛的神经营控机制

艾灸是针灸治疗的重要组成部分, 临床各科病症的治疗, 无论寒、热、虚、实证均可使用艾灸, 故有“灸治百病”之说。艾灸包括普通灸法(艾条灸、隔物灸等)、特殊灸法(麦粒灸、雷火灸等)和热敏灸。

3.1 普通灸法和特殊灸法的中枢镇痛机制

普通灸法通常使用艾条灸或隔物灸, 特殊灸法种类繁多、手法独特, 在疾病治疗过程中较普通灸法更具有针对性, 是古今医者临床经验与灸法结合的智慧结晶。研究表明艾灸后原发性痛经患者右侧梭状回、左侧角回、左侧背外侧额上回、右侧中央旁小叶、左侧眶部额上回、左侧枕下回、左侧颞中回、右侧枕中回的 ReHo 值发生变化^[38]; 额叶、颞叶、岛叶、后扣带回等脑区的 ALFF 显著增高, 小脑、额叶、枕叶的 ALFF 显著降低^[39]。这说明艾灸镇痛疗效与大脑的神经营控密切相关。Zhu 等^[40]对腹泻型肠易激综合征患者进行隔附子饼灸后, 运用 fMRI 技术分析发现, 艾灸前被激活的前额叶和前扣带皮层激活消失, 说明艾灸可提高患者的排便冲动阈值和痛觉阈值, 并降低直肠球囊扩张后的疼痛评分。傅海扬等基于 fMRI 技术对比针刺与麦粒灸足三里穴发现, 针刺足三里穴可见双侧运动皮层的激活, 同时引起丘脑边缘系统广泛的负激活, 及双侧额叶、颞叶的负激活, 麦粒灸足三里穴可引起双侧额叶显著激活, 说明针刺与艾灸在作用机制上可能各有侧重^[41]。尽管该研究缺乏病理对照组, 但仍提示针刺与艾灸所引发的脑效应存在差异。徐道明等的研究发现, 原发性骨质疏松症疼痛(primary osteoporosis pain, POPP)存在“中枢致病学说”

机制,而雷火灸对 POPP 患者的岛叶、海马体等脑区产生了积极调节作用^[42]。艾灸治疗通常不会直接接触患者皮肤,故而不会对患者造成侵入性的伤害。通过艾热对腧穴进行刺激,在临床上可达到显著镇痛效果。

3.2 热敏灸的中枢镇痛机制

热敏灸是对传统艾灸的继承与升华。通过在艾灸中配合特定的探寻手法,若患者出现穴位透热、扩热、传热、局部不(微)热远部热、表面不(微)热深部热或非热感等以上一种或多种感觉,即可判定该腧穴热敏化。在施以足够灸量后,热敏灸感又会逐渐消失。热敏灸弥补了一般灸法常缺乏的“得气”感,因其临床疗效显著而被广泛应用。谢洪武^[43]和罗强等^[44]采用热敏灸治疗膝骨性关节炎(knee osteoarthritis, KOA)患者左侧犊鼻穴,配合 fMRI 技术分析发现 KOA 患者右大脑、外核、左小脑、左大脑、白质区的 ALFF 值较灸前明显升高,而中央前回、额叶、枕叶的 ALFF 值降低,丘脑、外核、顶叶脑区的 ReHo 值较灸前显著升高,而右大脑、左大脑、额叶的 ReHo 值降低。结果表明热敏灸疗效优于一般艾灸法,对 KOA 患者的镇痛治疗更有优势。熊俊等的研究发现,对痛经患者的关元穴进行热敏灸镇痛即刻效应显著,患者额上回、楔前叶、后扣带回、角回、颞中回、颞上回等脑区 FC 显著增强^[45]。在中医学的发展历程中,相比针刺,艾灸略显式微^[46]。田鹿等的研究显示,热敏灸通过调节 KOA 患者额叶、颞叶、枕叶等与认知、情感功能相关脑区的神经活动,从而实现镇痛的效果^[47]。

4 针刺与艾灸镇痛的中枢响应差异

针刺以局部刺激为基础,通过外周神经向中枢传递,经过中枢系统的加工和整合,实现整体调控镇痛的目的。根据刺激的穴位、操作手法的不同,针刺对脑区的镇痛效应机制也不同。对比如参与体感、运动、视觉、认知以及情绪等调控的脑区行针时,捻转法产生的负激活效应更明显,而提插法激活的脑区更广泛^[48]。电针不依赖复杂的行针手法,可以直接通过调节参数快速达到“得气”状态而提高疗效。相比毫针刺法,电针激活脑区范围更广,且有特异性的脑区抑制效应^[49-50]。

艾灸通过热刺激实施非侵入性治疗,可以调节脑部神经元的异常活动并重塑脑区之间的 FC,

这也从理论层面揭示了艾灸镇痛的中枢神经调控机制^[42, 51-53]。相较于普通艾灸,热敏灸在进行中枢神经调控时,对眶部额上中回—额中回—背外侧额上回矩阵的 FC 增强更为显著,对扣带脑回—丘脑—舌回—中央后回矩阵的 FC 抑制更明显^[43]。尽管热敏灸和非热敏灸存在差异,但是又存在不可分割的关联,两种灸法引起的脑区变化和脑网络连接存在着交叉重叠。

灸法在临床常与针刺联合使用,二者相互补充,相辅相成。针刺与艾灸的刺激方式不同,是否会引起中枢神经调控的差异成为研究关注的重点。研究表明中枢神经调控的镇痛机制是通过抑制边缘—旁边缘—皮层系统,从而激活躯体感觉皮层^[54]。不同操作方式的针刺与艾灸均能通过特定的刺激方式发挥镇痛作用。它们在中枢神经调控机制上既有差异,也有联系。这些差异体现在大脑对感觉、认知、情绪等功能进行调控的维度和强度上,另一方面,针刺和艾灸均通过对腧穴的刺激影响大脑皮层的神经元活动和脑区功能网络连接,进而改变疼痛信号的传递并发挥镇痛作用^[55]。大脑在静息态下能呈现出具有组织性和连贯性的功能网络,也称默认网络(default mode network, DMN)。疼痛默认网络在 DMN 的基础上,将大脑对疼痛的感知、疼痛调节和抑制以及对慢性疼痛的响应进行关联,形成了一个参与疼痛信息处理和整合的神经网络^[56]。fMRI 研究通过软件计算将大脑信号转化为数据,数据的变化可以客观反映脑区兴奋度和自发神经元活动情况^[57]。针刺与艾灸在临床治疗时的中枢响应特征在 fMRI 成像任务态和静息态中会呈现互补倒置的关系^[58]。具体而言,针刺和艾灸的中枢响应特征类似,针刺侧重于减少心理和环境因素对疼痛症状的影响,艾灸则侧重通过减轻疼痛症状调节精神和心理状态。

5 总结与展望

fMRI 成像技术为研究针灸神经调控机制提供了新的视角和思路,也为深入探讨针灸镇痛的神经理论调控机制提供了技术支持。目前针灸治疗在临床操作过程处方和手法缺乏统一标准,相关针灸治疗的 fMRI 研究缺乏多中心、大规模的随机对照临床试验。尤其在艾灸研究方面,可查阅的文献有限,且存在实验设计简单、纳入研究质量偏

低等问题。此外, 针灸治疗的 fMRI 研究也存在研究设计不严谨、样本量较小的问题, 进而导致研究偏倚风险增加。

fMRI 技术的研究同样存在实验设计不统一、实验条件差异性大及样本量小等问题。尽管这项技术以高分辨率的优势使针灸神经调控机制研究直观化, 但是血氧水平依赖信号仅能反映神经元活动时局部的血氧水平变化, 而与神经元活动之间缺乏联系, 这可能限制相关研究未来的发展空间。

为进一步完善针灸神经调控机制的 fMRI 研究, 未来可从以下几方面加以改进: 一是建立统一的操作规程, 避免混杂因素对研究结果的影响; 二是尝试将静息态脑功能磁共振成像 (resting-state functional magnetic resonance imaging, rs-fMRI) 与脑电图 (electroencephalogram, EEG) 和脑磁图 (magnetoencephalography, MEG) 相结合, 使 rs-fMRI 的高时空分辨率与 EEG、MEG 的高时间分辨率实现优势互补; 三是开展设计严谨的临床研究, 扩大样本量, 为深入探讨艾灸神经调控机制提供数据支持。

参考文献

- 1 赵吉平, 李瑛. 针灸学 (第 4 版) [M]. 北京: 人民卫生出版社, 2021, 1-6.
- 2 乔海法. 新技术是实现针灸现代研究突破的加速器 [J]. 针刺研究, 2025, 50(5): 526-530. [Qiao HF. New technologies serve as accelerators for breakthroughs in modern acupuncture research[J]. Acupuncture Research, 2025, 50(5): 526-530.] DOI: [10.13702/j.1000-0607.20250380](https://doi.org/10.13702/j.1000-0607.20250380).
- 3 高珍, 崔梦洁, 王海军, 等. 基于影像转录组学颈痛慢性化的中枢跨尺度机制研究 [J]. 磁共振成像, 2025, 16(3): 18-23. [Gao Z, Cui MJ, Wang HJ, et al. Investigation of central cross-scale mechanisms in the chronification of neck pain via imaging transcriptomics[J]. Chinese Journal of Magnetic Resonance Imaging, 2025, 16(3): 18-23.] DOI: [10.12015/issn.1674-8034.2025.03.003](https://doi.org/10.12015/issn.1674-8034.2025.03.003).
- 4 任圆圆, 刘胜. 针灸在乳腺癌化疗不良反应的应用及机制研究 [J]. 中国全科医学, 2025. [Ren YY, Liu S. Application and mechanism of acupuncture in adverse reactions to chemotherapy for breast cancer[J]. Chinese General Practice, 2025.] <https://link.cnki.net/urlid/13.1222.R.20250416.1511.010>
- 5 徐佐宇, 李昂, 李晓陵, 等. 针刺大钟穴激活脑区的功能 MRI 研究 [J]. 磁共振成像, 2014, 5(5): 332-335. [Xu ZY, Li A, Li XL, et al. A fMRI study of cerebral regions activated by acupuncture of Dazhong acupoint[J]. Chinese Journal of Magnetic Resonance Imaging, 2014, 5(5): 332-335.] DOI: [10.3969/j.issn.1674-8034.2014.05.003](https://doi.org/10.3969/j.issn.1674-8034.2014.05.003).
- 6 曹丹娜, 张帆, 王丰, 等. 老年抑郁症患者针刺右侧太冲穴前后静息态功能磁共振的局部一致性变化 [J]. 山东医药, 2019, 59(29): 9-11, 15. [Cao DN, Zhang F, Wang F, et al. Changes of ReHo of r-fMRI before and after acupuncture at right Taichong point in elderly patients with depression[J]. Shandong Medical Journal, 2019, 59(29): 9-11, 15.] DOI: [10.3969/j.issn.1002-266X.2019.29.003](https://doi.org/10.3969/j.issn.1002-266X.2019.29.003).
- 7 曾祥新, 冯楚文, 张沐华, 等. 基于功能磁共振探讨调神法电针治疗慢性疲劳综合征伴焦虑抑郁共病的中枢机制 [J]. 中国针灸, 2024, 44(1): 3-11. [Zeng XX, Feng CW, Zhang MH, et al. Exploring the central mechanism of mind-regulation electroacupuncture in treatment of chronic fatigue syndrome with anxiety and depression comorbidity based on functional magnetic resonance imaging[J]. Chinese Acupuncture & Moxibustion, 2024, 44(1): 3-11.] DOI: [10.13703/j.0255-2930.20230603-k0003](https://doi.org/10.13703/j.0255-2930.20230603-k0003).
- 8 闫立平, 孙忠人, 谢兵, 等. 电针曲池穴脑功能性磁共振成像的表现 [J]. 针灸临床杂志, 2005, 21(3): 61-63. [Yan LP, Sun ZR, Xie B, et al. fMRI manifestations of electroacupuncture stimulation at LI11 (QuChi acupoint)[J]. Journal of Clinical Acupuncture and Moxibustion, 2005, 21(3): 61-63.] DOI: [10.3969/j.issn.1005-0779.2005.03.045](https://doi.org/10.3969/j.issn.1005-0779.2005.03.045).
- 9 曹平, 陆加明, 陈钱, 等. 基于静息态功能磁共振成像研究 SCD 患者脑功能损伤与空间导航障碍的相关性 [J]. 临床放射学杂志, 2022, 41(8): 1402-1407. [Cao P, Lu JM, Chen Q, et al. Investigation of the correlations between brain functional impairment and spatial navigation deficits in patients with SCD based on resting-state functional magnetic resonance imaging[J]. Journal of Clinical Radiology, 2022, 41(8): 1402-1407.] DOI: [10.13437/j.cnki.jcr.2022.08.008](https://doi.org/10.13437/j.cnki.jcr.2022.08.008).
- 10 Pang Y, Liu HM, Duan GX, et al. Altered brain regional homogeneity following electro-acupuncture stimulation at Sanyinjiao(SP6) in women with premenstrual syndrome[J]. Front Hum Neurosci, 2018, 12: 104. DOI: [10.3389/fnhum.2018.00104](https://doi.org/10.3389/fnhum.2018.00104).
- 11 汤根华, 熊俊, 廖凯, 等. 脑功能连接分析在针灸脑机制研究中的应用进展 [J]. 中医临床研究, 2023, 15(9): 63-67. [Tang GH, Xiong J, Liao K, et al. A review on the application of brain functional connection analysis in the study of brain mechanism of acupuncture and moxibustion[J]. Clinical Journal of Chinese Medicine, 2023, 15(9): 63-67.] DOI: [10.3969/j.issn.1674-7860.2023.09.014](https://doi.org/10.3969/j.issn.1674-7860.2023.09.014).
- 12 张静莎, 张磊, 朱艳, 等. 基于磁共振成像阐释电针百会、印堂的抗抑郁机制 [J]. 世界中医药, 2023, 18(20): 2953-2958. [Zhang JS, Zhang L, Zhu Y, et al. Mechanism of electroacupuncture at Baihui(GV20) and Yintang(EX-HN3) in treating depression based on magnetic resonance imaging[J]. World Chinese Medicine, 2023, 18(20): 2953-2958.] DOI: [10.3969/j.issn.1673-7202.2023.20.017](https://doi.org/10.3969/j.issn.1673-7202.2023.20.017).
- 13 方继良, 荣培晶, 刘波. 现代脑功能磁共振诠释传统针刺机制 [J]. 磁共振成像, 2020, 11(2): 81-83. [Fang JL, Rong PJ, Liu B, et al. Modern fMRI exploring the neuromechanism of traditional acupuncture[J]. Chinese Journal of Magnetic Resonance Imaging, 2020, 11(2): 81-83.] DOI: [10.12015/issn.1674-8034.2020.02.001](https://doi.org/10.12015/issn.1674-8034.2020.02.001).
- 14 李晓陵, 王敬贤, 李昂, 等. 基于 fMRI 任务态与静息态对头针

- 疗法的研究进展[J]. 磁共振成像, 2021, 12(2): 98–100, 112. [Li XL, Wang JX, Li A, et al. Advances in brain fMRI research of scalp acupuncture therapy[J]. Chinese Journal of Magnetic Resonance Imaging, 2021, 12(2): 98–100, 112.] DOI: [10.12015/issn.1674-8034.2021.02.024](https://doi.org/10.12015/issn.1674-8034.2021.02.024).
- 15 Farver CM. The farver–campos labor coping scale as a replacement for the 10–point pain scale for labor[J]. J Perinat Educ, 2024, 33(1): 26–37. DOI: [10.1891/JPE-2022-0034](https://doi.org/10.1891/JPE-2022-0034).
- 16 Soni A, Wanigasekera V, Mezue M, et al. Central sensitization in knee osteoarthritis: relating presurgical brainstem neuroimaging and painDETECT–Based patient stratification to arthroplasty outcome[J]. Arthritis Rheumatol, 2019, 71(4): 550–560. DOI: [10.1002/art.40749](https://doi.org/10.1002/art.40749).
- 17 Hok P, Strauss S, Mcauley J, et al. Functional connectivity in complex regional pain syndrome: a bicentric study[J]. Neuroimage, 2024, 301: 120886. DOI: [10.1016/j.neuroimage.2024.120886](https://doi.org/10.1016/j.neuroimage.2024.120886).
- 18 Mürner–Lavanchy I, Kao Ht, Sele S, et al. Prefrontal oxygenation during experimental pain in adolescents engaging in non–suicidal self–injury[J]. J Affect Disord, 2024; 370: 100–108. DOI: [10.1016/j.jad.2024.10.076](https://doi.org/10.1016/j.jad.2024.10.076).
- 19 Flood A, Cavaleri R, Chang WJ, et al. Non–invasive brain stimulation beyond the motor cortex: a systematic review and meta–analysis exploring effects on quantitative sensory testing in clinical pain[J]. Pain Med, 2025, 26(2): 98–111. DOI: [10.1093/pm/pnae103](https://doi.org/10.1093/pm/pnae103).
- 20 Branco P, Bosak N, Vigotsky AD, et al. Hippocampal functional connectivity after whiplash injury is linked to the development of chronic pain[J]. Nat. Mental Health, 2024, 2: 1362–1370. DOI: [10.1038/s44220-024-00329-8](https://doi.org/10.1038/s44220-024-00329-8).
- 21 Kim DH, Jascimento TD, Lim M, et al. Exploring HD–tDCS effect on μ –opioid receptor and pain sensitivity in temporomandibular disorder: a pilot randomized clinical trial study[J]. J Pain, 2024, 25(4): 1070–1081. DOI: [10.1016/j.jpain.2023.11.001](https://doi.org/10.1016/j.jpain.2023.11.001).
- 22 Eto K, Cheung DL, Nabekura J. Sensory processing of cutaneous temperature in the peripheral and central nervous system[J]. Adv Exp Med Biol, 2024, 1461: 127–137. DOI: [10.1007/978-981-97-4584-5_9](https://doi.org/10.1007/978-981-97-4584-5_9).
- 23 Liberati G, Algoet M, Santos SF, et al. Tonic thermosensitive stimulation selectively modulates ongoing neural oscillations in the human posterior insula: evidence from intracerebral EEG[J]. Neuroimage, 2019, 188: 70–83. DOI: [10.1016/j.neuroimage.2018.11.059](https://doi.org/10.1016/j.neuroimage.2018.11.059).
- 24 Zhuang J, Fei L, Li H, et al. Anatomical–electroclinical phenotypes and SEEG–defined network patterns in pure insular lobe epilepsy: a study of 20 cases[J]. Epilepsy Res, 2025, 215: 107558. DOI: [10.1016/j.eplepsyres.2025.107558](https://doi.org/10.1016/j.eplepsyres.2025.107558).
- 25 Liu J, Zhang BL, Cui FY, et al. Scalp acupuncture targets for neurological disorders: evidence from neuroimaging studies (part 2)[J]. Zhen Ci Yan Jiu, 2024, 49(7): 777–786. DOI: [10.13702/j.1000-0607.20230016](https://doi.org/10.13702/j.1000-0607.20230016).
- 26 Li C, Hu Q, Zhang D, et al. Neural correlates of affective control regions induced by common therapeutic strategies in major depressive disorders: an activation likelihood estimation meta–analysis study[J]. Neurosci Biobehav Rev, 2022, 137: 104643. DOI: [10.1016/j.neubiorev.2022.104643](https://doi.org/10.1016/j.neubiorev.2022.104643).
- 27 Wang N, Zhang YH, Wang JY, et al. Current understanding of the involvement of the insular cortex in neuropathic pain: a narrative review[J]. Int J Mol Sci, 2021, 22(5): 2648. DOI: [10.3390/ijms22052648](https://doi.org/10.3390/ijms22052648).
- 28 Hagedorn JM, Falowski SM, Blomme B, et al. Burst spinal cord stimulation can attenuate pain and its affective components in chronic pain patients with high psychological distress: results from the prospective, international triumph study[J]. Spine J, 2022, 22(3): 379–388. DOI: [10.1016/j.spinee.2021.08.005](https://doi.org/10.1016/j.spinee.2021.08.005).
- 29 王浩, 王珑. 功能磁共振成像技术在针灸治疗抑郁症中枢机制研究中的应用进展[J]. 磁共振成像, 2023, 14(9): 103–107, 164. [Wang H, Wang L. Application of fMRI in the study of central mechanism of acupuncture and moxibustion in the treatment of depression[J]. Chinese Journal of Magnetic Resonance Imaging, 2023, 14(9): 103–107, 164.] DOI: [10.12015/issn.1674-8034.2023.09.019](https://doi.org/10.12015/issn.1674-8034.2023.09.019).
- 30 Lopes Alves R, Zortea M, Mayor D, et al. Effect of different frequencies of transcutaneous electrical acupoint stimulation (TEAS) on EEG source localization in healthy volunteers: a semi–randomized, placebo–controlled, crossover study[J]. Brain Sciences, 2025, 15(3): 270. DOI: [10.3390/brainsci15030270](https://doi.org/10.3390/brainsci15030270).
- 31 Di Carlo M, Beci G, Cipolletta E, et al. Predicting acupuncture efficacy in fibromyalgia: results of a pragmatic open–label study[J]. Clinical and experimental rheumatology, 2023(6): 41(6): 1254–1261. DOI: [10.55563/clinexprheumatol/1xr38b](https://doi.org/10.55563/clinexprheumatol/1xr38b).
- 32 赵彦琳, 黄木华, 章勇, 等. 椎间盘突出所致下腰痛患者后扣带回功能连接的静息态功能磁共振成像研究[J]. 临床放射学杂志, 2019, 38(6): 992–997. [Zhao YL, Huang MH, Zhang Y, et al. Posterior cingulate cortex functional connectivity in patients with low back–related leg pain due to herniated disk: a resting state magnetic resonance imaging analysis[J]. Journal of Clinical Radiology, 2019, 38(6): 992–997.] DOI: [10.13437/j.cnki.jcr.2019.06.012](https://doi.org/10.13437/j.cnki.jcr.2019.06.012).
- 33 王杏平, 蔡雲娟, 徐柏林, 等. 针灸治疗中风的量效关系研究现状探析[J]. 中医临床研究, 2023, 15(13): 86–91. [Wang XP, Cai YJ, Xu BL, et al. Study on the dose–effect relationship in treating stroke by acupuncture[J]. Clinical Journal of Chinese Medicine, 2023, 15(13): 86–91.] DOI: [10.3969/j.issn.1674-7860.2023.13.017](https://doi.org/10.3969/j.issn.1674-7860.2023.13.017).
- 34 赖淑华, 范志勇, 赵家友, 等. 旋转手法治疗对腰椎间盘突出症患者静息态脑功能的影响[J]. 新中医, 2017, 49(7): 96–98. [Lai SH, Fan ZY, Zhao JY, et al. effect of rotatory manipulation on brain function in resting state in patients with lumbar disc herniation[J]. New Chinese Medicine, 2017, 49(7): 96–98.] DOI: [10.13457/j.cnki.jncm.2017.07.032](https://doi.org/10.13457/j.cnki.jncm.2017.07.032).
- 35 俞燕丽, 程梦蝶, 马敏, 等. 薄氏腹针疗法对卒中后认知功能障碍患者脑静息态 fMRI 影响[J]. 上海针灸杂志, 2021, 40(11): 1293–1298. [Yu YL, Cheng MD, Ma M, et al. Effect of Bo's abdominal acupuncture therapy on the resting–state fMRI in patients with cognitive impairment after stroke[J]. Shanghai Journal

- of Acupuncture and Moxibustion, 2021, 40(11): 1293–1298.] DOI: [10.13460/j.issn.1005-0957.2021.11.1293](https://doi.org/10.13460/j.issn.1005-0957.2021.11.1293).
- 36 陈鹏, 王忠艳, 刘璐, 等. 基于静息态功能磁共振探讨火针点刺颅底穴位配合体针治疗对帕金森病伴抑郁患者的中枢影响[J]. 北京中医药, 2021, 40(12): 1325–1329. [Chen P, Wang ZY, Liu L, et al. Discussion on the central influence of fire acupuncture at skull base combined with body acupuncture on patients with Parkinson's disease accompanied with depression based on resting state functional magnetic resonance imaging(fMRI)[J]. Beijing Journal of Traditional Chinese Medicine, 2021, 40(12): 1325–1329.] DOI: [10.16025/j.1674-1307.2021.12.005](https://doi.org/10.16025/j.1674-1307.2021.12.005).
 - 37 何永强. 头针结合靳氏肩三针治疗中风后肩手综合征 1 期的临床疗效及 BOLD-fMRI 机制探讨[D]. 辽宁中医药大学, 2022. [He YQ. Clinical efficacy of scalp acupuncture combined with Jin's Shoulder Three Needles in treating stage 1 post-stroke shoulder-hand syndrome and exploration of bold-fmri mechanisms[D]. Liaoning University of Traditional Chinese Medicine, 2022.] DOI: [10.27213/d.cnki.glnzc.2022.000014](https://doi.org/10.27213/d.cnki.glnzc.2022.000014).
 - 38 张亚男, 刘妮, 郝瑛, 等. 原发性痛经患者半球间镜像同伦功能连接的静息态 fMRI 研究[J]. 磁共振成像, 2020, 11(10): 872–876. [Zhang YN, Liu N, Hao Y, et al. The resting-state fMRI study of interhemispheric voxel-mirrored homotopic connectivity in patients with primary dysmenorrhea[J]. Chinese Journal of Magnetic Resonance Imaging, 2020, 11(10): 872–876.] DOI: [10.12015/issn.1674-8034.2020.10.008](https://doi.org/10.12015/issn.1674-8034.2020.10.008).
 - 39 宋云娥, 徐放明, 唐成林, 等. 原发性痛经患者关元穴艾灸前后的静息态功能磁共振研究[J]. 重庆医科大学学报, 2012, 37(9): 753–758. [Song YE, Xu FM, Tang CL, et al. Moxibustion of Guanyuan point for primary dysmenorrhea: a resting state functional magnetic resonance imaging study[J]. Journal of Chongqing Medical University, 2012, 37(9): 753–758.] DOI: [10.3969/j.issn.0253-3626.2012.09.002](https://doi.org/10.3969/j.issn.0253-3626.2012.09.002).
 - 40 Zhu Y, Wu Z, Ma X, et al. Brain regions involved in moxibustion-induced analgesia in irritable bowel syndrome with diarrhea: a functional magnetic resonance imaging study[J]. BMC Complement Altern Med, 2014, 14: 500. DOI: [10.1186/1472-6882-14-500](https://doi.org/10.1186/1472-6882-14-500).
 - 41 傅海扬, 殷长俊, 张志强, 等. 针刺与麦粒灸足三里穴的 fMRI 成像差异研究[J]. 江苏中医药, 2013, 45(1): 54–56. [Fu HY, Yin CJ, Zhang ZQ, et al. Study on differences in fMRI imaging between acupuncture and grain-sized moxibustion at Zusanli[J]. Jiangsu Journal of Traditional Chinese Medicine, 2013, 45(1): 54–56.] https://kns.cnki.net/kcms2/article/abstract?v=UThtwiquHbeoqIgTGvRmbellbwkVRtx-pVowDaBnga7A4BnWNMQXemzbXXIvfnHeJwLyvj1ss9dUHjsgApLdkKA0LGoHJlcS6yaAWJ0gmWb4TEJ83tC1yrex30KIZJf-FcIxcBrmFOR9nggWmY42f0hKWSEmyKiOGnQ8vTxUeLxZF_xYxFEsig=&uniplatform=NZKPT&language=CHS
 - 42 徐道明, 朱璐, 刘永康, 等. 雷火灸对原发性骨质疏松症腰背疼痛患者自发性脑活动影响的观察[J]. 中国骨质疏松杂志, 2021, 27(9): 1298–1302. [Xu DM, Zhu L, Liu YK, et al. The effect of thunder-fire moxibustion on spontaneous brain activity in primary osteoporosis patients with low back pain[J]. Chinese Journal of Osteoporosis, 2021, 27(9): 1298–1302.] DOI: [10.3969/j.issn.1006-7108.2021.09.011](https://doi.org/10.3969/j.issn.1006-7108.2021.09.011).
 - 43 谢洪武. 基于功能磁共振技术研究膝骨性关节炎患者慢性疼痛及热敏点艾灸镇痛的中枢机制[D]. 北京: 北京大学医学部, 2022. [Xie HW. Central mechanisms of chronic pain and moxibustion-induced analgesia in patients with knee osteoarthritis: a resting fMRI study[J]. Beijing: Peking University Health Science Center, 2022.] DOI: [10.44277/d.cnki.gbdyx.2022.000005](https://doi.org/10.44277/d.cnki.gbdyx.2022.000005).
 - 44 罗强, 谢洪武, 徐放明, 等. 热敏灸膝骨性关节炎患者犊鼻穴的静息态功能磁共振研究[J]. 北京中医药大学学报, 2013, 36(6): 429–432. [Luo Q, Xie HW, Xu FM, et al. Study on resting-state functional magnetic resonance imaging in patients with knee osteoarthritis treated with heat-sensitive moxibustion on Dubei acupoint[J]. Journal of Beijing University of Traditional Chinese Medicine, 2013, 36(6): 429–432.] DOI: [10.3969/j.issn.1006-2157.2013.06.016](https://doi.org/10.3969/j.issn.1006-2157.2013.06.016).
 - 45 熊俊, 项洁, 徐绍忠, 等. 艾灸原发性痛经患者热敏关元穴即刻效应的脑岛脑功能连接研究[J]. 时珍国医国药, 2023, 34(7): 1789–1792. [Xiong J, Xiang J, Xu SZ, et al. Study on immediate effects of moxibustion at Heat-Sensitive Guanyuan (CV4) on insular functional connectivity in patients with primary dysmenorrhea[J]. Journal of Li-shizhen Traditional Chinese Medicine, 2023, 34(7): 1789–1792.] DOI: [10.3969/j.issn.1008-0805.2023.07.72](https://doi.org/10.3969/j.issn.1008-0805.2023.07.72).
 - 46 周纹希, 任培中, 陆凤燕. 近十年针灸治疗呼吸系统疾病研究现状及趋势的可视化分析[J]. 中国针灸, 2025, 45(6): 841–850. [Zhou WX, Ren PZ, Lu FY, et al. Visual analysis of the research status and trends in acupuncture and moxibustion treatment for respiratory diseases in the past decade[J]. Chinese Acupuncture & Moxibustion, 2025, 45(6): 841–850.] DOI: [10.13703/j.0255-2930.2024.1125-k0007](https://doi.org/10.13703/j.0255-2930.2024.1125-k0007).
 - 47 田鹿, 谢洪武, 刘梅花, 等. 热敏灸治疗膝关节关节炎患者 60 例临床观察[J]. 中医杂志, 2025, 66(5): 492–500. [Tian L, Xie HW, Liu MH, et al. Clinical observation on 60 cases of knee osteoarthritis treated with heat-sensitive moxibustion[J]. Journal of Traditional Chinese Medicine, 2025, 66(5): 492–500.] DOI: [10.13288/j.11-2166/r.2025.05.010](https://doi.org/10.13288/j.11-2166/r.2025.05.010).
 - 48 高德强, 张东友, 崔炳南, 等. 针刺脑效应功能磁共振成像研究进展[J]. 中华中医药杂志, 2019, 34(4): 1328–1330. [Gao DQ, Zhang DY, Cui BN, et al. Review on functional magnetic resonance imaging research for effect of acupuncture[J]. China Journal of Traditional Chinese Medicine and Pharmacy, 2019, 34(4): 1328–1330.] <https://d.wanfangdata.com.cn/periodical/CiFQXJpb2RpY2FsQ0hJU29scjJTMjAyNTUwMjEwOTUwNDYSD3pneXl4YjIwMTkwNDAwNRoLenl0cjFibGY%3D>
 - 49 李香淑, 胡佳慧, 鲁海, 等. 基于 fMRI 技术探讨电针与手针中枢机制响应差异[J]. 分子影像学杂志, 2020, 43(1): 12–15. [Li XS, Hu JH, Lu H, et al. Response difference between electroacupuncture and manual acupuncture based on fMRI technology[J]. Journal of Molecular Imaging, 2020, 43(1): 12–15.] DOI: [10.12122/j.issn.1674-4500.2020.01.03](https://doi.org/10.12122/j.issn.1674-4500.2020.01.03).
 - 50 田鹿, 武晨, 陈燕玲, 等. 电针神经调控作用机制的功能磁共振成像研究进展[J]. 临床放射学杂志, 2025, 44(6): 1136–1139.

- [Tian L, Wu C, Chen YL, et al. Advances in functional magnetic resonance imaging research on the neuromodulation mechanisms of electroacupuncture[J]. Journal of Clinical Radiology, 2025, 44(6): 1136–1139.] DOI: [10.13437/j.cnki.jcr.2025.06.030](https://doi.org/10.13437/j.cnki.jcr.2025.06.030).
- 51 Yang J, Xiong J, Xu SZ, et al. Effect and cerebral mechanism of moxibustion at heat-sensitized Yaoyangguan (GV3) in patients with lumbar disc herniation and myofascial pain syndrome by resting-state functionality magnetic resonance imaging: protocol for an observational study[J]. J Tradit Chin Med, 2023, 43(1): 175–180. DOI: [10.19852/j.cnki.jtcm.20221006.002](https://doi.org/10.19852/j.cnki.jtcm.20221006.002).
 - 52 Zhang Q, Liang L, Lai Z, et al. Altered regional homogeneity following moxibustion in mild cognitive impairment[J]. Brain imaging and behavior, 2024, 18(2): 343–351. DOI: [10.1007/s11682-023-00830-1](https://doi.org/10.1007/s11682-023-00830-1).
 - 53 Wong KKL, Xu J, Chen C, et al. Functional magnetic resonance imaging providing the brain effect mechanism of acupuncture and moxibustion treatment for depression[J]. Front Neurol, 2023, 14: 1151421. DOI: [10.3389/fneur.2023.1151421](https://doi.org/10.3389/fneur.2023.1151421).
 - 54 Kobrzycka AT, Stankiewicz AM, Napora P, et al. Bilateral subdiaphragmatic vagotomy modulates the peripheral met-enkephalin and striatal monoamine responses to peripheral inflammation in rat[J]. Acta Neurobiol Exp (Wars), 2023, 83(1): 84–96. DOI: [10.55782/ane-2023-009](https://doi.org/10.55782/ane-2023-009).
 - 55 Li Q, Xu HY, Li B, et al. Analysis of the differences in brain function response after acupuncture and moxibustion at Zusanli (ST 36) in the patients with functional dyspepsia based on fractional amplitude of low frequency fluctuation of rest functional magnetic resonance imaging[J]. World Journal of Acupuncture–Moxibustion, 2021, 31(3): 181–186. <https://doi.org/10.1016/i.wjam.2021.05.013>
 - 56 Sezer I, Pizzagalli DA, Sacchet MD. Resting-state fMRI functional connectivity and mindfulness in clinical and non-clinical contexts: a review and synthesis[J]. Neurosci Biobehav Rev, 2022, 135: 104583. DOI: [10.1016/j.neubiorev.2022.104583](https://doi.org/10.1016/j.neubiorev.2022.104583).
 - 57 Wang X, Liu X, Zhao L, et al. Local neuronal activity and the hippocampal functional network can predict the recovery of consciousness in individuals with acute disorders of consciousness caused by neurological injury[J]. CNS Neurosci Ther, 2024, 30(11): e70108. DOI: [10.1111/cns.70108](https://doi.org/10.1111/cns.70108).
 - 58 刘灿. 基于 fMRI 研究针刺与艾灸 FD 患者足三里穴即时中枢响应特征差异 [D]. 湖南中医药大学, 2017. [Liu C. Based on fMRI to explore the acupuncture and moxibustion st 36 hole central mechanism for the treatment of FD and the differences between them[D]. Hunan University of Chinese Medicine, 2017.] https://kns.cnki.net/kcms2/article/abstract?v=UThTwiqHbfarDObqxpRBhqvTS-JhKaaFv6gm7APvvLTRgR9hKsPu8pUccB1yV_MwRu6xQgUFzpPFFVv1cRz44VK2LC00o2th4nYmT0mSEDmSlnOI9S3KoUFluEBIDYftwacCbDHculiZimdSqEkIuR8KoE0vXvWJJnX6LY4troQhB8h01MI-QOlhO7ZI8LX&uniplatform=NZKPT&language=CHS
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