Assessment of Biventricular Function in Clinically Well Pediatric Heart Transplantation Patients by Three-dimensional Speckle Tracking Echocardiography

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Research

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Abstract

Background Studies on pediatric heart transplantation (HTx) are uniquely challenging because pediatric HTx center volumes are generally low. And, the biventricular function plays an important role in the prognosis of pediatric HTx. The primary aim of our study was to evaluate biventricular function of pediatric HTx by three-dimensional speckle tracking echocardiography(3D-STE).

Methods We enrolled 30 clinically well pediatric HTx patients and 30 sex- and age- matched healthy controls. All subjects underwent comprehensive echocardiographic examinations. Left ventricular (LV) global longitudinal strain (GLS), global circumferential strain (GCS), LV and right ventricular (RV) ejection fraction (EF) and RV longitudinal strain (RVLS) of free wall and septum were acquired by 3D-STE. And the correlations between strains and clinical data were explored.

Results Compared with controls, LV GLS was decreased in pediatric HTx patients ($P<0.05$), while LV GCS and LVEF showed no difference. RVEF, RVLS (free wall) and RVLS (septum) in HTx group were diminished ($P<0.05$), but RVEF was still in normal range. Cold ischemic time was correlated inversely with LV GLS ($\beta=-0.401$, $P<0.05$). The mean pulmonary artery pressure ($\beta=0.447$, $P<0.05$) and postoperative tricuspid regurgitation pressure ($\beta=0.607$, $P<0.05$) were associated with RVLS (free wall).

Conclusion Biventricular longitudinal systolic function rather than global systolic function was impaired after HTx. 3D STE may be able to evaluate the ventricular function better. Prolonged ischemic time leads to impaired LV longitudinal systolic function in pediatric HTx patients. It's interesting that in HTx patients, it shows compensatory enhancement due to increased pulmonary vascular resistance.

Introduction

Orthotopic heart transplantation (HTx) is a well-established and effective therapeutic option for children with end-stage heart failure.[1–5] The assessment of ventricular function has been hotspot since the first HTx in 1967. Until now, many efforts have been made to in the aspect of characteristics of the transplanted heart.[6–11] Studies on adult HTx patients have showed that the myocardial function of HTx patients was different from normal people and patients undergoing other cardiac surgery.[5–9, 11–15] These studies found that the myocardial function decreased in both clinically stable and unstable HTx patients, and that left ventricular (LV) dysfunction after HTx was multifactorial and could be an indicator of graft rejection or coronary artery vasculopathy (CAV).[6–8, 12] In their recent study, Ingvarsson and his peers have reported the reference ranges for adults after HTx with no acute transplant associated cardiac complications or CAV.[6]

But, studies on pediatric HTx are uniquely challenging because pediatric HTx center volumes are generally low.[2, 4, 14] And, most of the existing studies were done by two-dimensional speckle tracking echocardiography (2D STE). As we all know, 2D STE algorithms only track speckles in 2D planes, while speckles move in 3-dimensions, so only a portion of the real motion can be detected. This limitation is particularly relevant in heart transplant recipients, in whom the typically greater size of the mediastinal cavity when compared with the donor heart, and the loss of support provided by the pericardial sac, results in a marked translational motion of the transplanted heart inside the chest during the cardiac cycle.[12] Fortunately, three-dimensional speckle tracking echocardiography (3D STE), as a novel technique, overcomes the limitation and has been suggested to be a more accurate tool for global and segmental assessment of LV function.

So, in this study, we tried to report 3D biventricular volume and strain in clinical well pediatric HTx population. And, we sought to describe possible impact of clinical variables on biventricular myocardial mechanics.

Method

The study was conducted in Union Hospital of Tongji Medical College, Huazhong University of Science and Technology, Wuhan, China. The study was approved by the ethics committee of the university and the entire studied population was enrolled after informed consent was obtained.

Study Population

Pediatric patients who underwent HTx in Union Hospital of Tongji Medical College, Huazhong University of Science and Technology after January 1, 2015 were enrolled during their routine follow up. The patients included were ≤ 18 years old when they underwent HTx. And, at the time of examination all patients were in sinus rhythm or a regular paced rhythm (10 patients were in regular paced rhythm). Exclusion criteria were as follows: (1) suspicion of graft rejection based on standard clinical findings (changes in LV function, ECG, arrhythmia, serologic examinations, valve regurgitation); (2) evidence of coronary artery disease (defined as the presence of a stenosis > 50% in any major artery or distal pruning of any secondary branch on the basis of angiographic or coronary CTA); (3) significant valvular regurgitation or stenosis (more than mild); (4) within 6 months after transplantation.

The control group consisted of age and sex matched healthy children. All children included were in sinus rhythm or a regular paced rhythm (4 were in regular paced rhythm).

Demographic and clinical data of the subjects were collected in detail and listed in Table 1. Mean pulmonary artery pressure pre-HTx was assessed by percutaneous cardiac catheterization. It’s hard for pediatric patients to take percutaneous cardiac catheterization in their routine follow up, as a result, we failed to acquire mean pulmonary artery pressure post-HTx.

Table 1
All baseline patient characteristics of the 30 pediatric HTx patients

	HTx (n = 30)	Control (n = 30)	P
Recipient			
Age (year), median (IQR)	12.5 (8.6–14.9)	11.0 (7.0-17.3)	0.200
Sex (M/F)	15/15	17/13	0.612
Hight (cm)	144.0 ± 23.9	143.9 ± 26.7	0.988
Weight (kg)	41.9 ± 15.8	39.4 ± 15.0	0.535
BSA (m^2)	1.3 ± 0.3	1.2 ± 0.4	0.560
HR (bpm)	98 ± 10	81 ± 11	< 0.001
SBP (mmHg)	110 ± 13	104 ± 7	0.037
DBP (mmHg)	64 ± 9	71 ± 7	0.002
Age at HTx (year), median (IQR)	11.0 (7.6–14.1)		
Elapsed time since HTx (month), median (IQR)	11.3 (7.5–22.2)		
Pulmonary arterial pressure pre-HTx (mmHg)	30.3 ± 12.9		
Previous rejection, n (%)	2 (6.7%)		
Previous cytomegalovirus infection, n (%)	4 (13.3%)		
Surgical Approach			
Biatrial, n (%)	2 (6.7%)		
Bicaval, n (%)	28 (93.3%)		
Reason for HTx			
CHD, n (%)	3(10%)		
DCM, n (%)	18 (60%)		
RCM, n (%)	4 (13.3%)		
HCM, n (%)	2 (6.7%)		
EFE, n (%)	2 (6.7%)		

HTx, heart transplantation; BSA, body surface area; HR, heart rate; SBP, systolic blood pressure; DBP, diastolic blood pressure; CHD, Congenital Heart Disease; DCM, Dilated Cardiomyopathy; RCM, Restrictive Cardiomyopathy; HCM, Hypertrophic Cardiomyopathy; EFE, Endocardial Fibroelastosis; MCLS, Mucocutaneous Lymph Node Syndrome; NYHA, New York Heart Association; P < 0.05, the difference was statistically significant.

	HTx (n = 30)	Control (n = 30)	P
MCLS, n (%)	1 (3.3%)		
NYHA pre-HTx			
III, n (%)	2 (6.7%)		
IV, n (%)	28 (93.3%)		
Complication			
Hypertension, n (%)	19 (63.3%)		
Diabetes mellitus, n (%)	2 (6.7%)		
Donor			
Age (year), median (IQR)	19.0 (10.5–26.0)		
Sex (M/F)	19/11		
Weight ratio (Donor/Recipient)	1.5 ± 0.5		
Cold ischemic time (min), median (IQR)	369 (330–375)		

HTx, heart transplantation; BSA, body surface area; HR, heart rate; SBP, systolic blood pressure; DBP, diastolic blood pressure; CHD, Congenital Heart Disease; DCM, Dilated Cardiomyopathy; RCM, Restrictive Cardiomyopathy; HCM, Hypertrophic Cardiomyopathy; EFE, Endocardial Fibroelastosis; MCLS, Mucocutaneous Lymph Node Syndrome; NYHA, New York Heart Association; P < 0.05, the difference was statistically significant.

Conventional Transthoracic Echocardiography (tte)

Standard TTE examination were performed in all subjects with an S5-1 or S8-3 transducer (1–5 or 3–8 MHz, EPIC 7, Philips Medical Systems, Andover, USA), according to patient body habitus. All the images were acquired without anesthesia and sedation during a single breath hold. Conventional chamber sizes and wall thickness were measured. RV fractional area change (FAC), tricuspid annulus systolic displacement (TAPSE) and s' velocities of RV free wall at the level of tricuspid annulus were also recorded.

3D STE

Three-dimensional (3D) TTE examination were performed in all subjects with an X5-1 transducer (1–5 MHz, EPIC 7, Philips Medical Systems, Andover, USA). 3D data sets consisted of LV and RV full pyramidal volumes from the apical view, respectively. Optimization of 3D images and adjustments in depth and full-volume sector angles yielded a temporal resolution of 20–30 volumes per second. Offline 3D STE analysis was performed using software for echocardiographic quantification (4D LV-Analysis 3.0 and 4D RV-Analysis 2.0, TomTec Imaging Systems, Unterschleissheim, Germany).

For the LV function analysis, the software automatically displays three apical and one short-axis views. Endocardial and epicardial surfaces are automatically detected with manual adjustments when necessary (Fig. 1). Finally, LV end-diastolic volume (EDV), end-systolic volume (ESV), LV ejection fraction (LVEF), LV end-diastolic mass (LVM), LV global peak value of each strain component (global longitudinal strain [GLS] and global circumferential strain [GCS]) were obtained from all patients.

For the RV function analysis, the software automatically displays one apical and three short-axis views. Endocardial surface is automatically detected with manual adjustments when necessary (Fig. 2). Finally, RV EDV, RV ESV, RV EF, RV interventricular septum longitudinal strain (RVLS [Septum]), and RV free wall longitudinal strain (RVLS [Free wall]) were obtained from all patients.

Reproducibility

Intraobserver variability was assessed in 10 randomly chosen studies on two distinct occasions separated by several weeks in time. Interobserver measurements in 10 studies were performed by two reviewers (M.L. and C.W.), each blinded to the other's assessment on two separate occasions.

Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics version 22.0 (SPSS, Inc., Chicago, IL). Continuous variables were shown as mean ± SD or median (interquartile range, IQR). Categorical variables are expressed as frequencies or percentages. Comparisons about continuous variables between two groups were performed using unpaired Student t test or Mann–Whitney U test, as appropriate. On the global myocardial mechanics aspect, Spearman or Pearson correlation tests, as appropriate, along with linear regression were conducted to test association between clinical data and global strain parameters. Intra- and interobserver variability for 3D STE parameters were assessed by intraclass correlation coefficients (ICCs) and Bland-Altman analysis. Statistical significance was defined as a 2-sided P value < 0.05.

Results

Participant characteristics

The study enrolled a total of 35 pediatric patients, and 32 healthy children. After exclusion (2 within 6 months after transplantation, 1 with moderate tricuspid regurgitation, 2 with poor image quality), 30 HTx patients were finally included. The median elapsed time since HTx was 11.3 (7.5–22.2) months. Meanwhile, 30 healthy children were finally included as control group (2 was excluded for poor image quality). According to the clinical records, 23 HTx patients underwent percutaneous cardiac catheterization before transplantation, and the preoperative mean pulmonary artery pressure was 30.3 ± 12.9 mmHg. Baseline characteristics of HTx group and control group were shown in Table 1. The heart rate and blood pressure of HTx group were significantly higher ($P < 0.05$), but blood pressure was in normal range.

Conventional TTE parameters

2D echocardiographic, color Doppler and tissue Doppler findings of the left and right heart are presented in Table 2 and Table 3, respectively. TASPE, s’ (Free wall) and RVFAC were decreased in HTx group ($P < 0.05$), but RVFAC was still in normal range. 13 HTx patients had mild tricuspid regurgitation at the time of examination. The mean tricuspid regurgitation velocity was 2.4 ± 0.4 m/s, and the mean tricuspid regurgitation pressure was 23.5 ± 6.8 mmHg, as estimated from the tricuspid regurgitation velocity (using the modified Bernoulli equation).

Table 2
Two-dimensional echocardiographic, color Doppler and tissue Doppler findings of the left heart

	HTx (n = 30)	Control (n = 30)	P
LA (mm)	37.5 ± 5.3	30.1 ± 4.4	< 0.001
LV (mm)	37.6 ± 4.1	39.0 ± 5.9	0.276
IVS (mm)	6.8 ± 1.1	5.8 ± 1.0	< 0.001
PW (mm)	6.4 ± 1.1	5.6 ± 1.9	0.005
E (Mitral, cm/s)	95.9 ± 17.7	102.0 ± 19.3	0.267
A (Mitral, cm/s)	51.3 ± 10.5	61.3 ± 13.9	0.003
E/A (Mitral)	1.9 ± 0.4	1.7 ± 0.5	0.073
E/e (Septum)	9.7 ± 2.7	7.3 ± 1.5	< 0.001
E/e (lateral)	6.6 ± 1.8	5.9 ± 1.7	0.132
E/e (Mean)	8.1 ± 1.9	6.6 ± 1.4	0.001

HTx, heart transplantation; LA, left atrial; LV, left ventricular; IVS, interventricular septum; PW, posterior wall; $P < 0.05$, the difference was statistically significant.

Table 3
Two-dimensional echocardiographic, color Doppler and tissue Doppler findings of the right heart

	HTx (n = 30)	Control (n = 30)	P
RA (mm)	32.0 ± 4.1	29.5 ± 3.7	0.017
RV (mm)	36.0 ± 3.9	28.6 ± 4.1	0.056
TAPSE (mm)	12.0 ± 2.1	21.5 ± 3.2	< 0.001
RVFAC (%)	44.8 ± 4.5	47.0 ± 2.5	0.018
s’ (Free wall, cm/s)	8.5 ± 1.9	13.2 ± 2.1	< 0.001
E (Tricupid, cm/s)	65.4 ± 11.4	67.7 ± 11.1	0.432
A (Tricupid, cm/s)	47.8 ± 11.0	48.6 ± 11.8	0.785
E/A (Tricupid)	1.4 ± 0.3	1.5 ± 0.3	0.553

HTx, heart transplantation; RA, right atrial; RV, right ventricular; TAPSE, tricuspid annulus systolic displacement; RVFAC, right ventricular fractional area change; P < 0.05, the difference was statistically significant.

Lv Strain Derived From 3d Ste Analysis

Data of the LV, derived from 3D STE, was showed in Table 4. In HTx group, GLS was decreased ($P < 0.05$), while GCS and LVEF remained ($P > 0.05$). All the clinical variables listed in Table 1 and tricuspid regurgitation pressure at the time of examination were entered into a simple linear correlation with GLS and GCS. Only LVEF pre-HT, donor sex and cold ischemic time showed significance or trends toward significance with GLS, while no variables showed significance or trends toward significance with GCS. They were entered into multivariate linear regression analyses. Only cold ischemic time was an independent predictor of GLS (β=-0.401, $P < 0.05$). The result was showed in Table 5.

Table 4

Data of the LV derived from 3D STE

	HTx (n = 30)	Control (n = 30)	P
LV EDV (ml)	63.1 ± 20.6	63.7 ± 25.5	0.914
LV ESV (ml)	21.4 ± 7.3	21.3 ± 9.2	0.960
LV SV (ml)	41.7 ± 13.8	42.4 ± 16.5	0.849
LVEF (%)	66.0 ± 3.5	66.9 ± 2.6	0.241
LVM index (g)	131.5 ± 32.7	118.3 ± 18.6	0.038
GLS (%)	-18.7 ± 1.1	-22.3 ± 1.9	< 0.001
GCS (%)	-34.2 ± 3.6	-33.4 ± 2.12	0.285
HTx, heart transplantation; LV, left ventricular; EDV, end-diastolic volume; ESV, end-systolic volume; SV, stroke volume; LVEF, left ventricular ejection fraction; LVM, left ventricular end-diastolic mass; GLS, global longitudinal strain; GCS, global circumferential strain; 3D STE, three-dimensional speckle tracking echocardiography; P < 0.05, the difference was statistically significant.			

Table 5

The results of multivariate linear regression analyses of GLS

	Univariate analysis		Multivariate analysis	
	r	p	β	p
LVEF pre-HTx	0.117	0.042		0.103
Cold ischemic time	0.079	0.076	-0.401	0.034
Donor sex	0.153	0.020		0.102
GLS, global longitudinal strain; HTx, heart transplantation; P < 0.05, parameters were statistically correlated.				

Rv Strain Derived From 3d Ste Analysis

Data of the RV, derived from 3D STE, was showed in Table 6. All the clinical variables listed in Table 1 and tricuspid regurgitation pressure at the time of examination were entered into a simple linear correlation with RVLS (free wall). Only mean pulmonary artery pressure pre-HTx, previous cytomegalovirus infection and tricuspid regurgitation pressure post-HTx showed significance or trends toward significance with RVLS (Free Wall). The result of multivariate linear regression analyses of RVLS (Free Wall) was showed in Table 7. Mean pulmonary artery pressure ($\beta = 0.447$, $P < 0.05$) and postoperative tricuspid regurgitation pressure ($\beta = 0.607$, $P < 0.05$) were independently associated with RVLS (free wall).

Table 6

Data of the RV derived from 3D STE

	HTx (n = 30)	**Control (n = 30)**	**P**
RV EDV (ml)	46.7 ± 13.5	44.6 ± 19.1	0.626
RV ESV (ml)	22.7 ± 6.9	18.3 ± 7.9	0.027
RV SV (ml)	24.0 ± 7.2	26.3 ± 11.6	0.356
RVEF (%)	51.4 ± 4.0	58.8 ± 4.1	< 0.001
RVLS (Septum, %)	-14.8 ± 3.1	-21.7 ± 1.8	< 0.001
RVLS (Free wall, %)	-21.4 ± 1.7	-27.5 ± 1.9	< 0.001

HTx, heart transplantation; RV, right ventricular; EDV, end-diastolic volume; ESV, end-systolic volume; SV, stroke volume; RVEF, right ventricular ejection fraction; RVLS, right ventricular longitudinal strain; P < 0.05, the difference was statistically significant.

Table 7

The results of multivariate linear regression analyses of RVLS (Free wall)

	Univariate analysis		**Multivariate analysis**	
	r	p	β	p
Pulmonary pressure pre-HTx (mmHg)	0.232	0.021	0.447	0.010
Previous cytomegalovirus infection (yes, %)	0.077	0.076		0.909
TR pressure at the time of examination(mmHg)	0.422	0.020	0.607	0.001

RVLS, right ventricular longitudinal strain; HTx, heart transplantation; TR, tricuspid regurgitation. P < 0.05, parameters were statistically correlated.

Intraobserver And Interobserver Reproducibility

The ICCs and Bland-Altman analyses for the intra- and inter- observer reproducibility of the strain parameters derived from 3D STE were showed in Table 8. All ICCs were consistent with good to excellent reproducibility and the range of the difference could be tolerated.

Table 8
Intraobserver and interobserver reproducibility

	ICC (95% CI)	Bias (95% CI)	Limits of agreement
Intraobserver			
GLS	0.88 (0.56–0.97)	0.11 (-0.33-0.55)	-1.10-1.31
GCS	0.93 (0.75–0.98)	-0.47 (-1.28-0.35)	-2.70-1.77
RVLS (free wall)	0.96 (0.84–0.99)	0.27 (-0.09-0.64)	-0.72-1.27
RVLS (septum)	0.92 (0.72–0.98)	0.34 (-0.43-1.11)	-1.77-2.46
Interobserver			
GLS	0.89 (0.62–0.97)	0.37 (0.05–0.80)	-0.78-1.54
GCS	0.92 (0.71–0.98)	-0.27 (-1.14-0.60)	-2.65-2.12
RVLS (free wall)	0.89 (0.62–0.97)	0.26 (-0.45-0.98)	-1.70-2.22
RVLS (septum)	0.90 (0.66–0.97)	0.02 (-0.65-0.68)	-1.81-1.84

GLS, global longitudinal strain; GCS, global circumferential strain; RVLS, right ventricular longitudinal strain

Discussion

We conducted this study to report 3D biventricular volume and strain and validate whether 3D STE can show more details in biventricular function in pediatric HTx population with stable clinical status. And we also tried to describe possible impact of demographic and clinical data on biventricular myocardial mechanics. To our knowledge, this is the first comprehensive evaluation of biventricular function in clinically well pediatric HTx patients by 3D STE. Though some investigators are actively trying to use parameters assessing diastolic function, but the results are conflicted, especially in pediatric patients.[16–23] In this study, we pay more attention to the systolic function.

Left Ventricular

Previous studies in both clinically well pediatric and adult HTx patients have showed a mean LVEF in the normal range,[6, 7, 12, 24–26] but some were statistically significantly lower than reference.[6, 12] Our pediatric HTx patients showed a mean LVEF in the normal range, no statistically significantly compared to control group, which agrees with some of the previous studies. [7, 24–26] HTx patients in our study maintained normal global LV systolic function.

We saw a reduction in GLS in our study, which agrees with the previous pediatric and adult study.[6, 7, 24, 25, 27] This reflect that the LV longitudinal systolic function was impaired even in clinical well HTx patients. GLS is mainly produced by subendocardial myocardium, and subendocardial myocardium is sensitive to ischemia, myocardial alignment disorder, and fibrosis. [28, 29] So, ischemic time during surgery, changes in post-operative load status, myocardial reperfusion injury, and some postoperative complications may affect its function. In multivariate linear regression, we found that cold ischemic time is an independent impactor on longitudinal systolic function, though the correlation was weak. This result indicated a promising trend that the longer the cold ischemic time, the worse the LV longitudinal systolic function. The previous studies also showed that GLS was significantly correlated with NYHA functional class, previous rejection, and CAV.[2, 6, 11, 30–33] However, we didn't find any other statistically significantly correlation.

Studies on GCS were less than GLS. Some of the previous studies showed a reduction in GCS.[7, 26] But, in our study, GCS remained normal, which agrees with Ingvarsson's study in 2017.[6] This reflect that the LV circumferential systolic function in HTx patients was remained. The circumferential systolic function remained, while longitudinal systolic function decreased. That might possibly indicate a compensatory mechanism, and this may also explain why LVEF remained normal. We did not find any significant indicators related to GCS. This may due to that circumferential systolic function was less influenced by the patients' clinical status pre-HTx and the habitats of donor heart.

We also found that the LV wall thickness and LVM increased in HTx patients. Wall thickness has been discussed in detail in previous adult HTx studies. Researchers explored that the LV morphology is characterized by an increase in LVM and wall thickness during the first month after HTx. After three months, the wall thickening mostly improved.[30, 34] A secondary increase in LVM and wall thickness may occur as a consequence of many factors such as repetitive rejection episodes, chronic tachycardia, and systemic hypertension, usually induced by immunosuppressive agents.[30, 34–36] Some patients in our study suffered from systemic hypertension and renal dysfunction after the surgery, though treated, the effect on the ventricular wall may not disappear completely.

Right Ventricular

RV dysfunction was sought to be one of the most important cause of death in the early post-HTx period.[30, 37–39] However, evaluation of RV function has always been a challenge. In our study, we used both conventional and 3D RV functional parameters to evaluate the RV function of pediatric HTx patients.

We found that RVLS (free wall), RVLS (septum) and RVEF all decreased, but RVEF still in a normal range in pediatric HTx patients. This reflected that the longitudinal RV systolic function rather than the whole RV function impaired more in pediatric HTx patients. This is mostly consistent with previous studies.[9, 40–42]

Since RVLS (eptum) is usually greatly affected by LV, we did not discuss it in detail and pay more attention to RVLS (Free wall). In multivariate linear regression, we found that in pediatric HTx patients, RV longitudinal systolic function was enhanced as mean pulmonary artery pressure pre-HTx and tricuspid regurgitation pressure increased. It's an interesting finding. Compared with normal, RV longitudinal systolic function was decreased, but it showed a compensatory enhancement as a response to increased pulmonary vascular resistance and RV afterload among pediatric HTx patients. Most of the patient underwent HTx had increased pulmonary vascular resistance and RV afterload. These changes persisted on even after surgery and may resulted in compensatory enhancement in RV longitudinal systolic function. In our study, the mediate follow up time was 1 year, whether the compensatory mechanism would exist in the future was unknown and needs further study. Previous studies had found that RV function was also significantly correlated with the ischemic time and requirement for mechanical circulatory support pre- or post-HTx.[41–43] However, we didn't find significant correlation between RV function with ischemic time. And, only few patients required mechanical circulatory support pre- or post-HTx, so we didn't take this factor into consideration.

In our study, both the conventional parameters, including TAPSE and s' (RV free wall), and RVLS derived from 3D-STE showed that the RV longitudinal systolic function was impaired. While, RV FAC and 3D RVEF showed normal global systolic function. However, previous studies revealed that TAPSE and s' may be reduced due a distorted anatomy in the context of a normal overall RV function and EF in HTx, and TAPSE, s' (RV free wall) and RV FAC measured by 2D echocardiography were insufficient to assess RV function due to the complex anatomy of the RV.[6, 30, 44] 3D echocardiography parameters, such as RVLS (Free wall) and RVEF, might be able to evaluate the RV function better.

Some of the findings in our study were also found by 2D STE. However, 2D STE algorithms only track speckles in 2D planes, only a portion of the real motion of the heart can be detected. Fortunately, 3D STE, as a novel technique, overcomes the limitation and has been suggested to be a more accurate tool for global and segmental assessment of LV function. What's more, 2D-STE is time-consuming. We need more than 30 minutes to analyses a patient by 2D STE, while we only need 10–15 minutes by 3D STE, while. So, we recommend 3D STE as a more appropriate technique for the analysis of LV function in HTx patients.

Limitations

The study volumes are generally low. It is difficult for children to take EMB, so whether rejection exists was judged according standard clinical findings in our study. In our study, the control group was included only according to the recipients.

Conclusion

Biventricular longitudinal systolic function rather than global systolic function was impaired after HTx. 3D STE may be able to evaluate the ventricular function better. Prolonged ischemic time leads to impaired LV longitudinal systolic function in pediatric HTx patients. It's interesting that the RV longitudinal systolic function was impaired compared with normal, but in HTx patients, it shows compensatory enhancement due to increased pulmonary vascular resistance and increased RV afterload.

Declarations

Ethics approval and consent to participate: It's a retrospective study. The study was conducted in Union Hospital of Tongji Medical College, Huazhong University of Science and Technology, Wuhan, China. The study was approved by the ethics committee of the university.

Consent for publication: The consent was obtained from the patients or their legal guardian.

Availability of data and materials: The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests: none.

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Authors' contributions:

Conception and design of the study: Q.L., M.L., Y.L., L.Z., M.X.

Acquisition of data: M.L., H.L., C.W.

Analysis and interpretation of data: M.L., H.L., C.W.

Drafting the article: Q.L., M.L.

Revising the article: Q.L., M.L., N.D., Y.L., L.Z., M.X.

Final approval of the article: Q.L., M.L., H.L., C.W., N.D., Y.L., L.Z., M.X.

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Figures

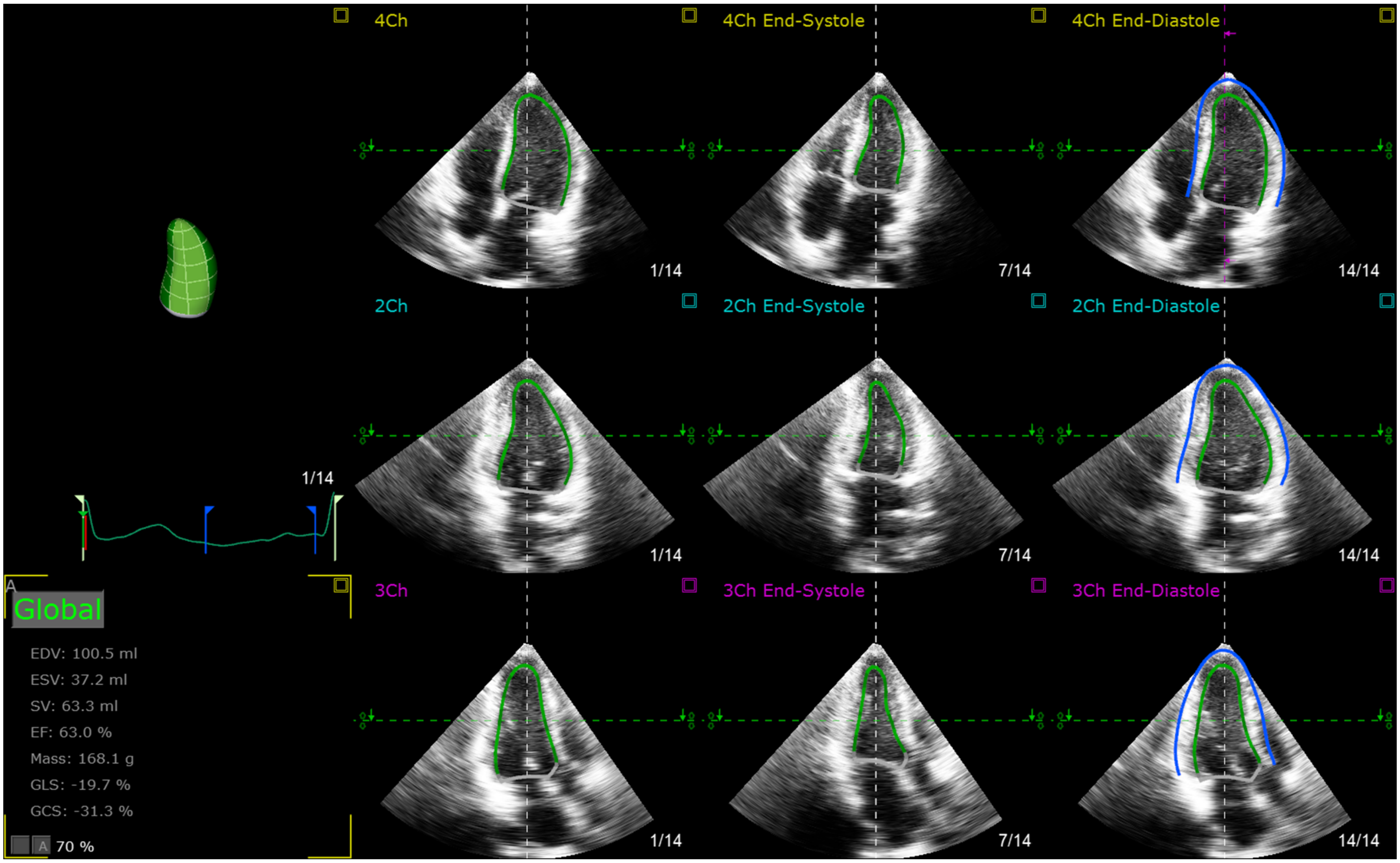

Figure 1

LV function analysis by 3D STE (LV, left ventricular; EDV, end-diastolic volume; ESV, end-systolic volume; SV, stroke volume; EF, ejection fraction; GLS, global longitudinal strain; GCS, global circumferential strain)

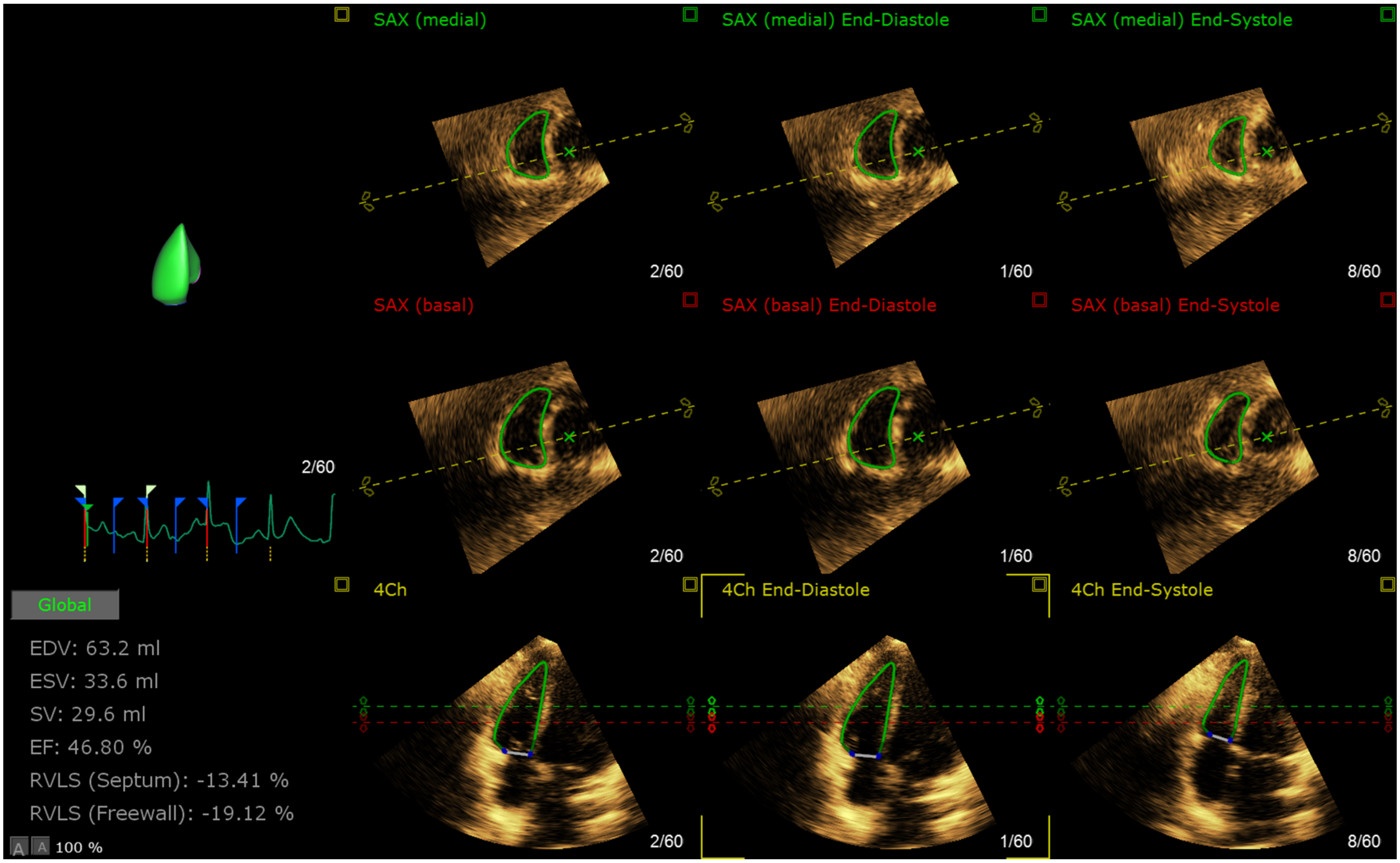

Figure 2

RV function analysis by 3D STE (RV, right ventricular; EDV, end-diastolic volume; ESV, end-systolic volume; SV, stroke volume; EF, ejection fraction; RVLS, right ventricular longitudinal strain)