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Analysis of association of ventricular strain parameters with LV mass index in children with remodeling LV after heart transplantation

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Abstract

Objectives: The differences in body surface area (BSA) between recipients and donors of heart transplantation (HT) are common in children. In this study, we investigated the association of the LV (left ventricle) mass index with the myocardial longitudinal strain (LS) over time up to 1 year after heart transplantation in children who had a relatively small BSA compared to donor.

Methods: We reviewed 81 consecutive patients under 18 years old who received the heart between August 1997 and June 2017. 29 patents had the donor BSA of more than 130% of the recipient's BSA. 16 of them had echocardiographic record in which we could analyze LV mass index and the strain. Also, we analyzed 19 patients with echocardiographic results whose BSA was less than 130% of donor's BSA. 3 analyzes were performed over a one-year period. The first, second and third analysis was done at 1.1±0.5, 4.9±1.7, 12.4±2.7 months after HT, respectively. Echocardiographic results obtained within 1 month after a diagnosis of acute rejection were excluded

Results: The study included 35 patients underwent HT. In the group of patient's BSA was greater than 130% of donor's, the mean LV mass index for each period was 147.9±57.8, 130.7±36.3, 108.9±35.7 g/m^2, which tend to decrease with time after HT as ventricular remodeling occurs (p=0.061). In the other group, the mean LV mass index for each period remained same as 99.1±36.9, 99.1±27.7, 92.1±18.7 g/m2 (p=0.614). The longitudinal strains of LV negatively increase -12.2±3.3, -14.4±5.1, -17.4±5.0 over time in 4 chamber view in the group of BSA ratio ≥ 130% (p=0.011) whereas there was no significant change in the other group (p=0196). There was no significant change in RV strain in both groups. Although the LV mass index and the longitudinal strain of LV did not correlate with each other until the second analysis, they were significantly correlated with each other in the third analysis (p=0.042) in the group of patient's BSA was greater than 130% of donor's.

Conclusions: The increasing tendency of LV LS of 4 chamber view was shown in children with remodeling process of LV only in children with BSA donor/recipient ratio ≥ 1.3. The association of LS and mass index of LV was clear only in patients with big BSA ratio after the 1 year from HT.

Key words: Ventricular remodeling, Pediatric, Heart transplantation, body surface area, Myocardial strain analysis

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Introduction

Heart transplantation is the definite therapeutic tool in patients with end-stage heart failure or complex heart disease without any other surgical therapeutic option.[1)] The transplanted heart need to adjust to the new hemodynamic condition of recipient. Adaptive growth of the transplanted heart was reported in several studies.[2-4)] Numerous factors such as the type of immunosuppressant drugs, ischemic time, donor brain death were associated with adaptation of transplanted heart.[5)] However there will be much more factors which affects to the process of ventricular remodeling than we recognize.

Monitoring ventricular function is the way to detect the adaptation process in heart recipients. Especially, echocardiography is widely used for monitoring ventricular function after heart transplant due to its accessibility and low cost.[6)] Although traditional echocardiographic ejection parameters such as ejection fraction (EF), fractional shortening (FS) are generally used to measure ventricular function, these indices have a low sensitivity for detecting regional dysfunction. Moreover, hemodynamic components such as preload, afterload and ventricular geometry can alter the results.[7, 8)] Two-dimensional speckle tracking echocardiography (STE) such as myocardial strain and strain rate is comparatively newer index with better sensitivity for identifying subtle regional change of ventricular wall motion.[7, 8)] In several reports, children following heart transplantation without any rejection showed markedly decreased longitudinal strain and strain rate in the immediate post-transplant period.[9, 10)] Even though left ventricle (LV) longitudinal, radial, and circumferential strain progressively improved over time, it remained abnormal compared with healthy control at 2years after transplantation.[10)] If allograft rejection and coronary vascular vasculopathy occurs, the ventricular function deteriorate much more than we expect.[11-13)] STE facilitated discovering recipients at risk of clinical manifestation of rejection by finding out the subtle change in ventricular function.[11-13)] However, there is paucity of data on other risk factor of decreased ventricular strain and strain rate after heart transplantation in pediatric cardiac recipients. Especially, in children, mismatch of body surface area (BSA) between recipient and donor is common. Although adaptive growth of ventricle is described in traditional 2D echo indices[2-4)], there is no data of ventricular strain and strain rate of cardiac pediatric recipients with who have the wide discrepancy of BSA as far as we know.

The purpose of this study was to evaluate ventricular remodeling after heart transplantation in children who had a relatively small BSA compared to donor. We analyzed echocardiography to investigate the association of the LV mass index with the myocardial strain over time up to 1 year after heart transplantation. Our hypothesis was LV mass index and strain in pediatric recipients of heart decrease to adapt to recipient's hemodynamic environment especially when there is the large discrepancy in BSA between donors and recipients.

Methods

This study was executed in a single institution, Asan medical center, Republic of Korea. 81 consecutive recipients of heart between August 1997 and June 2017 under 18 years old were enrolled. We retrospectively reviewed echocardiography of patients. Echocardiography not stored in DICOM format (performed before January 2010) and inadequate echocardiographic images which could not calculate strain were excluded. Patients who died within a year after heart transplant were excluded. Also, to eliminate the interpretation of the result of rejection, echocardiographic results obtained within 1-month after diagnosis of acute rejection were excluded. Rejection was defined as cellular (≥ grade 2R) or antibody-mediated rejection requiring regulation of immunosuppressive agents. Echocardiography and cardiac biopsy were generally performed at 1, 2, 3, 6, 12 months after transplantation.

In our institution, basiliximab and tacrolimus, mycophenolate mofetil and methylprednisolone were used to induce immune suppression. Tacrobell and mycophenolate mofetil were maintained lifelong to maintain immune suppression while corticosteroid was weaned off 6 months after heart transplant. The target trough level of tacrobell was between 10~15 ng/ml for the first 2 months, 8~12 ng/ml for the next 4 months, and 5~10 ng/ml thereafter.

In this study, echocardiography at 1.1±0.5, 4.9±1.7, 12.4±2.7 months after heart transplantation were analyzed. LV mass index was calculated in M-mode measurement at the parasternal long axis view.[14] The standard ASE formula was used for calculation LV mass and indexed to BSA to calculate LV mass index. STE measurements were performed using the vendor-independent 2D Cardiac Performance Analysis Software (Tomtec imaging software). LV peak systolic longitudinal strain and strain rate were calculated from apical two-, three-, and four-chamber and LV circumferential and radial strain were measured from parasternal short axis including the base (at the level of mitral valve), papillary muscle and apex level. RV functional area change (FAC) and LS was also measured at apical four-chamber view. 2 investigators performed after-processing measurements. The myocardial margin was traced semi-automatically and adjusted additionally by readers if needed.

To analyze the effect of the discrepancy of BSA between donor and recipient, we established the criteria for the large BSA discrepancy when the donor BSA of more than 130% of the recipient's BSA. The reason for adopting this criterion was to compare the subgroup with similar numbers of patients.

Data were reported as mean ± standard deviation and SPSS version 21.0 software package (IBM, Armonk, New York, USA) was used for statistical analyses. *P* values of <0.05 were regarded as statistically significant. Statistical analyses comprised Independent t tests, Pearson χ^2 tests, repeated measure ANOVA and Pearson correlation coefficient tests. Independent t tests were used to compare the subgroups of BSA at each point. Pearson χ^2 tests were performed to determine wheter recipient's sex was significantly affect to the BSA ratio of donor and recipient. To compare various ECHO variables at the specific time points, repeated measure ANOVA was used. Pearson correlation coefficient was used in detection association of ventricular strain parameters with LV mass index.

Results

In total, 81 cardiac transplant recipients were analyzed. In 29 of 81 recipients, donor's BSA was larger than 130% of the recipient's BSA. 16 patients of them had echocardiography stored in DICOM which can be analyzed. 16 patients with donor/recipient BSA ratio 1.3 or higher were compared with 19 patients under 1.3. Finally, 35 patients with 96 echocardiographic results were included for analysis. The mean age of total heart transplant recipients at heart transplantation was 10.2 ± 5.8 years, that of heart transplant recipients with BSA ratio 1.3 or higher was 9.1 ± 5.7 years, and that of heart transplant recipients with BSA ration under 1.3 was 11.1 ± 5.8 years (Table 1). There was no significant difference in the age of heart transplantation between the group of BSA ratio ≥ 1.3 and < 1.3(*p*=0.802). 1st, 2nd and 3rd time interval from heart transplantation to analysis had no significant difference in both groups (*p*=0.262, 0.994 and 0.321, respectively). The sex ratio also showed no defference between the two groups (*p*=0.142). Table 2 showed the median BSA of two groups. In our institution, total pediatric heart recipient's mean BSA was 1.1±0.5 m^2 while total donor's mean BSA was 1.4±0.5 m^2. Donor's BSA was higher than recipient's BSA. In total patients, BSA ratio of donor to recipient was 1.4±0.4.

The LV mass index of recipients and donor is listed in table 3. Although there is no statistic significance, there is tendency of decreasing LV mass index for recipients for total group and BSA ratio ≥ 1.3 group after heart transplantation (*p*=0.081 and 0.061, respectively). As a result, the median LV mass index of donor's BSA of 1 year after heart transplantation has significant difference bewtween BSA ratio ≥ 1.3 and < 1.3 group (*p*=0.013). This can be inferred that ventricular remodeling occurs after heart transplantation espceially in patients with the big BSA ratio of donor to recipient.

The longitudinal LV strain in both groups of 4, 3, 2 chamber view is presented in table 4. In 4 chamber view, the longitudinal LV strain negatively increased over time in total and BSA ratio ≥ 1.3 group (*p*=0.015 and 0.011, respectively). In 2 chamber view, the absolute value of longitudinal LV strain was significantly decreased in group of BSA ratio ≥ 1.3 than in group of BSA ratio < 1.3 at 1st and 2nd analysis point (*p*=0.014 and 0.008, respectively). This difference between two groups disappeared one year after transplantation (*p*=0.951). The global longitudinal LV strain, integrated strain value of 4, 3, 2 chamber view, of each group is indicated in the bottom of table 4. There was significant change of global longitudinal LV strain over time only in total recipients group (*p*=0.013). However, there was tednency of negatively increasing global longitudinal LV strain in BSA ≥ 1.3 without statistical evidence (*p*=0.061). Also, it seemed that absolute value of the global LS at the first analysis time tended to be smaller in the group of large BSA ratio although there was no statistical significance (*p*=0.053).

LV circumferential and radial strain also evaluated at 3 levels of ventrile. At mitral valve level, there was tendency of decreasing absolute value of both circumferential and radial strain over time in both groups (Table 5, 6). However, statistical significancy was proved only for LV radial strain in total and BSA ratio ≥ 1.3 group (*p*=0.003 and 0.023, respectively) (Table 6). No significant difference was observed with time or BSA ratio at mid-level (papillary muscle level). Although there was no significant change over time of LV circumferential in both groups, absolute value of LV circumferential strain of 1st and 2nd time points after heart transplantation was smaller in BSA ratio ≥ 1.3 group than in BSA ratio < 1.3 group (*p*=0.015 and 0.015, respectively) (Table 5). Similary, the radial strain at the apex level of 1st and 2nd time points in large BSA ratio group was smaller than in small BSA ratio group (*p*=0.029 and 0.002, respectively) (Table 6). These differences in both circumferential and radial strain between two groups also receded one year after transplantation (*p*=0.652 and 0.064, respectively). The global circumferential and radial LV strain level did not change over time in both groups . However, as global

LV radial strain likely to decrease over time after heart transplantation, absolute values of global longitudinal strain at 2nd and 3rd time point were smaller in BSA ratio ≥ 1.3 group than in BSA ratio < 1.3 group (*p*=0.021 and 0.023, respectively).

Additionally, RV strain was analyzed (Table 7). RV FAC and global longitudinal strain in apical 4 chamber view did not change over time. Also, there was no difference between group of BSA ratio ≥ 1.3 and < 1.3 at each time point.

Finally, we analyzed the association of global LV longitudianl strain and LV mass index (Table 8). There was no association exept 3rd time point of BSA ≥ 1.3 group(*p*=0.042). The value of Pearson correlation coefficient between LS and LV mass index at 3rd time point was 0.513.

Discussion

To the best of our knowledge, this is the first report on the overall clinical courses of ventricular remodeling after pediatric heart transplantation in Korea by analyzing ventricular strain especially considering the physique of donor and recipient, although there have been several reports of ventricular strain over time in general pediatric heart recipients. [9, 10, 12, 15, 16]

As previous studies reported[10, 16], LV strain values progressively improved over time in our patients. We initially thought as LV mass index reduces after accommodation in heart recipients[2], transplanted heart which was accommodated to donor's large physique will no longer need to contract in high power in relatively new small recipients. However, the result was different from our expectation. In this study, we newly investigated improving values of LV longitudinal strain is more evident especially in patients with the high discrepancy of BSA between donor and recipient as BSA ratio over 1.3. On the other hand, global LV radial strain for the group of BSA ≥ 1.3 tend to decrease after transplantation over time. This discrepancy of global LV radial strain between the group of BSA ratio ≥ 1.3 and <1.3 was evident in 6-month and 1-year echocardiogram after transplantation. One explanation of this finding is as follow. Initial relative decrement in longitudinal strain in a period of ischemia is already known and described by other reports with myocardial fiber structure and myocardial blood supply[17-19]. Longitudinal fibers in subendocardial location which lie distal in the coronary arterioles are susceptible to ischemic change[17-19]. After transplantation, to apply satisfiable coronary supply to subendocardial layer of heart, more blood supply will be needed to relatively large heart compared with recipient's small body than before transplantation. It will cause more severe ischemia in recipients with large discrepancy of physique between donor and recipient than in heart from similar physique of donor. On the contrary, circumferential fibers, in the middle cardiac layer is not as susceptible to ischemia as longitudinal fiber. As a result, circumferential and radial strain tends to decrease over time after temporal augmentation when longitudinal strain decreases. This change is also more evident in the group of large BSA discrepancy group.

In specific view, LV longitudinal strain changed over time only in apical 4 chamber. 3 chamber and 2 chamber view did not show significant change over time. The reason for this disparity between views is maybe because of relative difficulty of taking constant 3- and 2- chamber view in recipients. There was overt decrement in LV radial strain over time in patients with the large discrepancy of BSA between donor and recipient especially at the basal level. In previous study[20)], reduced LV basal rotation has reported in children and young adults received heart transplantation. However, that study did not include changes over time. In our study, LV radial strain at basal level reduced over time after transplantation especially in patients with BSA ratio $\geq$ 1.3. It seems like since global longitudinal strain recovered as time goes, basal radial strain no longer needed to be maintained in over value. At apex level, circumferential and radial strain of LV is diminished in the group of BSA ratio $\geq$ 1.3 compared with the group of BSA ratio <1.3. However, there was no clear tendency over time in both groups. In previous report, during exercise, increase in the torsion slope and basal radial displacement is the way of increasing cardiac output in transplanted patients whereas healthy controls showed increased rotational measurements, apical rotation and decreased in basal radial displacement and circumferential strain[21)]. Similarly, we suggest that LV basal strain augmentation is the way to overcome decreased cardiac output especially in patients with large donor/recipient BSA ratio. When judged collectively, because the LV LS recovered over time after heart transplantation especially in the group of large donor/recipient BSA ratio, the global radial strain of LV may tend be decreased over time.

Meanwhile, RV strain and FAC did not show the change over time. In previous reports, however, there was report of improved RV function over the first year after heart transplantation[22)]. This difference may be from our exclusion of echocardiography immediate after heart transplantation. RV systolic function also did not show significant difference between the group of BSA ratio $\geq$ 1.3 and the group of BSA ratio <1.3. This implies RV function may not be influenced by the change of body surface area.

Association of LV longitudinal strain and LV mass index was clear 1 year after transplantation only in patients with BSA ratio ≥ 1.3. For other time points, there was no association between longitudinal strain and LV mass index. Maybe this is the part of ventricular remodeling of patients with large BSA discrepancy.

This study has some limitations. First, as our study is retrospective study, there may be some bias in interpreting echocardiogram. As several sonographers took echocardiogram, it is possible that the quality of the echocardiogram is not constant. However, as there was a protocol to take an echocardiogram after heart transplantation, inter-sonographer variability may be overcome. Moreover, they were disciplined wall. Secondly, as it is a single institutional study, there may be some selection bias. Third, due to small number of participants, we could not show significant change of global longitudinal strain even though there was increasing tendency in the BSA ratio ≥ 1.3 group. Finally, we only traced for 1 year after transplantation. Long-term follow-up study will be needed to determine the tendency of strain after transplantation.

Conclusion

In conclusion, we found the increasing tendency of LV longitudinal strain in children with remodeling process of LV only in children with BSA donor/recipient ratio ≥ 1.3. At the basal level, LV radial strain in recipients with BSA ≥ 1.3 decreased over time. At apex level, there was significant divergence in LV circumferential and radial strain within 6 months after heart transplantation between the large and small BSA ratio groups. We could not find the change of RV FAC and global longitudinal strain over time and between the large and small BSA ratio group. The association of longitudinal strain and mass index of LV was clear only in patients with big BSA ratio after the 1 year from HT.

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요약

배경: 소아 환자에서는 수혜자와 기증자 사이에 체표면적이 차이나는 경우가 흔하다. 본 논문에서 저자들은 기증자에 비해 상대적으로 작은 체표면적을 가진 소아에서 심장이식 후 1 년까지의 좌심실 질량 지수와 심근 종축 변형률의 변화에 대해 조사하였다.

방법: 1997 년 8 월부터 2017 년 6 월 사이에 심장이식을 시행 받은 18 세 이하의 81 명의 소아의 데이터를 고찰하였다. 29 명의 환자에서 기증자의 체표면적이 수혜자 체표면적의 130% 이상에 달하였다. 그 중 16 명의 환자에서 좌심실 질량 지수와 변형률을 분석할 수 있는 심초음파 기록이 있었다. 또한 우리는 기증자의 체표면적이 수혜자 체표면적의 130% 이하의 심초음파 기록을 가지고 있는 19 명에 대해서도 분석을 시행하였다. 1 년 동안의 추적 관찰 기간 중 3 번의 분석을 시행하였다. 첫번째 두번째 그리고 세번째 분석 시점은 각각 심장이식 후 평균 1.1±0.5, 4.9±1.7, 12.4±2.7 개월이었다. 급성 거부반응이 진단되고 1 개월 안의 심초음파 기록은 분석에서 제외하였다.

Results: 본 연구에는 심장이식을 시행 받은 35 명의 소아가 포함되었다. 기증자의 체표면적이 수혜자 체표면적의 130% 이상에 달하는 그룹에서 평균 각 분석시점의 평균 좌심실 질량 지수는 147.9±57.8, 130.7±36.3, 108.9±35.7 g/m^2 로 심장 이식 후 심실 재형성이 일어나면서 그 값이 감소하는 경향을 보였다 (p=0.061). 다른 그룹에서는 각각의 기간 동안 평균 좌심실 질량지수는 99.1±36.9, 99.1±27.7, 92.1±18.7 g/m^2 정도로 큰 차이가 없었다 (p=0.614). 4 chamber view 에서 측정한 좌심실의 종축 변형률의 경우 공여자/수혜자 체표면적의 비가 1.3 이상인 그룹에서는 시간이 지남에 따라 -12.2±3.3, -14.4±5.1, -17.4±5.0 로 음의 값으로 커지는 양상을 보였고 (p=0.011) 이는 다른 그룹에서는 시간에 따른 차이가 없었던 것과 대조되는 발견이었다 (p=0196). 우심실의 경우 양 쪽 그룹에서 모두 시간에 따른 변형률의 차이가 관찰되지 않았다. 좌심실 질량지수와 좌심실의 종축 변형률 사이에 두번째 분석시점까지는 뚜렷한 연관성이 발견되지 않았음에도 불구하고 세번째 분석시점에서는 체표면적비가 1.3 이상인 그룹에서 두 지표가 연관이 관찰되었다 (p=0.042).

결론: 심실의 재형성 과정이 진행됨에 따라 공여자/수혜자의 체표면적 비가 1.3 이상인 소아에서만 4 chamber view 에서 좌심실 종축의 변형률의 절대값의 증가 경향을 관찰할 수 있었다. 같은 그룹에서 좌심실의 종축 변형률과 좌심실 질량지수 사이의 연관성은 심장이식 1 년 후에 분명해졌다.

Key words: 심실 재형성, 소아, 심장이식, 체표면적, 심근 변형률 분석

Table 1. The mean age of total heart transplant recipients at heart transplantation

	Age (years)	1st analysis point after HT (months)	2nd analysis point after HT (months)	3rd analysis point after HT (months)	Sex
	Heart transplantation	HT-1st analysis	HT-2nd analysis	HT-3rd analysis	M : F
Total N=35	10.2±5.8	1.1±0.4	5.3±1.6	12.6±2.8	1.3:1
BSA ratio ≥ 1.3 N=16	9.1±5.7	1.0±0.3	5.0±1.6	12.6±2.6	0.8:1
BSA ratio < 1.3 N=19	11.1±5.8	1.1±0.4	5.6±1.6	13.0±2.6	2.2:1

Table 2. The mean BSA of total heart transplant recipients and donors

	Recipient BSA(m^2)	Donor BSA(m^2)	BSA difference(m^2)	BSA ratio
Total N=35	1.1±0.5	1.4±0.5	0.3 ± 0.3	1.4 ± 0.4
BSA ratio ≥ 1.3 N=16	0.9±0.4	1.4±0.5	0.6 ± 0.3	1.7 ± 0.3
BSA ratio < 1.3 N=19	1.2±0.5	1.3±0.5	0.1 ± 0.2	1.1 ± 0.2

Table 3. The LV mass index of recipients and donor

		Total	BSA ratio ≥ 1.3	BSA ratio < 1.3	P value
LVMI_Recipient(mg/m^2)	1st	120.5 ± 52.5	147.9 ± 57.8	99.1 ± 36.9	0.007*
	2nd	113.9 ± 35.4	130.7 ± 36.3	99.1 ± 27.7	0.009*
	3rd	100.0 ± 28.9	108.9 ± 35.7	92.1 ± 18.7	0.107
	P value	0.081	0.061	0.614	
LVMI_Donor(mg/m^2)	1st	87.0 ± 27.0	84.4 ± 24.8	89.1 ± 29.1	0.638
	2nd	89.7 ± 27.6	82.0 ± 21.5	96.5 ± 31.1	0.14
	3rd	84.5 ± 24.4	73.7 ± 21.0	94.1 ± 23.8	0.013*
	P value	0.727	0.392	0.725	

* means that there is a significant difference between groups within same time point.

Table 4. The longitudinal LV strain at each point after heart transplantation

		Total	BSA ratio ≥ 1.3	BSA ratio < 1.3	*P* value
4 chamber	1st	-13.1 ± 4.0	-12.2 ±3.3	-13.8 ± 4.5	0.261
	2nd	-15.8 ± 5.1	-14.4 ± 5.1	-17.1 ± 5.1	0.156
	3rd	-16.5 ± 5.3	-17.4 ± 5.0	-15.7 ± 5.6	0.348
	P value	0.015*	0.011*	0.196	
3 chamber	1st	-12.7 ± 5.3	-9.9 ± 2.7	-12.7 ± 5.3	0.147
	2nd	-14.2 ± 6.4	-14.1 ± 6.0	-14.3 ± 6.9	0.956
	3rd	-15.4 ± 9.7	-13.8 ± 5.7	-16.0 ± 7.4	0.368
	P value	0.102	0.132	0.360	
2 chamber	1st	-15.1 ± 5.2	-10.0 ± 4.1	-15.1 ± 5.2	0.014ˆ
	2nd	-18.4 ± 5.9	-11.7 ± 12.4	-18.4 ± 5.9	0.008ˆ
	3rd	-15.3 ± 6.1	-15.2 ± 5.7	-15.3 ± 6.8	0.951
	P value	0.447	0.260	0.263	
Global longitudinal strain	1st	-12.5 ± 3.7	-10.6 ± 2.7	-13.6 ± 3.9	0.053
	2nd	-15.2 ± 5.8	-14.0 ± 6.4	-16.2 ± 5.4	0.411
	3rd	-16.2 ± 4.1	-15.6 ± 4.7	-16.9 ± 3.2	0.399
	P value	0.013*	0.061	0.1	

* means that there is a significant difference over time within group. ˆ means that there is a significant difference between groups within same time point.

Table 5. The circumferential LV strain at each levels and global strain of each point after heart transplantation

		Total	BSA ratio ≥ 1.3	BSA ratio < 1.3	*P* value
Mitral valve level	1st	-21.6± 6.1	-23.3±4.4	-20.5±7.0	0.23
	2nd	-21.4±5.2	-20.2±5.4	-22.4±5.0	0.277
	3rd	-19.3±6.2	-19.3±5.4	-19.3±7.0	0.992
	P value	0.257	0.138	0.418	
Mid-level	1st	-25.2±4.3	-24.9±2.6	-25.3±5.3	0.802
	2nd	-24.3±7.0	-22.8±6.0	-25.5±7.8	0.339
	3rd	-22.9±7.6	-21.6±7.0	-24.1±8.3	0.365
	P value	0.342	0.182	0.836	
Apex level	1st	-25.9±6.7	-22.7±4.9	-28.7±6.9	0.015*
	2nd	-30.3±11.3	-24.6±9.5	-35.1±10.6	0.015*
	3rd	-25.9±9.5	-26.7±7.8	-25.1±11.1	0.652
	P value	0.145	0.392	0.063	
Global LV circumferential strain	1st	-24.1±4.1	-23.5±2.9	-24.5±5.0	0.54
	2nd	-26.0±5.0	-23.4±3.7	-28.7±4.9	0.009*
	3rd	-23.0±5.7	-22.7±4.9	-24.0±6.2	0.542
	P value	0.111	0.848	0.085	

* means that there is a significant difference between both groups at each time point

Table 6. The radial LV strain at each levels and global strain of each point after heart transplantation

		Total	BSA ratio ≥ 1.3	BSA ratio < 1.3	*P* value
Mitral valve level	1st	19.9±9.0	20.4±11.5	19.5±7.1	0.805
	2nd	16.7±10.5	14.3±9.0	18.8±11.6	0.261
	3rd	10.9±10.6	10.2±6.9	11.5±13.4	0.733
	P value	0.003*	0.023*	0.126	
Mid-level	1st	25.8±15.0	23.7±17.6	27.3±13.0	0.513
	2nd	20.9±10.8	21.6±19.9	20.3±13.1	0.764
	3rd	22.7±16.1	19.9±16.0	25.5±16.3	0.331
	P value	0.427	0.793	0.372	
Apex level	1st	24.0±13.8	18.0±12.5	29.2±13.0	0.029*
	2nd	20.9±17.2	10.2±12.7	30.1±15.3	0.002*
	3rd	22.9±13.8	18.1±8.4	27.7±16.6	0.064
	P value	0.751	0.149	0.913	
Global LV radial strain	1st	23.2±8.6	20.6±10.5	25.3±6.4	0.194
	2nd	19.5±8.9	15.3±6.3	23.8±9.3	0.021*
	3rd	19.5±9.3	15.8±6.7	24.0±10.2	0.023*
	P value	0.226	0.206	0.889	

* means that there is a significant difference between both groups at each time point

Table 7. The RV FAC and RV global longitudinal strain of each point after heart transplantation

	RV FAC				RV global longitudinal strain			
	1st	2nd	3rd	*P* value	1st	2nd	3rd	*P* value
Total	20.0±13.3	18.4±9.2	18.6±8.4	0.837	-7.7±5.2	-7.4±3.6	-8.4±4.7	0.655
BSA ratio ≥ 1.3	17.9±12.2	18.3±9.3	19.1±6.4	0.937	-6.4±4.0	-6.6±3.5	-7.8±4.3	0.588
BSA ratio < 1.3	21.8±14.2	18.4±9.5	18.2±10.0	0.595	-8.7±5.9	-8.2±3.6	-8.9±5.0	0.959
P value	0.431	0.979	0.764		0.238	0.228	0.538	

Table 8. The association of LV longitudinal strain with LV mass index

	1st		2nd		3rd	
	Pearson correlation coefficient	*P* value	Pearson correlation coefficient	*P* value	Pearson correlation coefficient	*P* value
Total	0.249	0.177	0.231	0.204	0.267	0.133
BSA ratio ≥ 1.3	0.210	0.471	0.283	0.306	0.513	0.042*
BSA ratio < 1.3	0.164	0.530	-0.041	0.876	0.125	0.633

* shows statiscally significant correlation between LV mass index and LV longitudinal strain.