应用心脏磁共振特征追踪技术评估左心房应变临床应用进展

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【摘要】 左心房在维持左心室充盈方面起着至关重要的作用,左心房形态及功能改变与多种心血管疾病相关。基于心脏磁共振技术的心房应变评估可以克服单纯测量心房容积的局限性,并且在心血管疾病早期阶段就被检测出来,且具有可重复性高、无需特殊序列等特点。现综述心脏磁共振特征追踪技术评估心房功能在临床实践中的应用现状,探讨其临床及科研价值。

【关键词】 心房功能;左心房应变;心脏磁共振;特征追踪
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Progress in the Clinical Application of Left Atrial Strain Assessment Using Cardiac Magnetic Resonance Feature Tracking Technology

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【**Abstract**】 The left atrial plays a crucial role in maintaining left ventricular filling. Changes in the left atrial are associated with a variety of cardiovascular diseases. The recently proposed cardiac magnetic resonance atrial strain assessment can overcome the limitations of atrial volume measurements. In addition, left atrial strain injury can be detected in the early stages of cardiovascular disease. Cardiac magnetic resonance feature tracking (CMR-FT) is increasingly proving to be a feasible and reproducible technique for assessing left atrial function by strain. In this literature review on atrial strain analysis, we describe recent applications and prospects for the development of CMR-FT for the study of atrial function in clinical practice.

【**Keywords**】 Atrial function; Left atrial strain; Cardiac magnetic resonance; Feature tracking

近年来,人们对左心房(left atrial,LA)功能障碍在心血管疾病发生发展中的重要性的认识逐渐深入。LA 容积增大被认为是心脏不良事件的重要风险。然而,该参数在疾病早期被检测出来的敏感性及准确性均不理想。已有研究[1]表明,LA 功能在其容积增大之前就已受损,并且与左心室功能不全密切相关。因此,LA 功能可以更敏感地反映心血管疾病的病理生理变化。

LA 功能在正常生理状态下可分为 3 个部分:(1)储存功能——左心室收缩期肺静脉血的收集;(2)导管功能——左心室舒张早期肺静脉血向左心室输送;(3)收缩功能——左心室舒张晚期使左心室充盈。在整个心动周期中,LA 通过储存、导管和收缩功能调节左心室舒张、充盈及整体功能[2]。心肌应变是量化心肌变形的一种方法,可反映心肌组织收缩与舒张状态之间的变化,目前常用拉格朗日计算公式表示,$(L_1 - L_0)/L_0$(L_0 代表舒张末期心肌肌节长度,L_1 代表收缩末期心肌肌节长度)[3],可用于分析心肌局部或整体不同走行方向的心肌纤维的收缩力。与常规射血分数相比,心肌应变可以更早期、更灵敏地反映心脏局部和整体的功能变化。LA 的心肌应变评估提供了基于心动周期的 LA 功能三个阶段的独特评估。以往多采用超声心动图斑点追踪技术测量心肌应变,但其易受声窗影响,对图像质量和采集帧率要求较高,重现性不强,限制了其在临床上的广泛应用。随着技术的发展,心脏磁共振特征追踪(cardiac magnetic resonance-feature tracking,CMR-FT)技术越来越多应用于心肌应变的测量,其通过常规扫描的电影序列手动描绘并自动追踪心动周期中心内膜及心外膜解剖结构的运动即可计算得出心肌应变,极大地增加了临床操作可行性。而其他心脏磁共振(cardiac magnetic resonance,CMR)应变技术均需要专用序列,包括心肌组织标记、应变编码成像、受激回波位移编码等,不仅增加了扫描时间,对患者呼吸屏气配合度要求较高,

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且图像后处理复杂耗时,极大增加了临床操作难度。CMR 应变分析常用的参数主要包括径向、周向、纵向 3 个方向的应变及应变率[3]。LA 的解剖特点是壁薄、形态不规则,通常只测量心房的纵向应变,主要测量参数包括被动应变(对应 LA 的导管功能)、主动应变(对应 LA 的收缩功能)、整体应变(对应 LA 的储存功能);峰值正向应变率、峰值早期负向应变率、峰值晚期负向应变率[4]。CMR-FT 评估 LA 功能,在空间分辨率、视野和可重复性方面均优于超声心动图斑点追踪技术[5]。

目前研究[6]显示利用 CMR-FT 可快速评估健康志愿者正常 LA 应变及应变率参数,且重复性良好。但 CMR-FT 测量的心房应变正常值参考范围尚无明确共识。最新的荟萃分析[7]显示,LA 储存应变、导管应变和收缩应变的合并平均值分别为 34.9% (95% *CI* 29.6% ~40.2%)、21.3% (95% *CI* 16.6% ~26.1%)、14.3% (95% *CI* 11.8% ~16.8%)。

LA 与左心室在整个心动周期中协同工作,心房-心室偶联功能的评估对了解心血管疾病病理生理机制提供更加全面的临床价值,研究表明 LA 心肌应变参数是评估 LA 或左心室功能更为敏感的指标[8-9]。从这些研究[10]看出,CMR-FT 衍生的心肌应变评估因其快速、重复性良好、准确性及敏感性高,是一种评估 LA 动力学受损,量化 LA 动力学,并可定量心房-心室偶联的重要影像学评估手段。下面就这一技术在不同心血管疾病中的应用进行分析归纳。

1 心肌梗死

尽管目前对于心肌梗死患者的诊断和管理已取得显著进展,但包括死亡在内的不良事件发生率仍然很高,因此,精确危险分层和确定治疗干预目标对于降低心肌梗死后的再住院率和死亡率至关重要[11]。然而,常规左室射血分数并不能检测出心功能的细微变化,评估预后仍存在局限性;而 CMR-FT 心肌应变评估可以更敏感地预测心室功能变化及临床预后[12]。LA 与左心室功能密切相关,当左心室功能异常时可以直接导致 LA 的容积及功能改变。急性心肌梗死后 LA 功能与主要不良心血管事件(major adverse cardiovascular event, MACE)的关系也逐渐受到关注,所有心房应变参数均与 MACE 相关[13]。在多变量回归模型中,LA 储存应变成为 MACE 的独立预测因子($HR=0.92$, $P=0.033$)[14]。LA 储存和导管应变为已建立的预测模型(包括左室射血分数、左心室质量指数和心肌梗死面积)增加了预测价值,储存应变及导管应变的截断值分别为 22% 和 10%[15],且心肌梗死面积 >15% 的患者发生心肌梗死后 LA 重构和功能障碍更明显[16]。急性 ST 段抬高型心肌梗死(ST segment elevation myocardial infarction, STEMI)合并继发性二尖瓣反流患者的 LA 动力学相关研究[17]显示,LA 整体应变、主动应变及被动应变值均显著升高,可以检测 LA 功能的早期变化。LA 应变评估还显示 STEMI 患者性别差异与预后之间存在相关性[18],也与 STEMI 后新发房性心律失常[包括心房颤动(房颤)或心房传导阻滞]显著相关,并且包含 LA 导管应变参数的模型具有更强的预测价值[19-20]。LAST-PASS 研究[21]显示,LA 舒张应变斜率作为反映舒张期心房-心室偶联的指标,是前壁 STEMI 后血流动力学恢复的重要指标。应用 LA 储存和导管应变还可预测 STEMI 后左心室逆重构[22]。

2 房颤

心房重构是房颤的重要特征,早期发现有助于在临床实践中实现对于房颤的最佳管理。CMR-FT 评估阵发性房颤患者 LA 应变参数发现,其可以识别左房射血分数尚未反映的细微的 LA 收缩功能障碍[23]。与正常人相比,房颤患者 LA 整体应变值更低,整体应变与 LA 容积和射血分数之间存在很强的相关性[24]。并且,房颤患者中 LA 储存应变与 LA 纤维化相关[25],纤维化程度较高者其储存应变和导管应变均较低[26]。

在房颤射频消融术围手术期的管理方面,因肺静脉导管消融导致的 LA 重构逆转与术后房颤的复发呈负相关[27]。在接受过射频消融术的持续性房颤患者中,术前 LA 储存应变与术后房颤复发之间存在独立关联($OR=0.92$, 95% *CI* 0.85 ~ 0.99)[28]。基于 CMR-FT 数据进行精确评估,有助于选择从射频消融术中获益较多的患者,避免不必要的治疗从而降低医疗负担。在扩张型心肌病(dilated cardiomyopathy, DCM)患者中 LA 应变与植入型心律转复除颤器植入后房颤发生显著相关[29]。CMR-FT 可以有效评估房颤合并瓣膜性心脏病患者的 LA 功能,并提供有关卒中风险评估和指导抗凝治疗额外的临床价值[30]。

3 DCM

DCM 是最常见的原发性心肌疾病。在 DCM 患者中,LA 应变明显受损,并与左心室功能障碍显著相关[31]。基于 CMR-FT 的 LA 应变对于原发性 DCM 患者的预后研究[32]发现,LA 储存应变和导管应变是主要终点全因死亡和心脏移植的独立预测因子,也是次要终点心源性猝死和心力衰竭再住院的独立预测因子。针对不同的 LA 功能指标进行分析发现,LA 导管应变对于 DCM 预后具有强有力的预测价值[33],故临床医生可考虑将 LA 导管应变参数纳入 DCM 患者的危险分层[34]。与没有遗传变异的患者相比,具有肌连

蛋白截短变异体的 DCM 患者的 LA 储存应变及收缩应变值均较低[35]。

4 肥厚型心肌病

肥厚型心肌病(hypertrophic cardiomyopathy, HCM)是一种常染色体显性遗传疾病,其发病率和死亡率与左心室舒张功能障碍、左心室流出道梗阻、心力衰竭和室性心律失常有关。然而,目前识别高危 HCM 患者仍具有挑战性。HCM 中的大多数心力衰竭表现为射血分数保留的心力衰竭(heart failure with preserved ejection fraction, HFpEF),LA 应变可更好地反映 HCM 的 LA 病理生理学变化,提供更多的预后价值[36]。Shi 等[37]研究表明,LA 储存应变($\beta = 0.90$, 95% *CI* 0.85 ~ 0.96)、导管应变($\beta = 0.93$, 95% *CI* 0.87 ~ 0.99)和收缩应变($\beta = 0.86$, 95% *CI* 0.78 ~ 0.95)均与 HCM 患者的 HFpEF 独立相关。

LA 应变与左心室舒张功能和心肌纤维化程度之间存在一定的关联[38]。心尖 HCM 患者,LA 储存及导管应变均受损[39]。HCM 基因突变阳性患者相较于阴性患者,LA 储存和收缩应变明显受损[40]。通过 CMR-FT 应变分析发现 LA 应变可能成为 HCM 不良预后(尤其是心血管死亡和心力衰竭)的一种新的预测因子[41],LA 储存和导管应变对于 HCM 不良预后具有更强的预测价值[42]。LA 储存与收缩应变还可预测 HCM 患者新发房颤的风险[43]。此外,LA 收缩应变与室性心动过速显著相关[44],还可应用 LA 储存和收缩应变对室间隔切除术的治疗效果进行评估[45]。

5 心肌淀粉样变性

心肌淀粉样变性(cardiac amyloidosis, CA)是不溶性淀粉样纤维在心肌细胞间质沉积引起的浸润性心肌病。CA 患者的死亡率很高,因此,早期明确诊断至关重要。CA 患者中存在与 LA 功能障碍相关的 LA 重构,并与不良预后相关[46]。与健康人群和 HCM 患者相比,CA 患者的 LA 应变和应变率明显降低,CA 患者 CMR-FT 心房应变与其他肥厚表型有明显的区别[47],LA 应变可为 CA 与高血压性心肌病变的鉴别诊断提供一定的临床依据[48]。CMR-FT LA 收缩应变与 CA 患者的心力衰竭再住院或死亡复合终点显著相关[49]。还有研究[50]表明,LA 储存应变可作为轻链型 CA 新发房颤的预测因子。LA 储存和收缩应变对 CA 患者血栓事件(与房颤无关)的发生具有独立预测价值[51]。在 CA 患者中,基于 CMR 的 LA 应变和应变率测量数据相对较少,但在 CA 早期无创诊断和鉴别诊断方面具有巨大潜力。

6 应激性心肌病

Takotsubo 综合征(Takotsubo syndrome, TTS)通常与应激诱因有关,症状表现类似于急性冠脉综合征。但由于其症状以及亚型的多样性,诊断往往存在一定难度。目前临床常用的诊断标准均参照梅奥诊所建立的标准。除了典型的累及心室表型之外,也有累及心房的报道[52]。CMR-FT 分析 TTS 心房应变发现,LA 相关应变及应变率均受损,有助于揭示 TTS 新的病理生理学机制[53]。利用 CMR-FT 心房应变参数评估 TTS 心房功能病理生理变化显示:第一,LA 储存功能在急性期受损,提高了诊断准确性,并且可以预测 TTS 的死亡风险;第二,LA 收缩功能的代偿性增加是急性 TTS 的一个显著特征,对于总死亡率具有独立的预测价值,可优化 TTS 的诊断和预后评估[54]。LA 收缩应变在亚急性期升高,在恢复期逐渐下降,并且与左心室功能参数变化无关,LA 收缩应变是区分亚急性期和恢复期 TTS 患者的最佳指标。心房应变参数有助于识别 TTS 高危患者[55],Cau 等[56]还利用机器学习方法提取基于 CMR 的 LA 及左心室应变参数,建立对于 TTS 有预测价值的风险模型。

7 心肌炎

急性心肌炎后的随访对于发现持续性或进展中的心力衰竭以及是否能够安全恢复体力活动非常重要,为了确定患者的风险和优化治疗,建议对急性心肌炎患者采用 CMR 进行随访[57]。定量 CMR-FT 衍生的心房应变参数与 Lake-Louise 参数相结合,可提高对疑似心肌炎患者的诊断能力[58]。在急性心肌炎后 3 个月,对患者行 LA 及右心房应变分析后发现,LA 及右心房功能变化情况与临床表现不相关。心房应变监测可能是急性心肌炎个体化预后评估的一个重要工具[59-60]。在亚临床或有明显的舒张功能不全的情况下,LA 应变可对急性心肌炎进行危险分层,其敏感性为 83%,特异性为 80%[61]。LA 储存和导管应变是急性心肌炎患者不良临床结局的独立预测因素[62]。LA 峰值早期负向应变率诊断急性心肌炎后 HFpEF 特异性为 92.9%[63]。

8 其他类型心肌病

限制型心肌病的总体预后较差,其特点亦是舒张功能不全导致心室充盈受损,心室收缩功能保留,进而导致 LA 增大。CMR 成像中 LA 储存应变是限制型心肌病患者预后的独立预测因子,其与生存率和心血管疾病住院率相关[64]。利用 CMR-FT 来描述致心律失常型右心室心肌病中心房受累的特征,LA 应变参数可预测房性心律失常的发生[65]。法布里病早期治疗可以获得较大收益,LA 储存应变在法布里病的各个疾病阶段(包括早期疾病)均显著受损(均 $P < 0.001$)。疾病早期阶段的 ROC 曲线分析显示,LA 储存应变(曲

线下面积为 0.88,敏感性为 89%,特异性为 75%)优于左心室应变(曲线下面积为 0.82)[66]。

9 总结

本文系统综述了基于 CMR-FT 的心房应变评估在各类心血管疾病中的应用,CMR-FT 可对心房功能三个阶段进行综合评估,从而发现不同病因导致的早期 LA 功能损害,提供增量诊断价值,进一步认识 LA 功能在疾病危险分层、房室血流动力学和房室偶联损伤评估、MACE 预后评价等方面的价值,从而为临床提供更精确的决策依据。然而 LA 应变应用仍存在一些问题,如因不同软件计算方法之间的差异,目前针对不同性别和年龄的正常值参考范围尚缺乏统一标准;大规模临床研究尚欠缺,未来应开展大规模前瞻性多中心、多参数、长期随访的研究,以深入探索 LA 应变在心血管疾病中的潜在价值。

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