·综述·

磁共振成像在脊椎关节病诊断中的研究进展*
Research Progress of Magnetic Resonance Imaging in the Diagnosis of Spondyloarthritis*

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脊椎关节病(SpA)是一组以炎性腰背痛为核心特征的慢性炎症性风湿性疾病，涵盖了强直性脊柱炎、银屑病关节炎、肠炎性关节病等多种类型[1]。该疾病常首先影响骶髂关节，随后可能波及脊柱及周围关节[2-5]。磁共振成像(MRI)作为一种非侵入性且无辐射的成像技术[6]，以其在检测骶髂关节及脊柱炎性病变方面的高敏感性和特异性而受到广泛关注。MRI已被纳入国际脊椎关节炎协会的分类标准，成为评估病情活动性和治疗反应的重要工具。本文将探讨不同成像序列在脊椎关节病诊断中的最新研究进展。

1 T1、T2加权序列及短时反转恢复序列(STIR)在强直性脊柱炎早期诊断中的作用

磁共振成像(MRI)目前被认为是诊断脊柱关节病(SpA)患者早期是否存在轴向受累，即脊柱和骶髂关节的最佳影像学工具。传统的T1加权、T2加权序列以及短时反转恢复序列(STIR)分别用于评估结构性病变(如侵蚀和强直)与功能性病变(如炎性水肿)。T1加权序列在评估慢性结构变化时表现出良好的解剖对比，而FS-T2W和STIR在疾病严重程度的评估上具有一致性，且敏感性与特异性俱佳。Ozgen[7]的研究表明，T2WI-Dixon成像在诊断活动性与非活动性骶髂关节炎时，优于传统MRI序列，显示出更佳的对比度。

短时反转恢复序列(STIR)[6]是一种基于脂肪组织短T1特性设计的脂肪抑制序列。该序列不仅能有效抑制脂肪组织信号，同时也能部分抑制水信号，从而突显水肿病变的高信号，尤其是那些在传统MRI序列中难以识别的病灶。因此，STIR凭借其对游离水含量的高度灵敏性，成为目前唯一对磁场均匀性不敏感的脂肪抑制技术。有研究显示，STIR-MRI与临床活动度评分(ASDAS)及脊柱炎症之间存在正相关性[8-9]，进一步确认了其在评估中轴型脊柱关节炎(SpA)疾病活动度方面的独特价值。然而，由于其无法量化炎症，STIR的应用仍面临一定的局限性[10]。

2 DWI-MRI序列是一种可量化中轴型脊椎关节病(axSpA)疾病活动性的新方法

临床疾病活动度与炎症之间的关系尚存不确定性，且在很大程度上依赖于使用的成像序列。弥散加权成像(DWI)是较新的一种MRI序列，能够利用水分子的阻抗可视化骨髓的炎性改变(骨髓水肿)。通过去除伪影，DWI生成的表观扩散系数(ADC)图为炎症强度测量提供了更客观的指标[11]。研究表明[12-13]，DWI在定量疾病活动方面优于短时反转恢复序列(STIR)，尽管后者拥有较高的空间分辨率，能够更好地显示炎症范围，但其在炎症强度上的敏感性较差。以往的研究发现，ADC值与强直性脊柱炎(SpA)患者的C反应蛋白(CRP)相关[11]，并在活动性骶髂关节炎患者中显著升高。研究者Chung等[8]在大量axSpA患者中证实了DWI序列与脊柱炎症强度的关联，指出ADC可能成为axSpA患者疾病活动性的潜在生物标志物[14]。因此，在传统STIR成像中引入ADC的评估，显著增强了定量炎症的价值。然而，需要注意的是，当STIR图像上炎症信号强度较低时，ADC可能无法有效检测此类变化。

3 全身MRI(WB-MRI)检测周围炎症在中轴型脊椎关节病(axSpA)中的分布及诊断价值

全身不同部位的炎症发现对于脊椎关节病的诊断具有重要意义[15]。全身磁共振成像(WB-MRI)[16]由一系列高空间分辨率图像构成，视野(FOV)范围为25-50cm，通过图像融合形成全身图像。自二十年前首次引入临床以来，WB-MRI最初应用于肿瘤评估，如淋巴瘤、骨髓瘤及实体肿瘤转移，取得了与骨显像相似的优良效果。随着技术的不断进步，WB-MRI在炎症检测中的敏感性得到了显著提升，现已广泛应用于多个医学领域。

目前，磁共振成像(MRI)在风湿病学领域的应用日益广泛，尤其是在分析脊椎关节炎(AS)的早期阶段、随访以及治疗反应的评估方面。血清阴性的脊椎关节炎通常呈现腰背部僵硬疼痛和非对称性下肢关节肿痛等典型症状，而影像学特征则包括骨侵蚀、骨硬化以及向强直的发展，这些损伤主要局限于骶髂和脊柱纤维软骨关节，且可并发周围关节炎[17]。传统放射学方法因其较低的敏感性和特异性而常导致AS诊断的延误，进而影响基于特定影像学改变的治疗药物及时应用，例如TNF-α抑制剂[18-19]。相比之下，MRI能全面观察中轴骨骼，在早期发现骶髂炎和脊柱炎，从而为早期治疗提供了帮助。全身磁共振成像(WB-MRI)不仅能够识别骶髂关节表面的软骨下骨髓炎症，还能发现整个中轴骨的亚临床病变，尤其是在腰背部，从而显著提高了诊断的准确性。此外，后纵韧带和肋椎关节的受累高度提示强直性脊柱炎(AS)，而胸壁作为另一个重要的易受累区域，尤其容易涉及肋软骨关节、胸锁关节和胸骨关节。

全身磁共振成像技术能够全面评估周围小关节炎的分布情况，而周围性关节炎的存在则有助于脊椎关节炎的早期诊断[15]。基于现有技术的改进，WB-MRI有望实现更高效、准确的疾病检测与评估，为临床提供更为可靠的依据。

4 DCE-MRI在定量评估强直性脊柱炎骶髂关节的应用价值

动态增强磁共振成像(DCE-MRI)通过静脉注入钆对比剂后对特定层面进行连续T1加权成像，获得每一像素点的时间－信号曲线，从而反映对比剂在器官中的浓度动态变化。通过数学模型计算，可以得到定量参数，以评估病灶局部的生理和功能学改变。王娟等[20]的研究表明，在强直性脊柱炎炎性活动期，K^{trans}、K_{ep}和V_e三个参数均显著高于炎性静止期，显示出MRI在观察活动性炎症方面的敏感性。杨慧等[21]的研究则强调了定量DCE-MRI参数在评价骶髂关节早期微环境渗透性变化中的重要性，特别是K^{trans}作为强直性脊柱炎早期炎症活动的敏感指标，对临床医生采取有效干预措施具有重要意义。

5 多糖 (糖胺聚糖)化学交换饱和转移成像技术(GagCEST)在评估中轴骨关节炎疾病中的作用

GagCEST成像是一种基于糖胺聚糖(GAG)与水分子之间化学交换的MRI技术。该技术通过施加频率选择性的饱和脉冲，诱导溶质池中的饱和质子与自由水池中的不饱和质子进行交换，导致自由水池信号的降低。由于溶质池浓度较低，常规MRI难以直接观察，但不间断的饱和转移能够放大信号，使得低浓度的GAG信息得以检测。通过分析磁化转移比不对称性，研究者可以量化特定频率范围内的GAG浓度，进而形成椎间盘的相关磁共振功能成像。Daniel等[22]研究表明，强直性脊柱炎(AS)患者的GagCEST值显著低于健康志愿者，提示GAG消耗与病理状态密切相关。这些发现不仅揭示了软骨在AS中的病理生理作用，还表明GagCEST成像在评估轴骨关节炎相关病理表现中的潜在应用价值。

目前gagCEST成像技术在胸椎水平的应用面临挑战，主要因其易受运动伪影的影响，特别是呼吸伪影。此外，研究显示女性腰椎IVD中的蛋白多糖含量高于男性，而在对照组中女性比例较患者组更高，这可能对研究结果产生一定影响。然而，在采用包含“性别”因素的线性混合模型进行统计分析时，性别分布的差异对结果的影响较小。

6 骨成像在中轴型脊柱关节炎(axSpA)疾病中的运用及附加价值

尽管传统的序列在骨侵蚀监测中展现出较高的诊断价值[23]，但MRI常规序列在骨皮质成像方面存在局限性，主要因为其无法直接描绘低信号的皮质骨，需依赖骨、骨髓与软骨之间的对比。相比之下，X线和CT虽能直接成像骨骼，但会涉及辐射暴露且对活动性炎症的显示能力较弱，导致其在鉴别诊断中的特异性不足。目前，T1加权梯度回波序列(T1SGRE)[24]、超短回波时间序列(UTE)[25]、零回波时间序列(ZTE)[26]、"黑骨"序列[27]、MR-SWI[28]及MR-FRACTURE序列[29]等新技术已被应用于骨成像。研究表明，T1-SGRE和UTE在椎体骨折及退行性改变的形态学评估中具有良好的诊断性能，3D T1-SGRE图像的诊断准确性与CT相当，未来有望替代脊柱CT检查。此外，"黑骨"序列在儿童头部创伤的初步筛查中显示出可替代CT的潜力[30]。

近年来，磁敏感加权成像(MR-SWI)在骨皮质成像方面取得了显著进展，尤其在监测患者周围关节炎的骨质侵蚀[31]方面显示出其应用潜力。SWI通过检测和定量钙原子周围的小磁场不均匀性，能够直接描绘钙的结构[32]，并生成类似于CT的图像。这种成像技术已经被尝试用于评估骶髂关节(SIJ)的结构性损伤，包括侵蚀、硬化及关节间隙变化方面。Dominik等[28]首次利用SWI生成的类CT图像对68例疑似或已确诊的axSpA患者进行了研究，结果表明，相较于T1WI，SWI在描述骨侵蚀与硬化方面更为准确，进一步验证了其在临床应用中的价值。

MR-FRACTURE序列，亦称为sCT，是由JOHNSON等[29]提出的一种基于高分辨率三维梯度回波技术。该技术通过多个恒定回波间隔的回波和后处理减影，生成类似CT的图像。其关键在于记录多个固定间隔的回波，这些间隔对应于MR场强的同相TE(在3T时为2.3ms，1.5T时为4.6ms)。同相时间分辨率的应用有助于提高骨皮质和骨小梁的对比度，减少化学位移伪影，从而更清晰地描绘骨皮质信号并降低边缘模糊。此外，经过后处理步骤的FRACTURE序列能够显著提升骨皮质、骨髓及周围组织之间的对比度。国外文献表明，类CT图像在肩关节[33]和膝关节[34]等部位已获得有效的临床验证，能够有效展示骨皮质及骨小梁的结构。

基于MRI的合成CT(sCT)在评估轴性脊柱关节炎(axSpA)患者脊柱结构性骨损伤的研究中显示出显著成果。Morbee等[35]的研究表明，sCT在几何测量方面与传统CT具有相等性。此外，WILLESEN等[36]的研究在比较sCT、低剂量CT(IdCT)和X线摄影时发现，sCT在检测脊柱新骨形成及小关节病变方面展现出更高的灵敏度和特异性，其表现远超传统X线摄影，进一步支持了sCT作为一种有效的评估工具。

综上所述，随着核磁共振成像技术的不断进步[37]，其在脊椎关节病的早期诊断与治疗评估中扮演了重要角色[38]。与此同时，MRI骨成像能够提供与计算机断层扫描相似的图像[39]，从而更有效地评估脊椎关节病的结构变化，减少患者的辐射暴露。这一技术的改进无疑为患者的诊疗过程带来了积极的影响。

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