·临床研究·

心肌最大壁厚和左室流出道解剖学参数评估肥厚型心肌病心肌纤维化的对照研究

钱芷君，施夏韵，殷　凡，刘王琰，徐　怡，王云飞，朱晓梅*

南京医科大学第一附属医院放射科，江苏　南京　210029

［摘　要］　**目的：**探讨并对比心脏磁共振（cardiac magnetic resonance，CMR）左室舒张末期心肌最大壁厚（maximal wall thickness，MWT）和左室流出道（left ventricular outflow tract，LVOT）解剖学参数在评估肥厚型心肌病（hypertrophic cardiomyopathy，HCM）心肌纤维化中的预测价值，并建立预测模型。**方法：**回顾性分析77例行CMR检查的HCM患者，测量参数包括部分二尖瓣前叶长度、总二尖瓣前叶长度、舒张末期和收缩末期的LVOT直径和基底前间隔厚度、左室舒张末期MWT以及心肌延迟强化百分比（percentage of late gadolinium enhancement，LGE%）等，以LGE%来评估心肌纤维化。利用统计软件随机选择70%的样本分配至建模组（n=54），通过单因素及多因素回归分析，建立LGE%的预测模型；剩余30%的样本为内部验证组（n=23），所有患者的超声心动图参数作为外部验证组，评估预测模型的准确性。绘制受试者工作特征曲线，通过计算曲线下面积来确定模型的预测性能，评估预测模型的灵敏度及特异度。**结果：**在建模组中，多因素线性回归分析提示，MWT是LGE%的独立预测因子，线性公式为LGE%=−10.009+0.832×MWT（r=0.466，P < 0.001），而LVOT解剖学参数均与LGE%无线性相关性。在外部验证组中，超声MWT与CMR MWT呈高度正相关（r=0.856，P < 0.001），且内部验证和外部验证的LGE%预测值均与实际LGE%差异无统计学意义；当心脏CMR MWT≥30 mm或超声MWT≥25 mm时，其预测LGE%≥15%的准确率分别为82.6%和81.7%。**结论：**在评估HCM心肌纤维化时，MWT比LVOT解剖学参数更有预测价值。

［关键词］　肥厚型心肌病；左室舒张末期心肌最大壁厚；左室流出道；心脏磁共振；延迟强化

［中图分类号］　R542.2；R445.2　　　［文献标志码］　A　　　［文章编号］　1007-4368（2025）09-1286-08

doi：10.7655/NYDXBNSN250189

A comparative study of maximal wall thickness and anatomical parameters of left ventricular outflow tract for evaluating myocardial fibrosis in hypertrophic cardiomyopathy

QIAN Zhijun，SHI Xiayun，YIN Fan，LIU Wangyan，XU Yi，WANG Yunfei，ZHU Xiaomei*

Department of Radiology，the First Affiliated Hospital of Nanjing Medical University，Nanjing 210029，China

［**Abstract**］　**Objective：**To comparatively explore the value of left ventricular end-diastolic maximal wall thickness（MWT）and anatomical parameters of left ventricular outflow tract（LVOT）for evaluating myocardial fibrosis in hypertrophic cardiomyopathy（HCM）by cardiac magnetic resonance（CMR）and propose a prediction model. **Methods：**Seventy-seven HCM patients who underwent CMR examination were retrospectively analyzed. CMR data included partial anterior mitral leaflets length and total anterior mitral leaflet length. During end-diastole and end-systole，the diameter of LVOT and the thickness of basal anteroseptum were measured. Additionally，left ventricular end-diastolic MWT was collected and the percentage of late gadolinium enhancement（LGE%）was analyzed. LGE% was used to assess myocardial fibrosis. Seventy percent of the samples selected randomly by statistical software were assigned to the modeling group（n=54）for establishing a prediction model of LGE% through univariate and multivariate analysis. The remaining thirty percent of the samples served as the internal validation group（n=23），and parameters of the echocardiogram of all patients were used as the external validation group to assess the accuracy of the prediction model. Receiver operating characteristic curves were plotted，and the predictive efficiency of the prediction model was determined by calculating the area under the curve. The sensitivity and specificity of the prediction model were also evaluated. **Results：**In the modeling group，multivariate analysis indicated

［基金项目］　国家自然科学基金（82302163）；南京医科大学第一附属医院青年学者培养基金（PY2022036）

*通信作者（Corresponding author），E-mail：xiaomeizhu@njmu.edu.cn（ORCID：0000-0002-7591-9930）

that MWT was an independent predictor of LGE% with the linear equation LGE%=−10.009+0.832×MWT（r=0.466，P < 0.001），while no anatomical parameters of LVOT were correlated with LGE%. In the external validation group，MWT measured by echocardiogram was highly positively correlated with MWT measured by CMR（r=0.856，P < 0.001）. Additionally，the predicted LGE% values from both internal and external validation groups showed no statistically significant difference from LGE%. The accuracy of predicting LGE% ≥15% was 82.6% with MWT≥30 mm measured by CMR，and 81.7% with MWT≥25 mm measured by echocardiogram，respectively. **Conclusion:** When evaluating myocardial fibrosis in HCM，MWT has more predictive value than anatomical parameters of LVOT.

［**Key words**］ hypertrophic cardiomyopathy；left ventricular end-diastolic maximal wall thickness；left ventricular outflow tract；cardiac magnetic resonance；late gadolinium enhancement

［J Nanjing Med Univ，2025，45（09）：1286-1292，1315］

肥厚型心肌病（hypertrophic cardiomyopathy，HCM）患者的心肌纤维化可导致心律失常、心源性猝死（sudden cardiac death，SCD）等临床事件[1-2]。心脏磁共振（cardiac magnetic resonance，CMR）广泛应用于心脏结构和功能评估，特别是延迟强化（late gadolinium enhancement，LGE）成像是识别左室局灶替代性纤维化的金标准[3-7]。LGE百分比（percentage of late gadolinium enhancement，LGE%）的获取需要注射钆对比剂，而钆剂一旦积聚极易带来中枢神经系统损害[8-9]。既往研究曾基于CMR平扫获得的Native T_1组织学特征来预测LGE%，然而超声作为指南推荐的一线随访手段，不能获得Native T_1值，因此限制了该参数的应用[10]。而左室舒张末期（end diastole，ED）心肌最大壁厚（maximal wall thickness，MWT）和左室流出道（left ventricular outflow tract，LVOT）解剖学参数均可通过平扫CMR及超声获得，便于随访。

左室ED的MWT被定义为美国心脏病协会（American Heart Association，AHA）16节段模型的心肌厚度的最大节段，可以通过平扫电影CMR及超声获得。既往研究表明：MWT越大，心肌重塑及心肌纤维化越明显[11-13]；而LVOT解剖学参数则与梗阻性HCM左心室LGE%呈线性关系[14-15]。因此，MWT及LVOT解剖学参数均可能与心肌纤维化相关[16-17]，但究竟何者与纤维化的相关性更强以及二者联合能否提高预测效能还需进一步明确。故本研究旨在对比CMR左室ED的MWT和LVOT解剖学参数在评估HCM心肌纤维化的预测价值，建立预测模型并以超声参数验证其效能，为临床提供更多指导。

1 对象和方法

1.1 对象

回顾性分析南京医科大学第一附属医院2018年1月—2022年8月行CMR和超声心动图检查的HCM患者。纳入标准：左室ED的MWT≥15 mm或有HCM家族史的患者左室MWT≥13 mm；超声检查与CMR检查时间间隔≤3个月；CMR图像完整且质量佳。排除标准：有心肌梗死或其他心脏病史；有心脏手术史；左心室心肌肥厚由心脏负荷异常或代谢性疾病引起。

本研究共纳入77例HCM患者，通过SPSS 26软件随机选择70%的样本分配至建模组，余下30%为内部验证组；由于6例患者超声心动图缺少MWT值，故71例超声MWT作为外部验证。建模组患者54例，男41例，女13例，年龄（50.8±17.1）岁；内部验证组患者23例，男16例，女7例，年龄（51.8±15.1）岁；外部验证组患者71例，男52例，女19例，年龄（51.4±16.4）岁。建模组用来获得LGE%的预测模型，使用模型公式计算LGE%预测值（$LGE\%_{predict}$）；验证组通过内部验证和外部验证评估$LGE\%_{predict}$与LGE%的一致性，验证预测模型的可靠性。

本研究为回顾性研究，已通过南京医科大学第一附属医院伦理委员会批准（2021-SR-452）。

1.2 方法

1.2.1 CMR检查方法

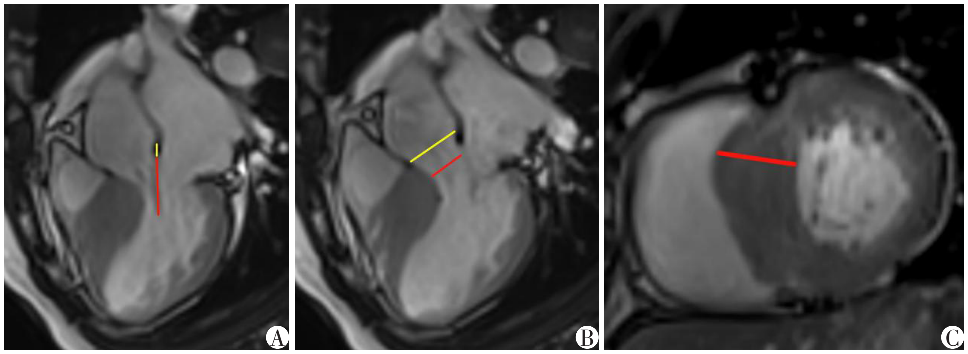
采用Siemens 3.0 T MR扫描仪（Siemens公司，德国）获取CMR资料，包括从基底到心尖水平的左室短轴位电影图像以及各腔心层面的左室长轴位电影图像。嘱患者吸气末屏气，采用回顾性心电门控以及平衡稳态自由进动序列进行扫描。扫描参数为：视野340 mm×380 mm，重复时间3.4 ms，回波时间1.4 ms，矩阵208 mm×188 mm，翻转角47°，层厚8 mm，层间距2 mm。此外，获取LGE图像时需静脉注射0.2 mmol/kg剂量的钆喷酸葡胺，等待15 min

后，在左室短轴和长轴切面运用相位敏感反转恢复序列进行采集。扫描参数为：视野340 mm×380 mm，重复时间2.88 ms，回波时间1.24 ms，矩阵256 mm×220 mm，翻转角55°，层厚8 mm，层间距2 mm。

1.2.2　图像分析与后处理

采用CVI 42.0软件（CVI42，Circle Cardiovascular Imaging公司，加拿大）处理导出的CMR图像。在短轴位图像上勾勒左室心内膜及心外膜的轮廓，并计算经体表面积标化的左室心功能参数。在舒张中期的三腔心层面，二尖瓣瓣叶最大程度伸展并平行于前间隔和左室游离壁，此时测量二尖瓣前叶长度最为清晰，包括部分二尖瓣前叶长度（partial anterior mitral leaflet length，PAMLL）和总二尖瓣前叶长度（total anterior mitral leaflet length，TAMLL）[18]。在三腔心层面的ED及收缩末期（end systole，ES）于主动脉瓣平面下1 cm处测量左室流出道直径（left ventricular outflow tract diameter，LVOTD）$LVOTD_{ED}$和$LVOTD_{ES}$；在ED及ES的左心室短轴位上，测量基底前间隔厚度（basal anteroseptal，BAS）BAS_{ED}和BAS_{ES}。此外，还记录了基于短轴电影获得的左心室ED的MWT。这些参数的测量示例见图1。

在短轴位的LGE图像上勾勒左室心肌纤维化的范围，计算纤维化心肌占心肌总质量的百分比，即可得到心肌组织学特征参数LGE%，其中纤维化心肌的增强信号至少比远处正常心肌信号高5个标准差[19]。根据超声心动图检查报告，记录超声MWT值。



Male，61 years old，HCM. A：In the three-chamber view at the middle of diastole，PAMLL is defined as the length from the hinge point of the mitral valve to the tip of the valve leaflet（the red line segment），and TAMLL is defined as the length from the insertion point of the mitral valve under the aortic valve to the tip of the valve leaflet（the length shown by the sum of the red and yellow line segments）. B：In the three-chamber view at the end diastole，$LVOTD_{ED}$（the red line segment）is measured 1 cm below the aortic valve plane（the yellow line segment）. C：In the short-axis view at the end diastole，BAS_{ED} is measured（the red line segment）.

图1　测量方法示意图

Figure 1　Schematic diagram of the measurement method

1.3　统计学方法

采用SPSS 26软件进行统计分析。通过柯尔莫戈诺夫-斯米尔诺夫法及夏皮洛-威尔克法进行正态性检验。正态分布的定量资料以均值±标准差（$\bar{x} \pm s$）表示，组间比较采用独立样本t检验；偏态分布的定量资料以中位数及四分位数[M（P_{25}，P_{75}）]表示，组间比较采用Mann-Whitney U检验。采用单因素及多因素线性回归模型，探讨建模组LGE%的独立预测因子。根据预测模型，计算LGE%≥15%的MWT值，并评估该MWT值预测LGE%≥15%的准确性。绘制受试者工作特征（receiver operating characteristic，ROC）曲线，通过计算曲线下面积（area under the curve，AUC）确定预测效能，根据LGE%≥15%的MWT值得出预测模型的灵敏度及特异度，$P < 0.05$为差异有统计学意义。

2　结　果

2.1　影像学参数比较

在HCM建模组和内部验证组中，左室心功能参数、LVOT解剖学参数、左室ED的MWT及LGE%差异均无统计学意义（表1）。

2.2　建模组LGE%与左室相关解剖学参数的线性回归分析

建模组的线性回归分析显示，左室ED的MWT与LGE%之间存在显著正相关性（r=0.466，$P < 0.001$，图2），根据回归分析的系数即可得到线性公式LGE%=−10.009+0.832×MWT。而LVOT解剖学参数中仅BAS_{ED}呈现一定趋势。在单因素回归模型的

表1 建模组与内部验证组HCM患者的影像学参数比较

Table 1 Comparison of imaging parameters between the modeling group and internal validation group in patients with HCM

Imaging parameter	Modeling group（n=54）	Internal validation group（n=23）	P
CI[L/（min·m²），$\bar{x} \pm s$]	3.0 ± 0.9	3.1 ± 0.8	0.567
LVEF[%，$M(P_{25}, P_{75})$]	63.0（54.4，66.3）	62.2（51.3，67.6）	0.991
SVI（mL/m²，$\bar{x} \pm s$）	46.5 ± 12.8	47.7 ± 10.8	0.680
LVMI[g/m²，$M(P_{25}, P_{75})$]	73.0（59.1，100.8）	77.8（68.4，93.8）	0.772
PAMLL（mm，$\bar{x} \pm s$）	26.0 ± 4.2	26.0 ± 5.8	0.880
TAMLL（mm，$\bar{x} \pm s$）	31.2 ± 5.3	32.8 ± 7.8	0.375
$LVOTD_{ED}$（mm，$\bar{x} \pm s$）	18.4 ± 4.9	17.6 ± 4.0	0.480
$LVOTD_{ES}$（mm，$\bar{x} \pm s$）	14.6 ± 3.6	13.4 ± 3.8	0.177
BAS_{ED}（mm，$\bar{x} \pm s$）	18.5 ± 5.9	18.5 ± 5.0	0.930
BAS_{ES}[mm，$M(P_{25}, P_{75})$]	21.6（16.7，26.2）	21.3（16.0，23.2）	0.348
PAMLL/$LVOTD_{ED}$[$M(P_{25}, P_{75})$]	1.4（1.1，1.9）	1.6（1.2，1.8）	0.705
PAMLL/$LVOTD_{ES}$[$M(P_{25}, P_{75})$]	1.8（1.5，2.4）	2.0（1.6，2.3）	0.336
TAMLL/$LVOTD_{ED}$[$M(P_{25}, P_{75})$]	1.7（1.4，2.2）	2.0（1.7，2.3）	0.163
TAMLL/$LVOTD_{ES}$[$M(P_{25}, P_{75})$]	2.3（1.7，2.5）	2.4（2.0，3.0）	0.186
MWT[mm，$M(P_{25}, P_{75})$]	22.1（17.1，26.2）	21.2（17.1，28.0）	0.802
LGE%[%，$M(P_{25}, P_{75})$]	4.2（2.0，8.8）	6.7（2.8，13.5）	0.259

CI：cardiac index；LVEF：left ventricular ejection fraction；SVI：stroke volume index；LVMI：left ventricular mass index；PAMLL：partial anterior mitral leaflet length；TAMLL：total anterior mitral leaflet length；ED：end diastole；ES：end systole；LVOTD：left ventricular outflow tract diameter；BAS：basal anteroseptal；MWT：maximal wall thickness；LGE%：percentage of late gadolinium enhancement.

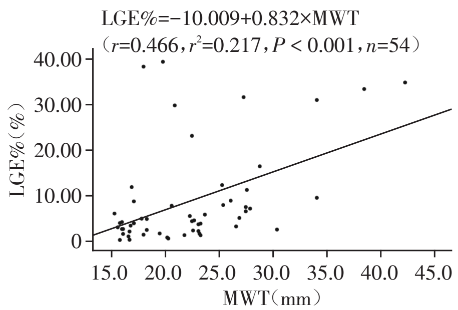


图2 建模组LGE%与MWT的关系

Figure 2 The relationship between LGE% and MWT in modeling group

基础上进一步行多因素回归分析，结果表明MWT是LGE%的独立预测因子（表2）。

2.3 模型准确性内部验证及外部验证

在内部验证组中，由线性公式计算得出的$LGE\%_{predict}$与LGE%之间的差异无统计学意义（P=0.808）。根据预测模型计算，当MWT≥30 mm时，$LGE\%_{predict}$≥15%；MWT≥30 mm预测LGE%≥15%的准确率，在建模组中为85.2%，在内部验证组中为82.6%（表3）。

Pearson相关性分析显示：外部验证组超声所测得的MWT与CMR所测得的MWT呈高度正相关（r=0.856，P < 0.001，图3A）；由于外部验证组超声

表2 建模组左室相关解剖学参数的单因素及多因素线性回归结果

Table 2 Univariate and multivariate regression analysis of anatomical parameters of LVOT in the modeling group （n=54）

Parameter	Univariate			Multivariate		
	B	P	r	B	P	r
PAMLL	0.319	0.381	0.123	–	–	–
TAMLL	0.095	0.743	0.046	–	–	–
$LVOTD_{ED}$	0.050	0.873	0.022	–	–	–
$LVOTD_{ES}$	0.406	0.343	0.133	–	–	–
PAMLL/$LVOTD_{ED}$	0.566	0.848	0.027	–	–	–
PAMLL/$LVOTD_{ES}$	−1.215	0.645	0.065	–	–	–
TAMLL/$LVOTD_{ED}$	−0.181	0.941	0.010	–	–	–
TAMLL/$LVOTD_{ES}$	−1.363	0.511	0.092	–	–	–
BAS_{ED}	0.432	0.088	0.234	–	–	–
BAS_{ES}	−0.032	0.758	0.043	–	–	–
MWT	0.832	<0.001	0.466	0.832	<0.001	0.466

For the abbreviations，please see those in Table 1.

MWT比CMR测得的MWT小4.63 mm，经校正，超声$LGE\%_{predict}$=−10.009+0.832×（超声MWT+4.63）。由线性公式计算得出的超声$LGE\%_{predict}$与LGE%之间的差异也无统计学意义（P=0.099），且外部验证组超声MWT≥25 mm预测LGE%≥15%的准确率为

81.7%（表3）。外部验证组超声 $LGE\%_{predict}$ 和CMR所测LGE%的相关性见图3B。

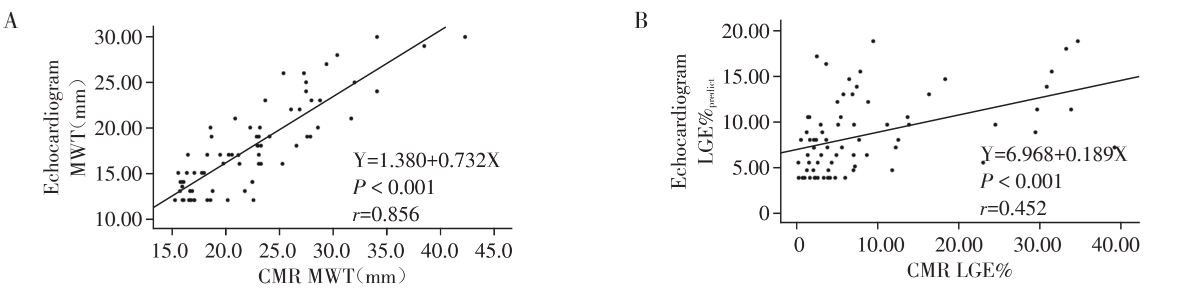
3 讨论

本研究结果显示：在HCM的左室解剖学参数中，MWT与LGE%呈线性正相关，线性公式为LGE%=-10.009+0.832×MWT（r=0.466，P < 0.001），MWT是LGE%的独立预测因子，MWT越大，心肌纤维化就越明显。虽然在HCM建模组的线性回归分析中，参数 BAS_{ED} 与LGE%有一定的相关性，但并无

表3　建模组、内部验证组及外部验证组预测LGE%的准确性

Table 3　The accuracy of predicting LGE% in modeling group, internal validation group, and external validation group

Group	$LGE\%_{predict}$	LGE%		AUC	Sensitivity (%)	Specificity (%)	Accuracy (%)
		<15%	≥15%				
Modeling group（n=54）	<15%	43	6	0.744	33.3	95.6	85.2
	≥15%	2	3				
Internal validation group（n=23）	<15%	18	3	0.868	25.0	94.7	82.6
	≥15%	1	1				
External validation group（n=71）	<15%	55	9	0.792	25.0	93.2	81.7
	≥15%	4	3				



A: The scatter plot and the linear equation between MWT measured by echocardiogram and MWT measured by CMR. B: The scatter plot and the linear equation between LGE% predicted by echocardiogram and LGE% measured by CMR（n=71）.

图3　超声心动图和CMR检测的MWT的相关性和二者检测的LGE%的相关性

Figure 3　The correlation between MWT detected by echocardiogram and CMR, and the correlation between LGE% detected by echocardiogram and CMR

统计学意义（r=0.234，P=0.088）。只有MWT是LGE%的独立预测因子（r=0.466，P < 0.001）。该结果表明，在评估HCM心肌纤维化时，左室ED的MWT比LVOT解剖学参数更有预测价值。此结论与既往研究结论略有不同[14-15]，施夏韵等[14]表明在梗阻性HCM中，LVOT解剖学参数中 BAS_{ED} 为LGE%的独立预测因子，而本研究中LVOT参数均为阴性结果。其原因可能在于梗阻性与非梗阻性HCM患者MWT的位置不同。在梗阻性HCM中，BAS_{ED} 多与MWT值一致，而对于非梗阻性HCM，MWT与 BAS_{ED} 不一定重合，因而本研究结果与既往研究结果不冲突。MWT与LGE%相关不仅适用于梗阻性HCM，同时也适用于非梗阻性HCM，本研究结果进一步扩展了MWT的适用范围。此外，由于梗阻性与非梗阻性HCM肥厚特点不同且血流动力学有一定差异，在今后研究中可进行分组讨论，进一步提高模型的预测效能。

既往研究表明，LGE%≥15%的HCM患者发生SCD的风险明显增加[20-21]；在调整其他风险因素后，LGE%≥15%的HCM患者发生SCD的风险，比LGE%<15%的患者高3倍[22-23]。在本研究中，建模组预测LGE%≥15%的准确率为85.2%，内部验证组预测LGE%≥15%的准确率为82.6%，充分表明了CMR所测得的MWT在筛查SCD高危患者中的潜在价值。超声作为指南推荐的一线随访手段，经济便捷，更易于长期动态评估MWT的变化[24-25]。为了便于随访，本研究中同样验证了超声心动图测得的MWT的预测效果，结果显示：超声所测得的MWT与CMR所测得的MWT呈高度正相关（r=0.856，P < 0.001）。Spiewak等[26]研究也提示超声心动图和

CMR检查在HCM患者的MWT测量中具有高度一致性，与本研究类似。本研究进一步明确基于超声MWT≥25 mm预测LGE%≥15%的准确率为81.7%。因此，建议将左室ED的MWT纳入超声心动图和非增强CMR的常规随访中，以便较为简便准确地筛选出LGE%≥15%的SCD高危患者；特别是当平扫CMR测得的MWT≥30 mm或超声测得的MWT≥25 mm时，应推荐HCM患者行增强CMR检查，进一步明确心肌纤维化程度，从而为该类患者的临床检查或治疗提供指导意见。

Spiewak等[26]研究结果显示，与CMR测得的MWT相比，超声测量低估的最大值为13 mm（超声心动图测得MWT为19 mm，而CMR测得MWT为32 mm）。与此结果类似，本研究中，超声MWT比CMR MWT小4.63 mm，原因可能是超声心动图受经典采集层面限制，无法精确显示所有心肌节段，因此较CMR易低估MWT。而Maron等[27]表明：基底前游离壁和前室间隔的连接部分是HCM中左心室壁增厚的最常见区域。本研究表明基于超声获得的MWT虽被低估，但与CMR MWT呈高度正相关，因而经公式矫正后，超声测量的MWT预测LGE%的价值依然具有临床意义。

由于HCM患者左室ES时经常看不清心腔，测量MWT不方便，因此本研究选择在ED测量MWT。既往研究同样选择了ED的MWT，并且已经证实LGE%与左室ED的MWT相关（r=0.486，P < 0.001）[28]，与本研究结果一致。

本研究存在局限性。首先，这是一项单中心研究，患者数量相对较少，由于CMR结果极易受机器和检查序列影响，不同医院测得的数据差异性较大，很可能影响结论的准确性，因此研究推广还需要更多数据验证。其次，伴有心衰的LVEF<50%的患者，其心肌厚度可能不一定变薄，但该类患者心肌纤维化往往很重，这将导致MWT与LGE%二者不相关，是否会影响预测效能，仍需更多病例进一步验证。最后，LGE%不仅与MWT相关，还与心肌增厚所累及的节段数以及双室累及都有一定的相关性。因此，可以扩大样本量，增加对不同HCM亚型的讨论，进一步优化模型，探究该预测模型的实际操作性。

总之，在评估HCM心肌纤维化时，左室ED的MWT比LVOT解剖学参数更有预测价值。CMR检测的MWT≥30 mm或超声检测的MWT≥25 mm预测LGE%≥15%的准确性较高，分别为82.6%和81.7%。建议在HCM随访检查中常规测量左室ED的MWT，为判断心肌纤维化程度提供参考。

利益冲突声明：

所有作者均声明无利益冲突。

Conflict of Interests:

All authors declare no conflict of interests.

作者贡献声明：

钱芷君负责实验，数据整理和分析和论文撰写。施夏韵负责软件分析，参与撰写和审阅论文。殷凡负责图片处理，参与撰写和审阅论文。刘王琰监督研究，参与撰写和审阅论文。徐怡参与撰写和审阅论文。王云飞负责研究资金获取，参与撰写和审阅论文。朱晓梅设计研究思路，监督研究，撰写、编辑和审阅论文。

Author's Contributions:

QIAN Zhijun was responsible for the experiment, data organization and analysis, and paper writing. SHI Xiayun was responsible for software analysis and participated in writing and reviewing the paper. YIN Fan was responsible for image processing and participated in writing and reviewing the paper. LIU Wangyan supervised the research and participated in writing and reviewing the paper. XU Yi participated in writing and reviewing the paper. WANG Yunfei was responsible for obtaining research funds and participated in writing and reviewing the paper. ZHU Xiaomei designed the research idea, supervised the research, wrote, edited, and reviewed the paper.

［参考文献］

[1] YAZDANFARD P D, CHRISTENSEN A H, TFELT-HANSEN J, et al. Non-diagnostic autopsy findings in sudden unexplained death victims[J]. BMC Cardiovasc Disord, 2020, 20(1): 58

[2] PAN J A. Late gadolinium enhancement in hypertrophic cardiomyopathy: is there more to it than size?[J]. JACC Cardiovasc Imaging, 2024, 17(5): 498-500

[3] CHENG S N, CHOE Y H, OTA H, et al. CMR assessment and clinical outcomes of hypertrophic cardiomyopathy with or without ventricular remodeling in the end-stage phase[J]. Int J Cardiovasc Imaging, 2018, 34(4): 597-605

[4] HABIB M, ADLER A, FARDFINI K, et al. Progression of myocardial fibrosis in hypertrophic cardiomyopathy: a cardiac magnetic resonance study[J]. JACC Cardiovasc Imaging, 2021, 14(5): 947-958

[5] KIAOS A, DASKALOPOULOS G N, KAMPERIDIS V, et al. Quantitative late gadolinium enhancement cardiac magnetic resonance and sudden death in hypertrophic cardiomyopathy: a meta-analysis[J]. JACC Cardiovasc Imaging, 2024, 17(5): 489-497

[6] 殷 凡，施夏韵，刘王琰，等. 左心室室间隔瘢痕对左束支起搏术实现左束支夺获的影响[J]. 南京医科大学学报（自然科学版），2024，44（10）：1377-1382

YIN F, SHI X Y, LIU W Y, et al. Effect of ventricular septal scars on the capture of left bundle branch during left bundle branch pacing[J]. Journal of Nanjing Medical University(Natural Sciences), 2024, 44(10): 1377-1382

[7] 陈 杨,朱晓梅,秦 捷,等. 基于压缩感知的心脏实时电影技术在评估左心房功能中的价值[J]. 南京医科大学学报(自然科学版), 2021, 41(2): 252-257
CHEN Y, ZHU X M, QIN J, et al. The value of compressed sensing cardiac cine magnetic resonance imaging for analysis of left atrial function[J]. Journal of Nanjing Medical University(Natural Sciences), 2021, 41(2): 252-257

[8] KULINNA-COSENTINI C, ARNOLDNER M A, SCHIMA W, et al. Performance of a new natural oral contrast agent (LumiVision®) in dynamic MR swallowing[J]. Eur Radiol, 2021, 31(11): 8578-8585

[9] MCDONALD R J, LEVINE D, WEINREB J, et al. Gadolinium retention: a research roadmap from the 2018 NIH/ACR/RSNA workshop on gadolinium chelates[J]. Radiology, 2018, 289(2): 517-534

[10] 张艳娟,王璎瑛,赵 迪,等. 运用超声心动图多模态参数评估肥厚型心肌病患者早期左心室功能变化[J]. 南京医科大学学报(自然科学版), 2025, 45(2): 240-244, 259
ZHANG Y J, WANG Y Y, ZHAO D, et al. Assessment of early left ventricular functional changes in HCM patients by multimodality echocardiographic parameters[J]. Journal of Nanjing Medical University(Natural Sciences), 2025, 45(2): 240-244, 259

[11] OMMEN S R, MITAL S, BURKE M A, et al. 2020 AHA/ACC guideline for the diagnosis and treatment of patients with hypertrophic cardiomyopathy: executive summary: a report of the American college of cardiology/American heart association joint committee on clinical practice guidelines[J]. J Am Coll Cardiol, 2020, 76(25): 3022-3055

[12] SILAJDZIJA E, RASMUS VISSING C, BASSE CHRISTENSEN E, et al. Family screening in hypertrophic cardiomyopathy: identification of relatives with low yield from systematic follow-up[J]. J Am Coll Cardiol, 2024, 84(19): 1854-1865

[13] NORRISH G, DING T, FIELD E, et al. Relationship between maximal left ventricular wall thickness and sudden cardiac death in childhood onset hypertrophic cardiomyopathy[J]. Circ Arrhythm Electrophysiol, 2022, 15(5): e010075

[14] 施夏韵,朱晓梅,徐盼盼,等. 心脏MR左室流出道解剖学参数与梗阻性肥厚型心肌病心肌纤维化的相关性分析[J]. 影像诊断与介入放射学, 2023, 32(4): 243-249
SHI X Y, ZHU X M, XU P P, et al. Correlation analysis between anatomical parameters of left ventricular outflow tract and myocardial tissue characteristics in obstructive hypertrophic cardiomyopathy[J]. Diagnostic Imaging & Interventional Radiology, 2023, 32(4): 243-249

[15] 徐盼盼,朱晓梅,陈 杨,等. 左心室流出道相关解剖学参数对肥厚性心肌病血流动力学的影响[J]. 中国医学影像学杂志, 2021, 29(9): 866-871
XU P P, ZHU X M, CHEN Y, et al. Influence of anatomic parameters of left ventricular outflow tract on hemodynamics in hypertrophic cardiomyopathy[J]. Chinese Journal of Medical Imaging, 2021, 29(9): 866-871

[16] CAPTUR G, MANISTY C H, RAMAN B, et al. Maximal wall thickness measurement in hypertrophic cardiomyopathy: biomarker variability and its impact on clinical care[J]. JACC Cardiovasc Imaging, 2021, 14(11): 2123-2134

[17] TOWER-RADER A, KRAMER C M, NEUBAUER S, et al. Multimodality imaging in hypertrophic cardiomyopathy for risk stratification[J]. Circ Cardiovasc Imaging, 2020, 13(2): e009026

[18] MARON M S, OLIVOTTO I, HARRIGAN C, et al. Mitral valve abnormalities identified by cardiovascular magnetic resonance represent a primary phenotypic expression of hypertrophic cardiomyopathy[J]. Circulation, 2011, 124(1): 40-47

[19] MAVROGENI S, BRATIS K, KOUTSOGEORGOPOULOU L, et al. Myocardial perfusion in peripheral Raynaud's phenomenon. Evaluation using stress cardiovascular magnetic resonance[J]. Int J Cardiol, 2017, 228: 444-448

[20] FAHMY A S, ROWIN E J, JAAFAR N, et al. Radiomics of late gadolinium enhancement reveals prognostic value of myocardial scar heterogeneity in hypertrophic cardiomyopathy[J]. JACC Cardiovasc Imaging, 2024, 17(1): 16-27

[21] YIN Y W, HU W J, ZHANG L S, et al. Clinical, echocardiographic and cardiac MRI predictors of outcomes in patients with apical hypertrophic cardiomyopathy[J]. Int J Cardiovasc Imaging, 2022, 38(3): 643-651

[22] WANG J X, YANG S J, MA X, et al. Assessment of late gadolinium enhancement in hypertrophic cardiomyopathy improves risk stratification based on current guidelines[J]. Eur Heart J, 2023, 44(45): 4781-4792

[23] CHAN R H, VAN DER WAL L, LIBERATO G, et al. Myocardial scarring and sudden cardiac death in young patients with hypertrophic cardiomyopathy: a multicenter cohort study[J]. JAMA Cardiol, 2024, 9(11): 1001-1008

[24] BOIS J P, AYOUB C, GESKE J B, et al. Ultrasound enhancing agents with transthoracic echocardiography for

(下转第1315页)

dynamic effects of molidustat on erythropoiesis in healthy cats[J]. J Vet Intern Med,2024,38(1):381-387

[22] COPUR S,DEMIRAY A,BASILE C,et al. Endocrinological disorders in acute kidney injury:an often overlooked field of clinical research[J]. J Nephrol,2023,36(3):885-893

[23] OLIVARI V,DI MODICA S M,LIDONNICI M R,et al. A single approach to targeting transferrin receptor 2 corrects iron and erythropoietic defects in murine models of anemia of inflammation and chronic kidney disease[J]. Kidney Int,2023,104(1):61-73

[24] SHIH H M,PAN S Y,WU C J,et al. Transforming growth factor-β1 decreases erythropoietin production through repressing hypoxia-inducible factor 2α in erythropoietin-producing cells[J]. J Biomed Sci,2021,28(1):73

[25] 汤 勇,牟 文,何 兵. 血液红细胞及网织红细胞参数对肾性贫血患者的临床检验价值[J]. 中国医药指南,2024,22(23):109-111
TANG Y,MOU W,HE B. Clinical value of red blood cell and reticulocyte parameters in patients with renal anemia[J]. Chinese Medicine Guide,2024,22(23):109-111

[26] NABITY M,HOKAMP J. Urinary biomarkers of kidney disease in dogs and cats[J]. Vet Clin North Am Small Anim Pract,2023,53(1):53-71

[27] MÅRTENSSON J,BELLOMO R. The rise and fall of NGAL in acute kidney injury[J]. Blood Purif,2014,37(4):304-310

[28] GOMAA S H,SHAMSEYA M M,MADKOUR M A. Clinical utility of urinary neutrophil gelatinase-associated lipocalin and serum cystatin C in a cohort of liver cirrhosis patients with renal dysfunction:a challenge in the diagnosis of hepatorenal syndrome[J]. Eur J Gastroenterol Hepatol,2019,31(6):692-702

[29] MOSTAFA E A,SHAHIN K M,EL MIDANY A A H,et al. Validation of cardiac surgery-associated neutrophil gelatinase-associated lipocalin score for prediction of cardiac surgery-associated acute kidney injury[J]. Heart Lung Circ,2022,31(2):272-277

[30] CHENG X,WU B,LIU Y,et al. Incidence and diagnosis of acute kidney injury in hospitalized adult patients:a retrospective observational study in a tertiary teaching hospital in Southeast China[J]. BMC Nephrol,2017,18(1):203

[收稿日期] 2024-11-22
(本文编辑:戴王娟)

(上接第1292页)

maximal wall thickness in hypertrophic cardiomyopathy[J]. Mayo Clin Proc Innov Qual Outcomes,2023,7(4):309-319

[25] URBANO-MORAL J A,GONZALEZ-GONZALEZ A M,MALDONADO G,et al. Contrast-enhanced echocardiographic measurement of left ventricular wall thickness in hypertrophic cardiomyopathy:comparison with standard echocardiography and cardiac magnetic resonance[J]. J Am Soc Echocardiogr,2020,33(9):1106-1115

[26] SPIEWAK M,KŁOPOTOWSKI M,KOWALIK E,et al. Sudden cardiac death risk in hypertrophic cardiomyopathy:comparison between echocardiography and magnetic resonance imaging[J]. Sci Rep,2021,11(1):7146

[27] MARON M S,MARON B J,HARRIGAN C,et al. Hypertrophic cardiomyopathy phenotype revisited after 50 years with cardiovascular magnetic resonance[J]. J Am Coll Cardiol,2009,54(3):220-228

[28] LI Y M,LIU J,CAO Y K,et al. Predictive values of multiple non-invasive markers for myocardial fibrosis in hypertrophic cardiomyopathy patients with preserved ejection fraction[J]. Sci Rep,2021,11(1):4297

[收稿日期] 2025-02-23
(本文编辑:陈汐敏)