无创心肌做功技术评估单纯主动脉瓣反流患者TAVR术后左心室心肌功能

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摘　要:目的:探讨无创心肌做功(Myocardial work, MW)技术在评估单纯主动脉瓣反流(Aortic regurgitation, AR)患者经导管主动脉瓣置换术(Transcatheter aortic valve replacement, TAVR)术后左心室心肌功能中的价值。**方法:**选取2023年8月至2024年8月于我院心内科TAVR治疗的35例单纯中重度及以上AR患者,于术前、术后即刻、术后1个月、3个月及6个月行经胸超声心动图检查,并脱机处理超声参数,分析各参数的变化趋势及各参数预测术后左心室逆重构(Left ventricular reverse remodeling, LVRR)的效能。**结果:**单纯AR患者TAVR术前及术后各随访节点左心室射血分数(LV ejection fraction, LVEF)、左心室整体纵向应变(Left ventricular global longitudinal strain, LVGLS)、整体做功指数(Global work index, GWI)、整体有用功(Global constructive work, GCW)、整体做功效率(Global work efficiency, GWE)呈先降低后增加趋势,整体无用功(Global wasted work, GWW)呈先增加后降低趋势,左室舒张末期内径(LV end-diastolic dimension, LVDD)则持续缩小;术前与术后6个月相比,单纯AR患者左心室功能显著改善。术前LVEF、LVGLS、GWI、GCW预测单纯AR患者TAVR术后LVRR的ROC曲线下面积(Area under the ROC curve, AUC)分别为0.783、0.835、0.868、0.857,差异均有统计学意义(P<0.05),而术前GWW、GWE预测单纯AR患者TAVR术后LVRR的AUC分别为0.569、0.637,差异均无统计学意义(P>0.05)。当GWI截断值为1 367.5 mmHg%时,AUC为0.868(95%*CI*:0.708~1.000,P=0.001),此时灵敏度93%,特异度85%。**结论:**单纯AR患者TAVR术后疗效显著,无创MW技术可有效评估左心室心肌功能改善情况,术前GWI可能是预测术后LVRR的潜在指标。

关键词:主动脉瓣关闭不全;经导管主动脉瓣置换术;心室;无创心肌做功
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Noninvasive myocardial work assessment of left ventricular myocardial function after TAVR in pure aortic regurgitation

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Abstract: Objective: To investigate the value of noninvasive myocardial work (MW) in assessing the improvement of left ventricular myocardial function after transcatheter aortic valve replacement (TAVR) in patients with pure aortic regurgitation (AR). **Methods:** Thirty-five patients with moderate to severe or more aortic regurgitation (AR) who underwent transcatheter aortic valve replacement (TAVR) in the cardiology department of our hospital from August 2023 to August 2024 were selected. Transthoracic echocardiography was performed before the operation and immediately after the operation, as well as at 1 month, 3 months, and 6 months postoperatively. The ultrasound parameters were processed offline, and the changing trends of each parameter and the predictive efficacy of each parameter for left ventricular reverse remodeling (LVRR) after the operation were analyzed. **Results:** In patients with pure aortic regurgitation (AR), the left ventricular ejection fraction (LVEF), left ventricular global longitudinal strain (LVGLS), global work index (GWI), global

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constructive work (GCW), and global work efficiency (GWE) at various follow-up time points before and after transcatheter aortic valve replacement (TAVR) showed a trend of first decreasing and then increasing. In contrast, the global wasted work (GWW) exhibited a trend of first increasing and then decreasing, while the left ventricular end-diastolic dimension (LVDD) continued to decrease. Compared with preoperative status, left ventricular function in patients with pure AR significantly improved at 6 months post-TAVR. The area under the curve (AUC) of preoperative LVEF, LVGLS, GWI, and GCW for predicting left ventricular reverse remodeling (LVRR) after TAVR in patients with isolated AR were 0.783, 0.835, 0.868, and 0.857, respectively, all of which were statistically significant (P<0.05). However, the AUC of preoperative GWW and GWE for predicting LVRR after TAVR in patients with pure AR were 0.569 and 0.637, respectively, with no statistical significance (P>0.05). When the GWI cutoff value was 1 367.5 mmHg%, the AUC was 0.868 (95% *CI*: 0.708 - 1.000, P=0.001), with a sensitivity of 93% and a specificity of 85%. **Conclusion**: The efficacy of postoperative TAVR in patients with pure AR is significant, noninvasive MW can effectively assess the improvement of LV myocardial function, and the preoperative GWI may be a potential predictor of postoperative LVRR in patients with pure AR undergoing TAVR.

Key words: Aortic regurgitation; Transcatheter aortic valve replacement; Ventricle; Noninvasive myocardial work

主动脉瓣反流(Aortic regurgitation, AR)及主动脉瓣狭窄(Aortic stenosis, AS)是常见的心脏瓣膜疾病,在我国以前者居多[1]。临床上治疗两者的金标准为主动脉瓣置换术(Surgical aortic valve replacement, SAVR)[2],对于不能耐受SAVR的重度AS患者,可采用导管主动脉瓣置换术(Transcatheter aortic valve replacement, TAVR)作为替代治疗[3],而AR因其特殊解剖结构一度成为TAVR禁忌证。随着经验积累及人工瓣膜技术发展,TAVR已试探性地在AR患者中进行,并初步证实了其安全可行性[4-11]。然而,目前对AR患者行TAVR后左心室心肌功能的改善情况报道较少,而左心室心肌功能对患者预后具有重要意义。超声心动图在TAVR术后评估中起着关键作用,其中斑点追踪显像(Speckle tracking imaging, STI)可检测心肌功能的轻微变化[12],而无创心肌做功(Myocardial work, MW)在STI基础上耦合后负荷,大大降低了STI参数的负荷依赖性,已广泛运用到AS患者TAVR术后左心室功能评估中[13-15],但在单纯AR患者TAVR术后左心室功能评估方面运用较少。本研究旨在运用无创MW技术评估单纯AR患者TAVR术后左心室心肌功能改变,初步探索MW参数在单纯AR患者TAVR术前及术后随访中的潜在价值,以期为临床实践提供指导。

1 资料与方法

1.1 一般资料 选取2023年8月至2024年8月于赣南医科大学第一附属医院心内科接受TAVR治疗的单纯中重度及以上AR患者35例为研究对象。纳入标准:(1)根据美国超声心动图学会指南[16]符合中重度及以上AR诊断标准且行TAVR患者;(2)患者均知情同意并签署知情同意书。排除标准:(1)合并中度以上主动脉瓣狭窄、先天性心脏病;(2)可导致心脏损伤的相关疾病。术后2例死亡,其中1例于术后3个月再入院后肺癌死亡,另1例死亡时间、原因不明;3例失访;3例超声图像质量差,余27例均完成随访。本研究获得赣南医科大学第一附属医院医学伦理委员会批准(编号:LLSC-2025-364)。

1.2 仪器与方法

1.2.1 仪器 使用配有M5Sc探头及4V探头的GE Vivid E95彩色多普勒超声诊断仪进行图像采集,同时配套Echo PAC 204工作站,可对图像进行脱机分析。

1.2.2 图像采集与后处理 所有患者均于术前、术后即刻、术后1个月、3个月及6个月行经胸超声心动图检查,采集图像时同步测量血压。储存连续5个心动周期的胸骨旁左室长轴及心尖二、三、四腔心切面动态图像,并将图像导入Echo PAC 204工作站进行分析,依次完成常规及应变参数测量。

1.2.3 观察指标 (1)心肌功能常规参数:左心室射血分数(Left ventricular ejection fraction, LVEF)、左心室舒张末期内径(Left ventricular end diastolic dimension, LVDD)、左心室整体纵向应变(Left ventricular global longitudinal strain, LVGLS)。(2)MW参数:①整体做功指数(Global work index, GWI)指的是从二尖瓣关闭到打开计算的左心室压力-应变环区域内的总功;②整体有用功(Global constructive work, GCW)定义为左心室心肌在收缩期缩短或等容舒张期延长所作的功;③整体无用功(Global waste work, GWW)定义为左心室心肌在收缩期延长或等容舒张期缩短所作的功;④整体做功

效率（Global work efficiency，GWE）：GWE=GCW/（GCW+GWW）×100%。

1.3　统计学处理　应用SPSS 27.0软件进行数据分析。计量资料以$\bar{x}\pm s$表示，多个时间点比较使用重复测量方差分析，两个时间点比较采用配对t检验。使用受试者工作特征（Receiver operating characteristic，ROC）曲线分析术前各参数预测单纯AR患者TAVR术后左心室逆重构（Left ventricular reverse remodeling，LVRR）的效能。检验水准α=0.05。

2　结果

2.1　TAVR术前及术后各随访节点参数变化　单纯AR患者TAVR术前及术后各随访节点LVEF、LVGLS、GWI、GCW、GWE整体呈先降低后增加趋势。术后即刻LVEF、LVGLS、GWI、GCW、GWE较术前显著降低（P<0.05）；术后1个月LVEF、LVGLS、GWE较术后即刻显著增加（P<0.05）；术后3个月LVEF、GWI、GCW较术后1个月显著增加（P<0.05）；术后6个月LVEF、LVGLS、GWI、GCW、GWE较术后3个月显著增加（P<0.05）。单纯AR患者TAVR术前及术后GWW呈现先增加后降低趋势，术后即刻GWW较术前增加（P<0.05），术后1个月GWW较术后即刻降低（P<0.05），术后6个月GWW较术前明显增加（P<0.05）。单纯AR患者TAVR术前及术后LVDD则呈现持续降低的趋势，术后即刻LVDD较术前显著降低（P<0.05），术后1个月、术后3个月、术后6个月LVDD改善趋于平缓，术后6个月GCW、LVDD较术前明显降低（P<0.05）（表1）。

表1　单纯AR患者TAVR术前及术后各随访节点参数比较$\bar{x}\pm s$

时间	LVEF/%	LVGLS/%	GWI/mmHg%	GCW/mmHg%	GWW/mmHg%	GWE/%	LVDD/mm
术前	55.0±1.5	15.9±0.8	1 531.9±90.4	1 995.6±107.3	289.1±27.0	84.6±1.0	59.6±0.9
术后即刻	48.3±1.5①	12.1±0.6①	1 126.2±71.7①	1 656.1±96.1①	489.9±34.0①	76.6±1.2①	53.8±1.2①
术后1个月	51.5±1.3②	13.4±0.7②	1 217.4±53.9	1 585.8±74.6	390.3±30.9②	80.3±1.1②	51.0±1.2②
术后3个月	53.3±1.2③	14.0±0.6	1 317.0±63.1③	1 686.0±73.0③	378.3±27.2	81.2±1.1	50.6±1.1
术后6个月	55.5±1.1④	15.0±0.6④	1 399.8±59.5①④	1 807.6±78.2①④	380.4±26.7①	82.6±0.9①④	49.2±1.1①
F	22.7	30.4	38.6	19.6	18.6	29.0	50.2
P	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

注：与术前比较，①P<0.05；与术后即刻比较，②P<0.05；与术后1个月比较，③P<0.05；与术后3个月比较，④P<0.05。

2.2　各参数预测TAVR术后LVRR的效能　术后共有14例患者发生LVRR。使用ROC曲线分析术前各参数与单纯AR患者TAVR术后LVRR之间的关系，分析各参数预测TAVR术后LVRR的效能。术前LVEF、LVGLS、GWI、GCW预测单纯AR患者TAVR术后LVRR的曲线下面积（Area under curve，AUC）分别为0.783、0.835、0.868、0.857，差异均有统计学意义（P<0.05），而术前GWW、GWE预测单纯AR患者TAVR术后LVRR的AUC分别为0.569、0.637，差异均无统计学意义（P>0.05）。其中术前GWI预测TAVR术后LVRR的AUC最大，且当GWI截断值为1 367.5 mmHg%时，AUC为0.868（95%CI：0.708~1.000，P=0.001），此时灵敏度93%，特异度85%（图1）。

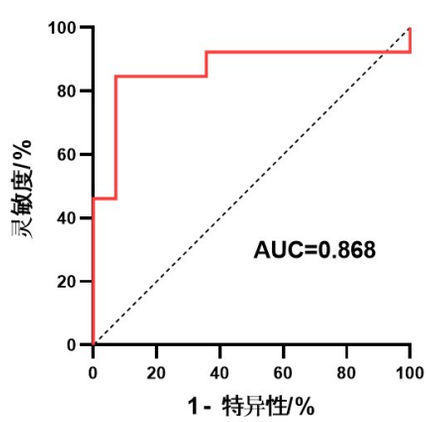

图1　术前GWI预测TAVR术后LVRR的ROC曲线

3　讨论

无创MW技术在STI基础上，结合了左心室后负荷，降低了参数的负荷依赖性，克服了后负荷的影响，可以更全面评估心肌功能，尤其是在负荷变化时（例如TAVR术前及术后左心室负荷发生变化）比STI参数更稳定[17]。赵星等[18]显示TAVR在LVEF保留或减少的主动脉瓣反流患者中均疗效

良好。袁凤等[19]研究表明AR患者TAVR术后LVRR效应明显。陶世鑫等[20]基于STI技术研究表明，AR患者TAVR术后发生LVRR且功能呈整体改善趋势。以上研究结果提示无创MW技术在AR的左心室功能评估中同样有效。但目前国内外关于单纯AR患者TAVR术后左心室功能变化的术后随访研究较少，且常局限于使用常规超声心动图参数或STI参数评估。

本研究采用无创MW评估单纯AR患者TAVR术后左心室心肌功能发现，单纯AR患者TAVR术前及术后LVEF、LVGLS、GWI、GCW、GWE整体呈先降低后增加趋势，而GWW呈先增加后降低趋势，术前及术后LVDD则呈持续降低趋势。这一结果表明，随着TAVR术后严重AR的纠正，左心室超负荷状态得到缓解，左心室前后负荷降低，但LVEF、LVGLS、GWI、GCW、GWE术后出现短暂降低。单纯AR患者TAVR术后LVEF、LVGLS、GWI、GCW、GWE出现短暂降低与陶世鑫等[20]研究结果一致，亦是因为左心室负荷的急剧降低，Frank-Starling代偿机制失效，左心室射血及左心室心肌应变降低；心肌无需再抵抗心室高负荷状态，从而做功降低。此外，LVEF、LVGLS、GWI、GCW、GWE逐渐增高则反映了心肌适应了最初的负荷急剧降低后的功能恢复，表明TAVR对于单纯性AR患者左心室心肌功能具有长期改善作用，显示了良好的LVRR效应。

值得注意的是，单纯AR患者TAVR术后6个月LVEF较术前略增加，术后6个月LVGLS较术前略降低，表明单纯AR患者TAVR术后6个月LVEF、LVGLS基本恢复到术前状态。术后6个月GWI、GCW、GWE、LVDD比术前降低，术后6个月GWW比术前增加，说明MW参数可以从能量学角度评估TAVR术后左心室心肌功能的改变：在恢复主动脉正常血流动力学后，左心室后负荷降低，心肌做功随之降低。根据欧洲心血管影像协会（European association of cardiovascular imaging，EACVI）指南[21]的MW参数参考值范围，GWI参考值下限是1 310 mmHg%，GCW是1 650 mmHg%。而本研究TAVR术后6个月的GWI、GCW分别为1 399.8 mmHg%、1 807.6 mmHg%，尽管均比术前明显降低，但仍处于正常参考值范围。这提示TAVR术后6个月左心室MW的显著降低并非功能受损，而是功能恢复的表现。

此外，单纯AR导致的LVRR往往是可纠正的，可在TAVR后被逆转，预测LVRR有显著的临床意义。本研究结果显示术前GWI预测TAVR术后LVRR的AUC最大，且GWI截断值为1 367.5 mmHg%。值得注意的是，该截断值略微高于EACVI指南[21]的GWI正常参考值范围下限（1 310 mmHg%）。提示当单纯AR患者术前GWI≥1 367.5 mmHg%时，TAVR术后很有可能获得较好的LVRR效应。

综上所述，单纯AR患者TAVR术后疗效显著，LVRR效应明显；无创MW技术可有效评估左心室心肌功能，但本研究样本量较小，随访时间6个月，且为单中心研究，未来需更大样本、多中心研究来进一步评估MW参数在单纯AR患者TAVR术后的价值。

所有作者均声明不存在利益冲突关系。

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