❖综述

Research progresses of 3D-ultrashort echo time MRI in evaluation on glenoid labrum

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[**Abstract**] Glenoid labrum is a key structure for maintaining cartilage homeostasis and the stability of the glenohumeral and hip joints, and early detection of its lesions is crucial. Due to the limitation of TE, conventional MR sequences is difficult to clearly display tissue signals with short transverse relaxation time of labrum. 3D-ultrashort echo time (UTE) sequence overcame the problem of signal attenuation in traditional sequence, making high-contrast imaging possible even with extremely short TE. The research progresses of 3D-UTE MRI in evaluation on glenoid labrum were reviewed in this article.
[**Keywords**] glenoid labrum; fibrocartilage; magnetic resonance imaging
DOI:10.13929/j.issn.1003-3289.2026.03.033

三维超短回波时间 MRI 评估盂唇研究进展

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[**摘　要**] 关节盂唇为维持软骨稳态和盂肱/髋关节稳定的关键结构,早期检出其病变十分重要。受 TE 限制,传统 MR 序列难以清晰显示盂唇组织短横向弛豫时间信号。三维超短回波时间(UTE)序列克服了传统序列信号衰减问题,能在极短 TE 下实现高对比度成像。本文就 3D-UTE MRI 评估盂唇研究进展进行综述。
[**关键词**] 盂唇;纤维软骨;磁共振成像
[**中图分类号**] R684;R445.2　[**文献标识码**] A　[**文章编号**] 1003-3289(2026)03-0479-04

盂唇是环绕关节盂外下缘的纤维软骨组织[1]。纤维软骨环在 MRI 中的 T2 极短、信号衰减迅速,传统梯度回波(gradient recalled echo, GRE)或自旋回波(spin echo, SE)序列表现为无/低信号;而盂唇在线圈接受信号前已衰减至近乎为零,导致难以清晰显像。盂唇损伤包括撕裂、撕脱/剥离、囊肿、钙化、骨化及肥厚/肿胀等[2-6],对精准成像形成更高要求(表 1)。3D-UTE 的 TE 极短(<0.1 ms)[14],可在信号衰减前精准捕捉盂唇,为评估盂唇病变提供了有效手段。本文就 3D-UTE MRI 用于评估盂唇研究进展进行综述。

1　盂唇病理及生物力学

盂唇有效增加关节窝表面积与深度,增强盂肱/髋关节稳定性,防止肱/股骨头等重要关节移位或脱位。急性外伤、运动过度、发育不良、关节脱位及骨关节炎均为盂唇损伤的常见原因[1,15]。盂唇由高活性纤维软骨细胞及其周围细胞外基质构成,后者主要包括胶原纤维、蛋白聚糖和水[16]。CO 等[17]研究发现,盂唇损伤后 $CD11b^+$ 细胞增加,继而产生白细胞介素-1β(interleukin-1β, IL-1β)和基质金属蛋白酶-13(matrix metalloproteinase-13, MMP-13)诱导基质降解酶释放,使盂唇发生黏液样变性、软骨细胞丢失和机械完整性降低,导致 T2 增加,在脂肪抑制序列中表现为体积增大、形态不规则及信号强度增加。在生物力学方面,盂唇与主要含Ⅱ型胶原纤维的软骨不同,其基质内高表

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[**收稿日期**] 2025-07-23　[**修回日期**] 2025-11-25

达致密粗大的Ⅰ型胶原纤维束并呈交织状排列;胶原纤维网中带负电荷的亲水大分子蛋白聚糖与Ⅰ型胶原纤维共同作用可使盂唇具有抵抗压缩负荷的能力[6]。

2　3D-UTE MRI 用于评估盂唇

2.1　优势与不足　受部分容积伪影及积液与软骨对比度限制,常规 MRI 显示盂唇微小结构易模糊而致漏、误诊(表 2)。亚毫米级别各向同性 3D-UTE MRI 采用半射频激发和径向 k 空间映射方式,无需选择层面或进行相位编码,将 TE 缩短至传统序列的 1/1 000～1/100[21]。

3D-UTE MRI 用于盂唇的主要优势[22-24]:①显示骨皮质和钙化软骨能力强,可评估盂唇基底部(盂唇-骨交界处)附着点是否完整、伴/不伴骨挫伤;②能显示纤维软骨基质,敏感检出基质内早期黏液样变性、软骨细胞丢失等变化;③增强盂唇信号,使盂唇撕裂等细微病变(尤其无积液渗入病变时)与正常盂唇组织产生足够的对比度。但以 3D-UTE MRI 用于评估盂唇亦存在不足:①极短 TE 将牺牲部分信号强度,导致图像整体信噪比(signal-to-noise ratio, SNR)降低;②盂唇信号增高将不可避免地造成其与中-高信号透明软骨和关节液的对比度下降;③为获得较高 SNR 和分辨率,需进行多次信号平均而致扫描时间延长。

2.2　3D-UTE MR 序列

2.2.1　3D-双回波减法 UTE(3D-dual echo subtraction UTE, 3D-dUTE-ES)序列　盂唇在常规序列 MRI 中呈无/低信号,故多根据渗入高信号积液评估撕裂等病变。UTE 可增强盂唇信号,但亦带来盂唇与积液信号相似、导致图像对比度下降等问题。3D-dUTE-ES 序列以双回波采集与回波减法相结合,能在一次射频脉冲激发后以 2 组 TE 获取不同自由感应衰减(free induction delay, FID)信号[25](图 1),并基于盂唇在短时间内快速衰减的特点(即盂唇与软骨、积液及脂肪在 2 组 TE 中的信号衰减程度不同)将采集到的 FID 信号相减,以充分抑制软骨及积液 T2 高信号,由此获得盂唇与周围组织的高对比度成像,但易受到磁化率效应影响而出现信号失真或变形[26]。

2.2.2　3D-绝热反转恢复 UTE(3D-adiabatic

表 1　盂唇病变病理与常规 MRI 表现

病变类型	病理改变	常规 MRI 表现
撕裂[7-8]	为较强机械力作用及盂唇相对供血不足所致	盂唇结构扭曲变形,T2WI 可见撕裂区高信号自盂唇实质延伸至盂唇表面
撕脱/剥离[1,9]	盂唇磨损后,滑液渗入盂唇与透明软骨间,逐渐向关节囊外周延伸,直至从盂缘完全剥离	盂唇软骨交界处可见高信号裂隙,盂唇与骨性盂边缘分离
盂唇旁囊肿[10-11]	滑液通过盂唇裂隙渗入关节周围软组织间隙并形成包膜,形成盂唇旁囊肿,可伴盂唇撕裂/剥离	盂唇旁见 T1WI 低-中信号、T2WI 高信号囊性肿块
钙化[3,12]	纤维软骨损伤导致盂唇细胞坏死凋亡,焦磷酸钙二水合物沉积诱导出现异常钙化结晶沉积	盂唇内呈边界相对清晰的低信号灶
骨化[4,13]	长期机械应力致基质内骨化相关基因表达上调,诱导盂唇组织骨化生而形成骨化灶	骨化灶信号强度与骨髓相似,呈 T1WI 高信号、T2WI 中-高信号
肥厚/肿胀[5-6]	盂唇胶原蛋白降解,纤维间基质肿胀	盂唇圆钝、膨大,T2WI 和质子密度加权成像表现为弥漫性信号增高

表 2　无症状人群盂唇 MRI 信号特征及其形成因素

信号	MRI 信号特征	MRI 信号形成因素
正常信号[18]	呈无信号或低弥漫性信号,边缘光整,形态多呈三角形/扁平状	符合盂唇纤维软骨组织磁敏感特性
异常信号[19-20]	出现异常中-高信号,形态不规则,边缘不清晰	①生理因素:盂唇发生黏液样变性,细胞外基质水合作用改变;存在纤维血管束,组织修复性增生;②解剖因素:盂唇相对菲薄;长骨近端呈曲面,MRI 存在多层面部分容积效应;③技术因素:盂唇旁隐窝形成,易与盂唇撕裂相混淆;魔角伪影,与胶原纤维排列有关

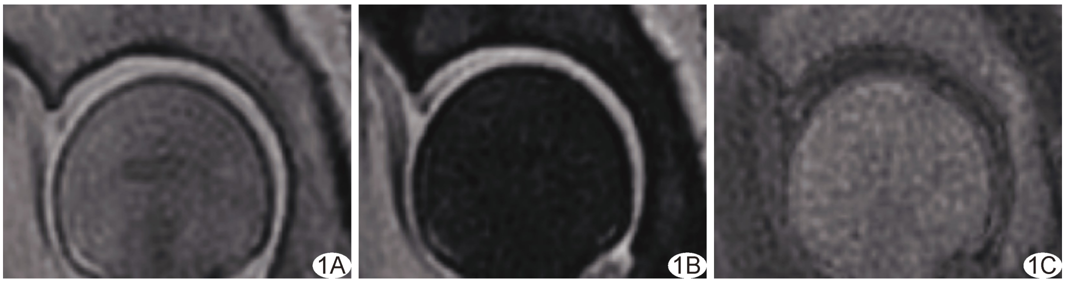

图 1　髋关节盂唇斜矢状 MR 3D-dUTE-ES 序列图像(图像来源于中国医科大学附属盛京医院,获伦理委员会批准[2024PS1838K(T1)])　A.以超短 TE(2.2 ms)采集时,盂唇(短 T2)、软骨及积液(长 T2)信号尚未衰减而呈高信号;B.以稍长 TE(4.8 ms)采集时,盂唇迅速衰减而呈低信号,软骨和积液信号缓慢衰减而仍呈高信号;C.将 FID 信号相减后,显示盂唇呈高信号、软骨和积液呈低/无信号

inversion recovery UTE，3D-IR-UTE）序列　受磁场均匀性限制，常规序列 MRI 中，积液与脂肪抑制不均，可能影响盂唇信号。绝热脉冲频谱带宽较宽，对 B1 和 B0 不均匀性不敏感[27]。3D-IR-UTE 序列先利用反转恢复脉冲将积液与脂肪磁化方向进行 180°翻转，使盂唇、肌腱及韧带等短 T1 组织保持正向；IR-UTE 计算 TI 时，反转的积液和脂肪磁化矢量从负向恢复正向，经过零点时启动 UTE 采集[28]，此时积液和脂肪由于未纵向磁化而无任何信号，同时盂唇等短 T2 组织磁化仍为正向，得以被捕捉到而呈高信号。3D-IR-UTE 的主要不足在于反转后的纵向磁化强度可能无法同时达到零点，导致长 T2 存在残留信号而干扰盂唇成像，使其评估盂唇表浅性损伤的敏感度较差。

2.2.3　3D-短重复时间绝热反转恢复准备 UTE（3D-short repetition time adiabatic inversion recovery prepared UTE，3D-STAIR-UTE）序列　3D-STAIR-UTE 基于 IR-UTE 数据采集方式，结合具有单优化 TI 的短 TR 和高 FA，能更彻底、均匀地抑制所有可能干扰盂唇的长 T2（如骨髓、肌肉、脂肪和积液）信号[29]。短 TR 表明两次激励脉冲间的时间缩短，即被抑制的长 T2 组织恢复时间更短。MA 等[30]报道，STAIR-UTE 可在短 TR（50/100/150 ms）下利用高 FA 增强图像 T1 权重对比，并结合 UTE 特有的“多辐射采集”方式（从多个方向快速填充 k 空间）获得 SNR 尚可的高分辨率图像[31]。但在实际应用中，3D-STAIR-UTE 受限于 MR 设备的特定吸收率（absorption rate，AR）限制，常使 TR 不够短，导致 STAIR 准备阶段无法完全抑制所有水信号而影响盂唇的成像效果[27]。

2.2.4　3D-UTE 水/脂肪成像序列　关节腔成像时，盂唇短 T2 纤维软骨的信号频谱宽度较宽，可能与脂肪频谱发生重叠，使基于化学位移的脂肪饱和方式在脂肪抑制时饱和部分盂唇信号[32]。此外，纤维软骨内含大量与大分子结合的水，对磁化转移（magnetization transfer，MT）效应十分敏感；施加 MT 脉冲亦会饱和短 T2 组织。WANG 等[33]指出，Dixon 技术在采集信号后通过数学方法分离水与脂肪信号而不会预先饱和脂肪；且分离过程在后处理中完成，短 T2 信号不受预饱和或 MT 脉冲影响，使盂唇 UTE 信号得以完好保留[34]。目前 3D-UTE 水/脂肪成像已在膝/踝关节、椎体及小腿等骨骼肌肉系统成像中展现出可行性。

3　小结

盂唇在维持关节内负压的“吸力密封”、增加股骨头/肱骨头覆盖范围、降低负荷、保护软骨及提高关节稳定性方面发挥重要作用[35-36]。3D-UTE MRI 可在盂唇发生异常形变时清晰显示相关结构，且图像对比度较高，为早期诊断盂唇损伤提供了有效方法；但目前该技术仍存在扫描时间长、易受磁化率效应影响等局限性，有待后续加以改进。

利益冲突：全体作者声明无利益冲突。

作者贡献：张赢查阅文献、撰写文章；罗宇婷查阅文献、修改文章；潘诗农和高月指导、审阅文章。

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