

三维斑点追踪成像技术对完全性左束支传导阻滞不同左心室射血分数患者右心室收缩功能评估的价值

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[摘要] **目的** 采用三维斑点追踪成像(3D-STI)技术对完全性左束支传导阻滞(CLB BB)不同左心室射血分数(LVEF)患者的右心室收缩功能进行评估。**方法** 选择 2024 年 6 月—2025 年 5 月于青岛大学附属医院确诊的 CLBBB 患者 52 例,根据患者的 LVEF 分为 LVEF 保留组(18 例)、LVEF 轻度减低组(20 例)、LVEF 减低组(14 例),同期随机选取健康受试者 35 例作为对照组。采用二维超声心动图测量各组受试者三尖瓣环收缩运动速度峰值(S')、三尖瓣环收缩期位移(TAPSE)、右心室面积变化分数(FAC)、右心室心肌做功指数(RIMP),采用 3D-STI 技术测量各组受试者右心室游离壁纵向应变(RVFWLS)、右心室间隔纵向应变(RVSLS)、右心室射血分数(RVEF)、右心室搏出量(RVSV)、右心室舒张末期容积(RVEDV)、右心室收缩末期容积(RVESV)、右心室舒张末期容积指数(RVEDVi)、右心室收缩末期容积指数(RVESVi)及右心室-肺动脉耦连指标 RVFWLS/肺动脉收缩压(PASP),对比各组受试者的二维超声心动图及 3D-STI 指标,采用 Spearman 检验分析 CLBBB 患者右心室 3D-STI 指标与 RVEF 间相关性,采用受试者工作特征(ROC)曲线和曲线下面积(AUC)评估 3D-STI 指标对 CLBBB 患者右心室收缩功能减低的诊断效能。**结果** 二维超声心动图结果显示,四组受试者 S' 、TAPSE、FAC、RIMP 等二维超声心动图指标均差异显著($F=4.607\sim68.009, P<0.01$)。3D-STI 指标比较结果显示,四组受试者的 RVESV、RVESVi、RVEF、RVSLS、RVFWLS、RVFWLS/PASP 均差异显著($H=18.449\sim66.740, P<0.001$);其中 CLBBB 各组 RVSLS 均显著低于对照组($P<0.05$);LVEF 减低组 RVEF、RVFWLS、RVFWLS/PASP 显著低于其他三组, RVSLS 显著低于 LVEF 保留组, RVESV、RVESVi 显著高于对照组及 LVEF 保留组($P<0.05$);LVEF 轻度减低组 RVEF 显著低于对照组, RVFWLS/PASP 显著高于对照组($P<0.05$)。Spearman 相关分析结果显示,3D-STI 指标 RVSLS、RVFWLS、RVFWLS/PASP 值均与 RVEF 值呈显著负相关($r=-0.698\sim-0.626, P<0.001$)。ROC 曲线结果显示,3D-STI 指标对 CLBBB 患者右心室收缩功能障碍评估效能较高($AUC=0.915$)。**结论** 3D-STI 指标可有效评价 CLBBB 患者右心室收缩功能变化,能够为临床早期识别右心室收缩功能障碍提供较为可靠的影像学诊断依据。

[关键词] 心室功能,右;束支传导阻滞;成像,三维;三维斑点追踪成像技术;超声心动描记术;每搏输出量

[中图分类号] R445.1 **[文献标志码]** A

Value of three-dimensional speckle-tracking imaging in assessing right ventricular systolic function in patients with complete left bundle branch block and different left ventricular ejection fractions XU

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[ABSTRACT] **Objective** To assess right ventricular systolic function in patients with complete left bundle branch block (CLBBB) and different levels of left ventricular ejection fraction (LVEF) using three-dimensional speckle-tracking imaging (3D-STI). **Methods** A total of 52 patients who were diagnosed with CLBBB in The Affiliated Hospital of Qingdao University from June 2024 to May 2025 were enrolled, and according to LVEF, they were divided into preserved LVEF group with 18 patients, mildly reduced LVEF group with 20 patients, and reduced LVEF group with 14 patients. A total of 35 healthy subjects during the same period of time were enrolled as control group. Two-dimensional echocardiography was used to measure the peak systolic velocity of the tricuspid annulus (S'), tricuspid annular plane systolic excursion (TAPSE), fractional area change (FAC) of the right ventricle, right ventricular index of myocardial performance (RIMP), and 3D-STI was used to measure right ventricular free wall longitudinal strain (RVFWLS), right ventricular septal longitudinal strain (RVSLS), right ventricular ejection fraction (RVEF), right ventricular stroke volume (RVSV), right ventricular end-diastolic volume (RVEDV), right ventricular end-systolic volume (RVESV), right ventricular end-diastolic volume index (RVEDVi), right ventricular end-systolic volume index (RVESVi), and the right ventricular-pulmonary arterial coupling parameter RVFWLS/pulmonary artery systolic pressure (PASP) ratio. Two-dimensional echocardiography and 3D-STI parameters were compared between groups; the Spearman correlation analysis was used to investigate the correlation between right ventricular 3D-STI parameters and RVEF; the receiver operating characteristic (ROC) curve

[收稿日期] 2026-01-18; **[修订日期]** 2026-05-12
[基金项目] 山东省自然科学基金面上项目(ZR2025M-S1468)
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dimensional echocardiography and 3D-STI parameters were compared between groups; the Spearman correlation analysis was used to investigate the correlation between right ventricular 3D-STI parameters and RVEF; the receiver operating characteristic (ROC) curve

and the area under the ROC curve (AUC) were used to assess the efficacy of 3D-STI parameters in the diagnosis of reduced right ventricular function in CLBBB patients. **Results** Two-dimensional echocardiography showed that there were significant differences in S' , TAPSE, FAC, and RIMP between the four groups ($F=4.607-68.009, P<0.01$). Comparison of 3D-STI parameters showed that there were significant differences in RVESV, RVESVi, RVEF, RVSLs, RVFWLS, and RVFWLS/PASP ratio across the four groups ($H=18.449-66.740, P<0.001$); the three CLBBB groups had a significantly lower RVSLs than the control group ($P<0.05$); the reduced LVEF group had significantly lower RVEF RVFWLS, and RVFWLS/PASP ratio than the other three groups, a significantly lower RVSLs than the preserved LVEF group, and significantly higher RVESV and RVESVi than the control group and the preserved LVEF group ($P<0.05$); compared with the control group, the mildly reduced LVEF group had a significantly lower RVEF and a significantly higher RVFWLS/PASP ratio ($P<0.05$). The Spearman correlation analysis showed that the 3D-STI parameters RVSLs, RVFWLS, and RVFWLS/PASP ratio were significantly negatively correlated with RVEF ($r=-0.698--0.626, P<0.001$). The ROC curve analysis showed that 3D-STI parameters had relatively high efficacy in assessing right ventricular systolic dysfunction in patients with CLBBB, with an AUC of 0.915. **Conclusion** This study shows that 3D-STI parameters can effectively assess the change in right ventricular systolic function in patients with CLBBB and thus provide reliable imaging data for the early identification of right ventricular systolic dysfunction in clinical practice.

[KEY WORDS] Ventricular funcion, right; Bundle-branch block; Imaging, three-dimensional; Three-dimensional speckle tracking imaging; Echocardiography; Stroke volume

完全性左束支传导阻滞 (CLBBB) 是一种以心室电激动顺序异常为特征的心律失常,常导致左心室机械收缩不同步,与心力衰竭的进展、再住院率及全因死亡率升高密切相关^[1-2]。既往研究多聚焦于 CLBBB 对左心室功能的影响^[3],但右心室收缩功能障碍在 CLBBB 患者中同样存在,且影响患者的心脏再同步化治疗 (CRT) 反应及预后^[4]。因此准确评估 CLBBB 患者的右心室收缩功能障碍对 CLBBB 患者右心室衰竭的早期识别及临床干预具有重要意义。三维斑点追踪成像 (3D-STI) 技术作为超声心动图领域的革新性进展,能够准确重建右心室复杂的几何形态和运动特征,量化心肌的运动速度和形变,反映右心室早期功能变化,早期发现心力衰竭患者亚临床右心室收缩功能障碍^[5]。本研究拟采用 3D-STI 技术定量评估 CLBBB 不同左心室功能分层患者的右心室收缩功能代偿与失代偿变化情况,旨在早期识别 CLBBB 患者右心室收缩功能障碍。

1 对象与方法

1.1 研究对象

选择 2024 年 6 月—2025 年 5 月在青岛大学附属医院确诊为 CLBBB 患者 52 例,根据左心室射血分数 (LVEF) 将患者分为 LVEF 保留组 (LVEF $\geq$

50%)、LVEF 轻度减低组 (40% $<$ LVEF $<$ 50%) 和 LVEF 减低组 (LVEF $\leq$ 40%)。另外选择健康受试者共 35 例作为对照组。CLBBB 患者纳入标准:经心电图诊断为 CLBBB 者^[6]。排除标准:①存在先天性心脏病或原发性右心室疾病 (如右冠状动脉缺血或梗死、致心律失常的右心室心肌病等) 者;②严重三尖瓣、肺动脉瓣反流者;③植入永久性心脏起搏器者;④合并甲状腺功能异常、严重肝肾功能不全或者自身免疫性疾病者。对照组受试者纳入标准:①LVEF $>$ 50%;②心电图诊断无 CLBBB^[6]。排除标准同 CLBBB 患者。四组受试者的年龄、性别、BMI 等基线资料均无显著差异 ($P>0.05$),具有可比性。见表 1。

1.2 研究方法

采用 Philips IE33 及 Philips EPIC 7C 彩色多普勒超声诊断仪对四组患者进行超声检查,选用频率 1.3~4.2 MHz 的 X5-1 三维超声探头,配有三导联心电图。同步连接三导联心电图,嘱受试者左侧卧位,分别使用 M 型、脉冲多普勒和组织多普勒超声^[7]测量受试者右心室二维超声心动图指标,记录三尖瓣环收缩运动速度峰值 (S')、三尖瓣环收缩期位移 (TAPSE)、右心室面积变化分数 (FAC),并计算右心室心肌做功指数 (RIMP)。

表 1 四组受试者基线资料比较

指标	对照组 ($n=35$)	LVEF 保留组 ($n=18$)	LVEF 轻度减低组 ($n=20$)	LVEF 减低组 ($n=14$)	F/χ^2	P
年龄 (岁, $\bar{x}\pm s$)	63.5 $\pm$ 7.8	67.0 $\pm$ 8.7	64.0 $\pm$ 9.2	66.5 $\pm$ 11.6	0.845	0.473
性别 [例 ($\chi/\%$)]						
女	24 (69)	9 (50)	14 (70)	6 (43)	4.373	0.224
男	11 (31)	9 (50)	6 (30)	8 (57)		
BMI (kg/m ² , $\bar{x}\pm s$)	24.7 $\pm$ 2.5	24.6 $\pm$ 3.1	24.7 $\pm$ 3.8	25.0 $\pm$ 3.5	0.039	0.990

进行完上述操作后,将多普勒超声诊断仪切换为全容积成像模式,完整显示右心室聚焦及标准的心尖四腔心切面,采集 4 个心动周期的 3D-STI 图像,将图像导入 Tomtec 软件并脱机分析,自动追踪左心室及右心室各节段心肌,并获得 LVEF 及右心室 3D-STI 指标,包括右心室三维应变指标:右心室游离壁纵向应变(RVFWLS)绝对值、右心室间隔纵向应变(RVSLS)绝对值,以及右心室三维容积及功能指标。右心室三维容积以及功能指标包括:右心室舒张末期容积(RVEDV)、右心室收缩末期容积(RVESV)、右心室舒张末期容积指数(RVEDVi)、右心室收缩末期容积指数(RVESVi)、右心室射血分数(RVEF)、右心室搏出量(RVSV),3D-STI 衍生的右心室-肺动脉(RV-PA)耦联指标为 RVFWLS/肺动脉收缩压(PASP)。

1.3 统计学处理

采用 SPSS 26.0 软件对数据进行统计学分析,所有计量资料均经 D-W 正态性检验及 Levene 方差齐性检验,满足正态分布且方差齐的计量资料以 $\bar{x} \pm s$ 表示,多组间比较采用单因素方差分析,组间两两比较采用 Bonferroni 事后检验;非正态分布计量资料以 $M(P_{25}, P_{75})$ 表示,多组间采用 Kruskal-Wallis 检验,组间两两比较采用 Bonferroni 事后检验。计数资料以例(率)表示,组间比较采用 χ^2 检验。采用 Spearman 检验分析 RVSLS、RVFWLS、

RVFWLS/PASP 与 RVEF 间相关性,采用受试者工作特征(ROC)曲线和曲线下面积(AUC)分析 3D-STI 指标对 CLBBB 患者右心室收缩功能的评估价值。以 $P<0.05$ 为差异有统计学意义。

2 结 果

2.1 四组受试者的二维超声心动图指标比较

四组受试者的 S' 、TAPSE、FAC、RIMP 均差异显著($F=4.607\sim68.009, P<0.01$)。其中 CLBBB 各组 RIMP 显著高于对照组($P<0.05$);LVEF 减低组 TAPSE、FAC 显著低于其他三组, S' 显著低于 LVEF 保留组及对照组($P<0.05$);LVEF 轻度减低组 RIMP 显著高于 LVEF 保留组,TAPSE 显著低于对照组及 LVEF 保留组($P<0.05$)。见表 2。

2.2 四组受试者的右心室 3D-STI 指标比较

四组受试者之间的 RVESV、RVESVi、RVEF、RVSLS、RVFWLS、RVFWLS/PASP 均有显著差异($H=18.449\sim66.740, P<0.001$)。其中 CLBBB 各组 RVSLS 均显著低于对照组($P<0.05$);LVEF 减低组 RVEF、RVFWLS、RVFWLS/PASP 显著性低于其他三组,RVSLS 显著低于 LVEF 保留组,RVESV、RVESVi 显著高于对照组及 LVEF 保留组($P<0.05$);LVEF 轻度减低组 RVEF 显著低于对照组,RVFWLS/PASP 显著性高于对照组($P<0.05$)。见表 3。

表 2 四组受试者二维超声心动图指标比较($\bar{x} \pm s$)

指标	对照组 (<i>n</i> =35)	LVEF 保留组 (<i>n</i> =18)	LVEF 轻度减低组 (<i>n</i> =20)	LVEF 减低组 (<i>n</i> =14)	<i>F</i>	<i>P</i>
$S'(v/cm \cdot s^{-1})$	12.00±2.40	12.70±2.60	11.60±2.30	9.80±2.00 ^{ab}	4.607	0.007
RIMP	0.39±0.07	0.57±0.11 ^a	0.68±0.09 ^{ab}	0.69±0.10 ^{ab}	68.009	<0.01
TAPSE(<i>d</i> /cm)	2.10±0.20	2.20±0.20	2.00±0.20 ^{ab}	1.60±0.30 ^{abc}	20.328	<0.01
FAC($\chi/\%$)	53.20±5.00	53.90±5.10	53.20±5.00	35.80±7.50 ^{abc}	39.232	<0.01

注:a 表示与对照组比较 $P<0.05$,b 表示与 LVEF 保留组比较 $P<0.05$,c 表示与 LVEF 轻度减低组比较 $P<0.05$

表 3 四组受试者右心室 3D-STI 指标比较[$M(P_{25}, P_{75})$]

指标	对照组 (<i>n</i> =35)	LVEF 保留组 (<i>n</i> =18)	LVEF 轻度减低组 (<i>n</i> =20)	LVEF 减低组 (<i>n</i> =14)	<i>H</i>	<i>P</i>
RVEDV(<i>V</i> /mL)	88.3(75.6, 114.7)	104.7(74.4, 121.8)	104.9(88.4, 131.3)	101.1(80.6, 172.4)	3.843	0.279
RVEDVi(mL/m ²)	55.1(46.3, 65.1)	60.0(44.2, 70.2)	62.6(54.2, 77.0)	63.4(48.2, 91.4)	4.421	0.219
RVESV(<i>V</i> /mL)	35.7(30.4, 51.6)	43.5(35.9, 53.9)	48.9(37.9, 62.6)	62.0(48.9, 96.8) ^{ab}	18.449	<0.001
RVESVi(mL/m ²)	23.1(18.3, 29.3)	25.0(20.7, 32.0)	28.8(24.0, 37.9)	38.4(30.8, 50.7) ^{ab}	20.688	<0.001
RVSV(<i>V</i> /mL)	53.1(45.8, 66.8)	58.0(39.5, 65.5)	59.1(49.2, 69.1)	44.4(30.8, 71.4)	2.244	0.523
RVEF($\chi/\%$)	59.0(56.3, 61.0)	55.3(52.5, 57.3)	51.8(50.4, 58.0) ^a	38.5(34.5, 44.5) ^{abc}	43.246	<0.001
RVSLS($\chi/\%$)	23.7(26.3, 21.9)	18.1(18.3, 16.7) ^a	14.4(15.6, 12.2) ^a	8.1(10.4, 6.3) ^{ab}	66.740	<0.001
RVFWLS($\chi/\%$)	30.2(34.3, 28.7)	29.2(35.9, 27.6)	30.6(33.0, 28.0)	16.5(18.0, 15.0) ^{abc}	35.500	<0.001
RVFWLS/PASP	0.9(1.1, 0.8)	1.1(1.4, 0.9)	1.3(1.4, 1.1) ^a	0.6(0.7, 0.5) ^{abc}	39.054	<0.001

注:a 表示与对照组比较 $P<0.05$,b 表示与 LVEF 保留组比较 $P<0.05$,c 表示与 LVEF 轻度减低组比较 $P<0.05$

2.3 RVEF 与 RVSLs、RVFWLS 以及 RVFWLS/PASP 的相关性分析

Spearman 相关性分析结果显示,3D-STI 指标 RVSLs、RVFWLS、RVFWLS/PASP 值均与 RVEF 值呈显著的负相关性($r = -0.698 \sim -0.626, P < 0.001$)。

2.4 ROC 曲线分析二维超声心动图及 3D-STI 指标对 CLBBB 患者右心室收缩功能的评估效能

依据 RVEF 值将本研究中男性 $RVEF < 46\%$ 、女性 $RVEF < 47\%$ 判定为右心室收缩功能减低^[8],52 例 CLBBB 患者中,右心室收缩功能减低者 16 例(31%),出现在 LVEF 轻度减低组及减低组,且主要集中在 LVEF 减低组(14 例)。采用 ROC 曲线分析二维超声心动图以及 3D-STI 指标对 CLBBB 患者右心室收缩功能的评估效能,结果显示 RVSLs、RVFWLS、RVFWLS/PASP 三个指标联合起来评估 CLBBB 患者右心室收缩功能减低的效能最高($AUC = 0.915$)。见表 4、图 1。

表 4 超声指标对 CLBBB 患者右心室收缩功能评估效能

指标	AUC(95%CI)	灵敏度 ($\chi/\%$)	特异度 ($\chi/\%$)
3D-STI 及衍生指标			
RVSLs	0.864(0.755~0.973)	62.5	97.2
RVFWLS	0.862(0.730~0.994)	75.0	100.0
RVFWLS/PASP	0.910(0.811~1.000)	81.3	97.2
三指标联合	0.915(0.818~1.000)	81.3	97.2
二维超声心动图指标			
TAPSE	0.493(0.318~0.668)	25.0	86.1
S'	0.217(0.090~0.344)	25.0	30.6
RIMP	0.648(0.485~0.811)	75.0	55.6
FAC	0.141(0.000~0.283)	25.0	2.8

3 讨 论

有研究表明,右心室收缩功能是 CLBBB 患者预后的重要影响因素,严重的右心室收缩功能障碍与 CLBBB 患者短期全因死亡率显著升高有关^[9]。CLBBB 患者的左心室壁收缩不同步可造成左心衰竭,左心室容积及顺应性的改变可通过直接的机械相互作用(即室间隔运动)影响右心室^[10],同时也可通过肺循环间接作用影响右心室收缩功能。三维超声全容积成像及 3D-STI 应变分析,可显示 CLBBB 患者右心室间隔及右心室游离壁异常收缩模式,量化右心室收缩功能,从而更敏感地检测右心室早期功能变化^[11-12]。此外,由 3D-STI 衍生的 RV-PA 耦联指标 RVFWLS/PASP 作为一种新型综合指标,可以用于评价与右心室后负荷相关的右心室收

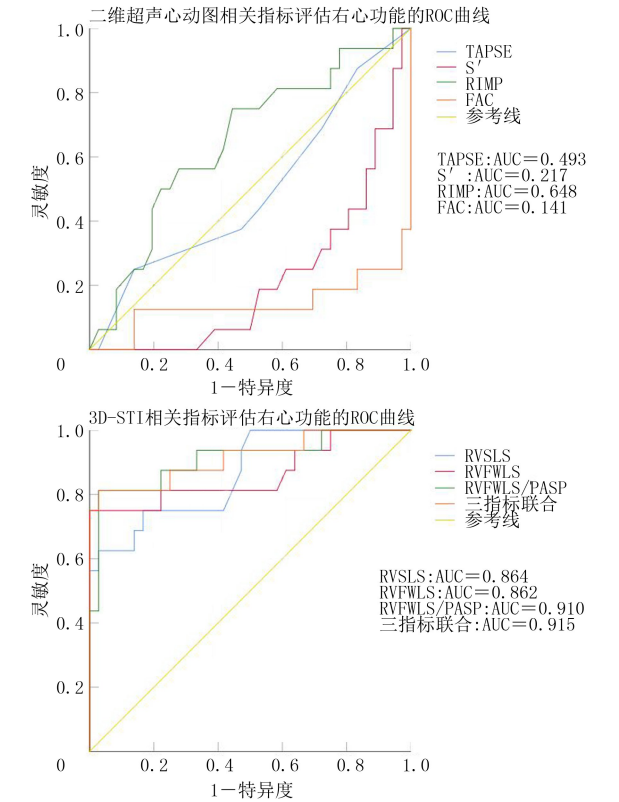


图 1 二维超声心动图及 3D-STI 技术评估右心功能的 ROC 曲线缩功能^[13-15]。

本研究首先分析了不同 LVEF 的 CLBBB 患者及正常受试者的常规二维超声心动图指标,其中 S'、TAPSE、FAC 以及 RIMP 均为评估右心室收缩功能的常用指标。本研究结果显示,LVEF 减低组 TAPSE 及 FAC 显著性低于其他三组,S' 显著低于 LVEF 保留组及对照组;LVEF 轻度减低组 TAPSE 显著低于 LVEF 保留组及对照组。该结果表明二维超声心动图指标多仅在 LVEF 明显减低时出现异常,而在 LVEF 早期轻度减低时不敏感。此外,CLBBB 各组的 RIMP 显著高于对照组,LVEF 轻度减低组及减低组 RIMP 显著高于 LVEF 保留组。RIMP 为右心室等容时间与射血时间的比值,在 CLBBB 发生时,右心室游离壁及室间隔收缩时间缩短,导致右心室射血时间缩短,故而右心室压力升高时间及等容舒张时间延长^[16],反映在 3D-STI 指标上即为 RIMP 升高。

本研究进一步分析了各组受试者的 3D-STI 指标,结果显示 CLBBB 各组 RVSLs 均显著性低于对照组;LVEF 轻度减低组 RVEF 显著低于对照组,RVFWLS/PASP 显著高于对照组。表明在 CLBBB 早期(LVEF 保留时),电激动异常已导致 RVSLs 受损,但 RVFWLS 可以通过代偿维持,患者的整体 RVEF 尚正常;LVEF 轻度减低时,随着 PASP 增

高,右心室后负荷增加,RVFWLS 表现出对抗后负荷及弥补室间隔收缩不足的代偿性增强趋势,从而导致 RVEF 下降^[17],RVFWLS/PASP 的升高正是此阶段右心室为维持有效泵血而进行代偿性耦联的关键体现。在本研究当中,LVEF 减低组 RVEF、RVFWLS、RVFWLS/PASP 显著低于 LVEF 轻度减低组,表明 CLBBB 晚期(LVEF 显著减低时),因右心室长期后负荷增加及右心室间隔应变持续减低,导致右心室游离壁收缩最终失代偿,RVFWLS 显著下降,RV-PA 耦联严重失调,最终使 RVEF 显著下降。上述右心室收缩功能由代偿到失代偿的演变规律,与 SURKOVA 等^[18]研究一致,即右心室通过增加代偿性收缩以维持功能,直至失代偿后整体收缩功能下降。此外,LVEF 减低组 RVESV、RVESVi 高于对照组及 LVEF 保留组,而在其他各组间无显著差异。这提示 CLBBB 的右心室重构主要表现为右心室收缩末期容积的增加,且仅在右心室收缩功能失代偿期才出现明显的容积变化。

Spearman 相关性分析结果显示,在 3D-STI 指标中,RVSLs、RVFWLS、RVFWLS/PASP 值均与 RVEF 值呈显著负相关,且 CLBBB 患者中右心室收缩功能减低者主要集中在 LVEF 减低组。上述结果同样印证了当右心室应变减低、RV-PA 耦联失调时,右心室射血功能随之下落的结论。ROC 曲线分析则显示,相较于传统二维超声心动图指标以及单一 3D-STI 指标,RVSLs、RVFWLS、RVFWLS/PASP 等 3D-STI 指标联合时,对 CLBBB 患者右心室收缩功能的评估效能最好。

本研究首次通过测量 3D-STI 相关指标,揭示了 CLBBB 患者随左心室功能的恶化,右心室功能从代偿到失代偿期的动态演变过程,特别是发现了 RVFWLS/PASP 这一指标识别右心室收缩功能由代偿状态转变为后期失代偿状态的敏感性。因此,对于拟行 CRT 的 CLBBB 患者,术前采用 3D-STI 技术评估其右心室收缩功能有助于预测患者的治疗效果及预后^[19-21]。同时,本研究存在一定的局限性,例如以 3D-STI 中 RVEF 指标作为评估右心室收缩功能的“金标准”,验证其他 3D-STI 指标的诊断效能,存在循环论证的局限性,未来应增加心脏磁共振等目前影像技术领域较为公认的右心室收缩功能评估检查,对本研究结果加以检验。

综上所述,CLBBB 患者随左心室功能下降,右心室收缩功能经历了从代偿到失代偿的演变过程,3D-STI 指标能敏锐捕捉到右心室功能的异常变化,

其中 RVSLs、RVFWLS、RVFWLS/PASP 指标联合对 CLBBB 患者右心室收缩功能具有较好的评估效能,可为患者的病情评估及早期干预提供重要影像学依据。

伦理批准和知情同意:本研究涉及的所有试验均已通过青岛大学附属医院医学伦理委员会的审核批准(文件号 QYFYWZLL30374)。所有试验过程均遵照《涉及人的生命科学和医学研究伦理审查办法》的条例进行。受试对象或其亲属已经签署知情同意书。

作者声明:徐玉婷、张文钟、杨濠玮、马建敏、孙瑞聪参与了研究设计,徐玉婷、何香芹、孙品参与了论文的写作和修改。所有作者均阅读并同意发表该论文,且均声明不存在利益冲突。

[参考文献]

- [1] HUANG H C, WANG J, LIU Y B, et al. Clinical outcomes of complete left bundle branch block according to strict or conventional definition criteria in patients with normal left ventricular function[J]. Acta Cardiol Sin, 2020,36(4):335-342.
- [2] IMANISHI R, SETO S, ICHIMARU S, et al. Prognostic significance of incident complete left bundle branch block observed over a 40-year period[J]. Am J Cardiol, 2006,98(5):644-648.
- [3] SMISETH O A, AALEN J M. Mechanism of harm from left bundle branch block[J]. Trends Cardiovasc Med, 2019,29(6):335-342.
- [4] VAN EVERDINGEN W M, WALMSLEY J, CRAMER M J, et al. Echocardiographic prediction of cardiac resynchronization therapy response requires analysis of both mechanical dyssynchrony and right ventricular function: A combined analysis of patient data and computer simulations[J]. J Am Soc Echocardiogr, 2017,30(10):1012-1020.e2.
- [5] 宋艳,师桃,刘森森,等. 右心纵向应变预测左心室辅助装置植入后早期死亡的价值[J]. 中华超声影像学杂志, 2024,33(12):1037-1042.
- [6] RAUTAHARJU P M, SURAWICZ B, GETTES L S, et al. AHA/ACCF/HRS recommendations for the standardization and interpretation of the electrocardiogram: Part IV: The ST segment, T and U waves, and the QT interval: A scientific statement from the American Heart Association Electrocardiography and Arrhythmias Committee, Council on Clinical Cardiology; the American College of Cardiology Foundation; and the Heart Rhythm Society: Endorsed by the International Society for Computerized Electrocardiology [J]. Circulation, 2009,119(10):e241-e250.
- [7] MITCHELL C, RAHKOP S, BLAUWET L A, et al. Guidelines for performing a comprehensive transthoracic echocardiographic examination in adults: Recommendations from the American society of echocardiography[J]. J Am Soc Echocardiogr, 2019,32(1):1-64.
- [8] ZHANG Y, WANG Y B, YAO G H, et al. Right ventricular volume and function by three-dimensional echocardiography:

Results of the echocardiographic measurements in normal Chinese adults (EMINCA) II[J]. MedComm, 2024,5(5):e550.

[9] PADANG R, CHANDRASHEKAR N, INDRABHINDU-WAT M, et al. Aetiology and outcomes of severe right ventricular dysfunction[J]. Eur Heart J, 2020, 41 (12): 1273-1282.

[10] HADDAD F, HUNT S A, ROSENTHAL D N, et al. Right ventricular function in cardiovascular disease, part I : Anatomy, physiology, aging, and functional assessment of the right ventricle[J]. Circulation, 2008,117(11):1436-1448.

[11] LI Y M, ZHANG L, GAO Y, et al. Comprehensive assessment of right ventricular function by three-dimensional speckle-tracking echocardiography: Comparisons with cardiac magnetic resonance imaging[J]. J Am Soc Echocardiogr, 2021,34 (5):472-482.

[12] MURARU D, NIERO A, RODRIGUEZ-ZANELLA H, et al. Three-dimensional speckle-tracking echocardiography: Benefits and limitations of integrating myocardial mechanics with three-dimensional imaging[J]. Cardiovasc Diagn Ther, 2018,8 (1):101-117.

[13] 贺晴,高朗,季萌萌,等. 右心室-肺动脉耦连在心血管疾病中的应用进展[J]. 中国医学影像学杂志, 2025,33(1):91-96.

[14] HE Q, LIN Y X, ZHU Y, et al. Clinical usefulness of right ventricle-pulmonary artery coupling in cardiovascular disease [J]. J Clin Med, 2023,12(7):2526.

[15] RICHTER M J, RAKO Z A, TELLO K. Ratio between right ventricular strain and systolic pulmonary artery pressure as a surrogate for right ventricular to pulmonary arterial coupling: Validation against the gold standard[J]. Eur Heart J Cardiovasc Imaging, 2023,24(3):e50-e52.

[16] STORSTEN P, AALEN J M, BOE E, et al. Mechanical effects on right ventricular function from left bundle branch block and cardiac resynchronization therapy[J]. JACC Cardiovasc Imag, 2020,13(7):1475-1484.

[17] THOMAS J D, EDVARSDEN T, ABRAHAM T, et al. Clinical applications of strain echocardiography: A clinical consensus statement from the American society of echocardiography developed in collaboration with the European association of cardiovascular imaging of the European society of cardiology[J]. J Am Soc Echocardiogr, 2025,38(11):985-1020.

[18] SURKOVA E, KOVÁCS A, TOKODI M, et al. Contraction patterns of the right ventricle associated with different degrees of left ventricular systolic dysfunction[J]. Circ Cardiovasc Imaging, 2021,14(10):e012774.

[19] 曹清琼,郭瑞强. 三维斑点追踪成像技术在心脏疾病中的应用进展[J]. 医学综述, 2021,27(7):1400-1405.

[20] 谢姝瑞,朱本胜,夏娟,等. 二维及三维斑点追踪成像评估二尖瓣脱垂并重度关闭不全患者右心室功能的变化[J]. 临床心血管病杂志, 2025,41(12):939-944.

[21] SLETTEN O J, AALEN J M, IZCI H, et al. Lateral wall dysfunction signals onset of progressive heart failure in left bundle branch block[J]. JACC Cardiovasc Imaging, 2021,14 (11):2059-2069.

(本文编辑 范睿心)

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[19] LI L, BAI L, LIN H, et al. Multiomics analysis of tumor mutational burden across cancer types[J]. Comput Struct Biotechnol J, 2021,19:5637-5646.

[20] ZHOU H, SUN D T, SONG S N, et al. Efficacy of immunotherapy in ARID1A-mutant solid tumors: A single-center retrospective study[J]. Discov Oncol, 2024,15(1):213.

[21] LI L, LI M Y, JIANG Z H, et al. ARID1A mutations are associated with increased immune activity in gastrointestinal cancer[J]. Cells, 2019,8(7):678.

[22] LO Y H, KOLAHI K S, DU Y H, et al. A CRISPR/Cas9-Engineered ARID1A-deficient human gastric cancer organoid model reveals essential and nonessential modes of oncogenic transformation[J]. Cancer Discov, 2021,11(6):1562-1581.

[23] MOLINARI C, SOLAINI L, REBUZZI F, et al. Genomic events stratifying prognosis of early gastric cancer[J]. Gastric Cancer, 2024,27(6):1189-1200.

[24] LANDRE T, DES GUETZ G. Microsatellite instability-high status as a pan-cancer biomarker for immunotherapy efficacy [J]. Cancer Immunol Immunother, 2025,74(4):122.

[25] SHEN J F, JU Z L, ZHAO W, et al. ARID1A deficiency promotes mutability and potentiates therapeutic antitumor immunity unleashed by immune checkpoint blockade[J]. Nat Med, 2018,24(5):556-562.

[26] D’AMBROSIO A, BRESSAN D, FERRACCI E, et al. Increased genomic instability and reshaping of tissue microenvironment underlie oncogenic properties of *Arid1a* mutations [J]. Sci Adv, 2024,10(11):eadh4435.

[27] LU S, DUAN R F, CONG L, et al. The effects of *ARID1A* mutation in gastric cancer and its significance for treatment[J]. Cancer Cell Int, 2023,23(1):296.

[28] MONTAUTI E, OH D Y, FONG L. CD4⁺ T cells in antitumor immunity[J]. Trends Cancer, 2024,10(10):969-985.

[29] MAXWELL M B, HOM-TEDLA M S, YI J, et al. ARID1A suppresses R-loop-mediated STING-type I interferon pathway activation of anti-tumor immunity [J]. Cell, 2024, 187 (13):3390-3408.e19.

[30] SUN S B, LIU L C, ZHANG J K, et al. The role of neoantigens and tumor mutational burden in cancer immunotherapy: Advances, mechanisms, and perspectives[J]. J Hematol Oncol, 2025,18(1):84.

[31] WANG Z Q. Machine learning-based dynamic predictive models for prognosis and treatment decisions in patients with liver metastases from gastric cancer[J]. Am J Cancer Res, 2024,14 (11):5521-5538.

(本文编辑 耿波)