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Left and Right Ventricular Functional Dynamics Determined by Echocardiograms Before and After Lung Transplantation

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Abstract

Impaired cardiac function is considered a contraindication for lung transplantation (LT). Since right ventricular (RV) function is expected to improve after LT, poor left ventricular (LV) function is often the determinant for LT eligibility. However, the changes in cardiac function before and after LT have not yet been elucidated. Therefore, we reviewed echocardiograms obtained from 67 recipients before and after LT. In a subset of 49 patients, both RV and LV longitudinal strains based on 2D speckle tracking echocardiography were analyzed. The cardiopulmonary exercise tests were also reviewed. All patients showed significant improvements in their exercise capacity after LT. RV-echo parameters improved in all patients following LT (RV fractional area change: 36.7 ± 5.6 to $41.5 \pm 2.7\%$, RV strain: -15.5 ± 2.9 to $-18.0 \pm 2.1\%$, RV E/E': 8.4 ± 1.8 to 7.7 ± 1.8 ; all $p < 0.05$). Overall, the LV ejection fraction (LVEF) did not change (58.7 ± 6.0 to $57.5 \pm 9.7\%$, $p = 0.385$); however, 20 patients (30%) showed more than a 10% decrease in LVEF after LT (61.5 ± 6.1 to $47.3 \pm 4.2\%$, $p < 0.001$), and an increase in LV E/E' (11.8 ± 1.8 to 12.9 ± 2.2 , $p = 0.049$). Multivariate logistic regression analysis revealed that pre-LT LV E/E' was associated with

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decrease in LVEF after LT [odds ratio (OR) 1.381, 95%CI (confidential interval) 1.010–1.947, $p=0.043$]. Furthermore, patients with strain data showed lower pre-LT LV strain was independently associated with LVEF decrease after LT (OR 1.293, 95%CI 1.088–1.614, $p=0.002$). While RV function improves after LT, LV systolic and diastolic functions deteriorate in a sizable proportion of patients. Impaired LV diastolic function before transplant appears to increase the risk of LVEF deterioration after LT.

Keywords

lung transplant; echocardiography; cardiac function

Introduction

Lung transplantation (LT) provides considerable survival benefits for patients with end-stage lung disease; however, its use is severely limited due to donor shortage.¹ Therefore, it is important to select the optimal candidate and optimal timing for LT.² Since LT candidates occasionally have cardiovascular risk factors such as smoking and older age, LT centers perform intensive cardiovascular evaluations before listing patients.³ Furthermore, patients with longstanding elevated pulmonary vascular resistance (PVR) are known to have right ventricular (RV) dysfunction.⁴ Prior studies have shown that preoperative RV dysfunction is an independent risk factor for primary graft dysfunction after LT,^{5, 6} and is associated with increased mortality and morbidity.⁷ Left ventricular (LV) dysfunction rather than RV dysfunction often becomes the primary reason for heart-lung transplant (not lung-alone), since RV function may improve after LT.^{8, 9} Pielsticker et al. performed a worldwide survey of transplant candidates with pulmonary hypertension and reported that the LV and RV functional cut-offs for choosing heart-lung was an LV ejection fraction (LVEF) of 32 to 55% and an RV fractional area change (RVFAC) of 15 to 25%.⁹ However, how the LV and RV functions change in LT recipients has not yet been investigated. The specific aim of the present study was to assess the LV function of LT recipients by reviewing their echocardiograms before and after transplant and investigating their ventricular functional dynamics.

Methods

A retrospective chart review was performed in all patients undergoing LT at Columbia University Medical Center between 2005 and 2011 who had right heart catheterizations and echocardiograms within 1-year pre- and 1-year post-LT. The cardiopulmonary exercise tests (CPETs) before and after LT were also reviewed. Both pre-transplant echocardiograms and CPETs were obtained as a part of transplant evaluation in all LT candidates. However, some post-LT echocardiograms are performed at local hospitals; therefore, a limited number of LT recipients had both pre-and post-echocardiograms available from our institutional database. In the present study, we defined LV deterioration as more than a 10% decrease in post-LT LVEF compared to pre-LT LVEF. Similarly, RV deterioration was defined as more than a 5% decrease in post-LT RVFAC. Patients with and without LV/RV function deterioration were compared, and associated pre-operative demographics and clinical variables were

examined. The Institutional Review Board of the New York Presbyterian-Columbia University Medical Center approved this study.

Both conventional echocardiography and tissue Doppler analysis were performed using Sonos-5500® or Sonos-7500® (Philips Healthcare Corp, MA, USA). All measurements obtained were in accordance with recommendations of the American Society of Echocardiography.^{10, 11} LV wall thicknesses and dimensions, left atrial diameter (LAD), percent fractional shortening (%FS), and LVEF calculated by the modified Simpson's method were recorded. RV parameters included RV free wall thickness, tricuspid annular plane systolic excursion (TAPSE), and RVFAC. Peak early (E) filling velocities of mitral and tricuspid inflow were measured by Doppler echocardiography. Tissue Doppler-derived early diastolic annular velocity (E') at the septal and lateral mitral annulus for LV E' and at RV free wall of the tricuspid annulus for RV E' were obtained, and the E/E' ratio was calculated as an index of ventricular filling pressures.^{12, 13} For patients whose echocardiographic images were analyzable off-line using QLAB quantification software (Philips Healthcare Corp, MA, USA), LV and RV global longitudinal systolic strain values were calculated as average strain values of 6 segments obtained from an apical 4-chamber view. Two examiners blinded to the clinical status of the patients interpreted the echocardiograms. Reproducibility was analyzed in 8 randomly selected patients. Intra-observer reproducibility was assessed with a single reader (TSK) on two separate occasions. Inter-observer reproducibility was assessed with two independent readers (MLK and TSK).

All subjects underwent symptom-limited exercise testing on a bicycle before and after LT, as previously described.¹⁴ Supplemental oxygen was used at pre-transplant CPET when needed. The peak oxygen consumption (peak VO_2) was defined as the highest value of oxygen uptake attained in the final 20 seconds of exercise. All subjects were given verbal feedback to continue exercising until the anaerobic threshold, defined as a respiratory exchange ratio > 1 , was reached.¹⁴ The slope of the ratio of minute ventilation to carbon dioxide production (VE/VCO_2) was calculated as the slope of the regression line relating VE to VCO_2 during exercise. Since peak VO_2 is affected by age, sex, muscle mass, and conditioning status; the percent of predicted peak VO_2 was also calculated.¹⁵

Right-sided heart catheterization was performed as a part of LT evaluation in all patients. The trans-pulmonary gradient (TPG) was calculated as $\text{TPG (mmHg)} = [\text{mean pulmonary artery pressure (mean PA)} - \text{pulmonary capillary wedge pressure (PCWP)}]$. PVR was calculated as $\text{PVR (Wood units)} = \text{TPG} / \text{cardiac output (CO)}$. RV stroke work index (RVSWI) was calculated as $\text{RVSWI (g}\cdot\text{m}^2\text{/beat)} = [\text{mean PA} - \text{mean right atrial pressure (RA)}] \times \text{stroke volume index} \times 0.0136$. Systemic vascular resistance (SVR) was calculated as $\text{SVR (dyne}\cdot\text{sec}\cdot\text{cm}^{-5}) = [\text{mean arterial pressure (MAP)} - \text{mean RA}] / \text{CO} \times 80$. Pulmonary hypertension was defined as mean PA ≥ 25 mmHg at rest.^{16,17}

All data were analyzed using the statistical analysis software JMP 7.0 (SAS Institute Inc. NC, USA). Continuous data were evaluated for normality using the Kolmogorov-Smirnov test. Normally distributed data are presented as mean $\pm$ standard deviation, and non-normal data are presented as median and interquartile range (IQR) (25–75%). Inter- and intra-observer variability was evaluated by the intraclass correlation coefficient. Patients with and

without echo-derived LV or RV functional deterioration were compared using Student's unpaired t-test for continuous variables and using chi-square test for categorical variables. Mann-Whitney's test was performed when the variables were not normally distributed. The values before and after the LT were assessed with Student's paired t-test. Univariate logistic regression analysis was used to determine potential variables associated with deterioration of echo-derived parameters through LT, and variables with a p value of <0.1 by univariate analysis were entered into a multivariate logistic regression model.

Results

Of the 230 LTs performed between January 2005 to March 2011, 135 (57%) had right-sided heart catheterizations and echocardiograms within 1 year of LT [mean $\pm$ SD: 164 $\pm$ 96 days; median (IQR): 155 days (78–229)], and 67 patients (29%) also had echocardiograms obtained later than 1-year post-LT [median (IQR): 416 days (369–741)]. These 67 patients' data were used for the study. None of them were supported by inotropes at the time of LT evaluation. Baseline clinical characteristics and pre-LT hemodynamic data of all patients are shown in Table 1. Theoretically, pulmonary hypertension in LT recipients is a form of pre-capillary pulmonary hypertension due to lung disease and/or hypoxia defined as Dana point Group 3 or pulmonary atrial hypertension defined as Group 1;¹⁸ however, about 10% of patients had a form of post-capillary hypertension with elevated PAWP, so-called pulmonary hypertension due to left heart disease, classified as Group 2.

Pre-and post-LT echocardiographic and CPET data of all studied patients are shown in Table 2. Intra-observer variability for LVEF, RVFAC and LV strain showed correlation coefficients of 0.81, 0.84 and 0.80, respectively. For inter-observer reproducibility, correlation coefficients were 0.77, 0.84, and 0.85, respectively. All patients had improved CPET parameters after LT. The LV echocardiographic parameters were not altered before and after LT when we analyzed all 67 patients (Table 2); however, among those, 20 patients (29.9%) showed more than a 10% decrease in LVEF after LT (Group LV-decreased), while the remaining 47 patients showed little changes or improvements (Group LV-preserved) (Figure 1). In contrast, RV systolic function before and after LT as indicated by RVFAC showed significant improvement in the analysis of all patients (Table 2, Figure 2), and no patient showed more than a 5% decrease in RVFAC. According to these results, we compared the variables between Group LV-decreased and Group LV-preserved, and evaluated the underlying factors of patients showing decrease in LVEF.

Table 3 summarizes the comparison of variables from Group LV-decreased and Group LV-preserved. The time from transplant surgery to post-LT echocardiography did not differ between the groups (414 days, range 366–639 versus 416 days, range 369–876, $p=0.3876$). Comparing the echocardiographic variables before and after LT, patients in Group LV-decreased showed an increase in LV E/E' and a decrease in the absolute value of LV strain after LT in addition to the remarkable decrease in LVEF. Conversely, patients in Group LV-preserved showed an increase in LVEF, but their LV E/E' and LV strain did not change after LT. In both groups, RV dilatation, hypertrophy, and systolic function as reflected by RVFAC and RV strain improved after LT. The RV E/E' decreased only in Group LV-preserved. A comparison of the pre-LT echo parameters between the groups revealed that

Group LV-decreased had a higher LVEF, LVFS, and LV E/E'. The absolute value of LV strain was lower in Group LV-decreased than in Group LV-preserved. The RV-associated parameters pre-LT did not significantly differ between the two groups.

Univariate logistic regression analysis was used to select potential variables associated with the decrease in LVEF 10% to be entered into a multivariate logistic regression model (Table 4). Since LV and RV strain parameters were not obtainable in all patients, they were not included in the multivariate model. Only the LV E/E' remained significantly associated with a post-LT LVEF decrease in the multivariate model. The analysis of patients with available strain parameters revealed that only the LV strain showed a significant association with a post-LT LV decrease by multivariate analysis [Odds ratio (OR) 1.293, 95% confidential interval (CI) 1.088–1.614, $p=0.0022$].

Discussion

We demonstrated that, (i) all patients showed significant improvements in their exercise capacity after LT, (ii) a majority of patients showed moderately decreased RV systolic function and RV hypertrophy before LT, but both parameters significantly improved after LT in all patients, (iii) LV systolic function was preserved before LT and did not change significantly after LT in the overall group; however, a subgroup of 30% of patients showed a remarkable decrease in LVEF after LT, and (iv) pre-LT LV diastolic dysfunction as reflected by elevated LV E/E' was a factor independently associated with post-LT LVEF decrease. Contrary to our hypothesis, a significant decrease in LV function occurred in a subset of patients after LT, while exercise capacity and RV function improved.

Severely decreased LV and/or RV systolic function is considered to be a contraindication for LT,¹ and indeed, patients with impaired cardiac function require heart-lung transplant rather than lung-alone transplant.^{8, 9} Since RV functional improvement is expected after LT due to a correction of elevated PVR (decrease of RV afterload), RV dysfunction is not considered a primary determinant for LT eligibility.^{9, 19} Our data confirmed that all patients' RV functional parameters improved after LT. Of note, RV hypertrophy was also resolved in all patients, in which mechanism can be seen in the reversibility of LV hypertrophy in hypertensive patients under antihypertensive therapies.^{20, 21} Meanwhile, pre-existing LV dysfunction is a primary determinant for eliminating LT candidacy at many centers.^{9, 19} In our cohort, all patients had a preserved LV function before LT (mean LVEF $58.9\pm6.0\%$), which did not change after LT ($57.9\pm9.7\%$). Despite a range from 48.5% to 73.8%, all patients with LVEF below 55% pre-LT did not show a remarkable decrease, except for one patient whose LVEF decreased from 52.5% pre-LT to 42.5% post-LT (Figure 1). However, in spite of the fact that the LV systolic function did not change based on the analysis of all patients, we found a subset of patients showing a remarkable decrease in LVEF after LT, a finding never reported before to our knowledge.

The heart of a patient with severe lung disease and hypoxic state must work at maximal capability to maintain exercise capacity. The resulting hyper-workload on LV causes a deterioration of LV function or a reduction in functional reserve, which has been shown in the pathophysiology of tachycardia-induced cardiomyopathy.^{22–24} Hyper-workload of LV

may first cause LV diastolic deterioration, which has been shown in patients with hypertensive LV hypertrophy.^{25, 26} Furthermore, Kitahori K. et al reported that RV hypertrophy due to pressure overload of the RV causes LV diastolic dysfunction while preserving ejection fraction through mechanical and molecular effects on the septum and LV myocardium.²⁷ They also reported that RV hypertrophy is associated with septal and LV apoptosis and reduced LV capillary density.²⁷ Indeed, in the present observation, all patients had RV hypertrophy, and the elevated LV E/E' pre-LT, which indicates LV diastolic dysfunction, was an independent factor associated with a decrease in LVEF after LT. In addition, in a sub-analysis including LV strain parameters, LV strain was also an independent factor for LVEF decrease post-LT. LV strain is a parameter for systolic function, but it also reflects LV relaxation and diastolic reserve.²⁸ We previously reported that LV strain was negatively correlated with tau,²⁸ showing that LV strain reflected elastic recoil determined by calcium-handling proteins, which is an important determinant of LV relaxation.²⁹ Our finding that pre-LT diastolic dysfunction is associated with a decrease in post-LT LVEF is also supported by the greater prevalence of patients having pre-capillary pulmonary hypertension in Group LV-decreased.

The present study has several limitations. First, only patients who were stabilized and had 1-year or later post-LT echocardiography were investigated. Patients who died due to insufficient cardiac functional reserve to tolerate post-LT complications or due to cardiac-related adverse events within a year of LT were not evaluated. Another major limitation is our definition of LV deterioration. We observed LVEF deterioration in a proportion of patients post-LT; however, their postoperative LVEF was within the normal or mildly decreased (over 40%) range. Moreover, several patients classified into Group LV-decreased had super-normal LVEF values before LT, which normalized after LT (from over 65% to around 55%). We realize that this observation may not be an actual LV functional deterioration, but instead a condition that reflects the “normalization of LV over-work,” a compensatory hyperkinetic LV under lung disease and the resolution of hyperkinetic state after LT. Further investigation with a larger cohort is required to find factors associated with “real” LV functional deterioration after LT. Further, cardiac magnetic resonance imaging or 3D echocardiography, which can provide more accurate volumetric measurements without geometric assumptions than 2D echocardiography,³⁰ was not utilized due to the retrospective nature of this study. Lastly, the prognosis and/or adverse outcome in patients with and without LVEF deterioration was not investigated.

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Figure 1.

Changes in LVEF before and after lung transplant in individual patients (A). Patients showing a 10 % or more decrease in LVEF through transplant were indicated by black square and black line. Patients without decrease in LVEF were indicated by gray circle and gray line. Changes in LVEF obtained from only patients with decrease in LVEF (B) and those without decrease in LVEF (C). P values were calculated by paired t-test. Bars indicate mean $\pm$ standard deviation.

Figure 2.

Changes in RVFAC before and after lung transplant in individual patients. Patients with decrease in LVEF through transplant as shown in Figure 1 were indicated by black square and black line and those without decrease in LVEF were indicated by gray circle and gray line. P values were calculated by paired t-test. Bars indicate mean $\pm$ standard deviation.

Table 1

Baseline clinical characteristics and hemodynamics obtained from all patients (n=67)

Clinical characteristics	
Age at transplant (years)	59 (42–64)
Male	36 (54%)
Body mass index (kg/m ²)	24.4±4.3
Etiology of lung disease	
Interstitial lung disease	22 (33%)
Chronic obstructive pulmonary disease	16 (24%)
Cystic fibrosis	12 (18%)
Pulmonary artery hypertension	5 (8%)
Sarcoidosis	4 (6%)
Bronchiectasis	4 (6%)
Scleroderma	2 (3%)
Bronchiolitis obliterans	1 (2%)
Pulmonary hypertension post atrial septal defect closure	1 (2%)
Type of surgery (Double lung/Single lung)	
Double-lung	55 (82%)
Pre lung transplant hemodynamic data	
Mean aortic pressure (mmHg)	86.5±10.2
Mean right atrial pressure (mmHg)	6.2±4.2
Mean pulmonary artery pressure (mmHg)	24.3±8.2
Pulmonary capillary wedge pressure (mmHg)	10.4±5.1
Cardiac index (L/min/m ²)	2.6±0.4
Trans-pulmonary gradient (mmHg)	14.0 ±7.4
Pulmonary vascular resistance (wood)	3.2±2.4
Systemic vascular resistance (dyne*sec*cm ⁻⁵)	1365(1246–1533)
Right ventricular stroke work index (g·m ² /beat)	7.96 ± 4.68
Patients with pulmonary hypertension	30 (45%)
Pre-capillary pulmonary hypertension	23 (34%)
Post-capillary pulmonary hypertension	7 (11%)

Table 2

Pre-and post-LTx echocardiographic and cardiopulmonary exercise test data obtained from all patients (n=67)

	Pre- Lung transplant	Post- Lung transplant	Paired t-test p value
Echocardiogram			
Left ventricular parameters			
Left ventricular end-diastolic diameter (mm)	44.6±4.9	44.9±4.7	0.623
Left ventricular end-systolic diameter (mm)	29.0±3.8	29.6±5.3	0.394
Interventricular septum wall thickness (mm)	10.1±1.3	10.5±1.4	0.067
Posterior wall thickness (mm)	10.0±1.7	10.3±2.2	0.357
Left ventricular ejection fraction (%)	58.7±6.0	57.5±9.7	0.385
%Fractional shortening (%)	34.8±5.5	34.3±7.9	0.707
Left atrial diameter (mm)	35.9±6.4	38.9±5.8	0.001
E/E'	11.0±2.0	11.5±2.2	0.051
Left ventricular strain (%) (n=49)*	-28.2±5.4	-26.7±6.2	0.117
Right ventricular parameters			
Right ventricular basal diameter (mm)	34.9±3.2	32.7±2.4	<0.001
Right ventricular free wall thickness (mm)	9.3±1.3	7.8±1.1	<0.001
Right ventricular fractional area change (%)	36.7±5.6	41.5±2.7	<0.001
Tricuspid annular plane systolic excursion (mm)	1.9±0.3	2.0±0.3	0.089
Right ventricular E/E'	8.4±1.8	7.7±1.8	0.018
Right ventricular strain (%) (n=49)*	-15.5±2.9	-18.0±2.1	<0.001
Cardiopulmonary exercise test			
Peak oxygen consumption (mL/min/kg)	14.5±5.8	17.1±4.7	<0.001
Predicted oxygen consumption (%)	44.8±19.5	57.8±14.3	<0.001
Slope of the ratio of minute ventilation to carbon dioxide	38.4±10.9	35.4±5.4	0.029

* We could obtain LV and RV strain information from 49 patients (71% of cohort).

Table 3

Comparison of parameters between Group LV-decreased and Group LV-preserved

	Group LV-decreased (n=20)	Group LV-preserved (n=47)	Unpaired t p value
Baseline characteristics			
Age at Lung transplant (years)	61.0 (52.5–64.0)	57.0 (36.0–63.0)	0.0929
Male	10 (50%)	26 (55%)	0.6897
Body mass index (kg/m ²)	24.7±4.1	24.3±4.4	0.8299
Etiology (n, %)			0.4913
Interstitial lung disease	8 (40%)	14 (30%)	
Chronic obstructive pulmonary disease	4 (20%)	12 (26%)	
Cystic fibrosis	2 (10%)	10 (21%)	
Pulmonary artery hypertension	3 (15%)	2 (4%)	
Others	3 (15%)	9 (19%)	
Type of surgery			
Double-lung	14 (70%)	41 (87%)	0.0923
Hemodynamics			
Mean aortic pressure (mmHg)	87.2±10.9	86.3±10.0	0.7454
Mean right atrial pressure (mmHg)	5.6±3.4	6.5±4.5	0.3893
Mean pulmonary artery pressure (mmHg)	24.3±8.1	24.4±8.3	0.9700
Pulmonary capillary wedge pressure (mmHg)	11.0±6.0	10.1±4.7	0.5362
Cardiac index (L/min/m ²)	2.6±0.4	2.6±0.5	2.6±0.4
Trans-pulmonary gradient (mmHg)	13.3±7.3	14.2±7.5	0.6405
Pulmonary vascular resistance (wood)	2.9±2.0	3.3±2.6	0.5791
Systemic vascular resistance (dyne*sec*cm ⁻⁵)	1320 (1229–1606)	1378 (1246–1527)	0.5846
Right ventricular stroke work index (g·m ² /beat)	8.1±3.5	7.9±5.1	0.8575
Pulmonary hypertension	11 (55%)	19 (40%)	0.2730
Pre-capillary pulmonary hypertension	7 (35%)	16 (34%)	0.9398
Post-capillary pulmonary hypertension	4 (20%)	3 (6%)	0.0954

	Pre-Lung transplant	Post-Lung transplant	Paired t p value	Pre-Lung transplant	Post-Lung transplant	Paired t p value	Comparison of pre-transplant value
Echocardiogram							
Left ventricular end-diastolic diameter (mm)	44.5±5.7	45.5±5.0	0.968	44.2±4.6	44.7±4.7	0.594	0.357
Left ventricular end-systolic diameter (mm)	28.5±4.9	35.6±4.4	<0.001	29.3±3.4	27.9±4.8	0.049	0.221
Interventricular septum wall thickness (mm)	10.3±1.4	10.7±1.2	0.340	10.0±1.2	10.4±1.5	0.123	0.457
Posterior wall thickness (mm)	10.1±1.2	10.3±1.3	0.498	10.0±1.8	10.3±2.6	0.471	0.300
Left ventricular ejection fraction (%)	61.5±6.1	47.3±4.2	<0.001	57.5±5.7	61.8±7.9	<0.001	0.011
%Fractional shortening (%)	37.4±7.3	26.3±3.6	<0.001	32.7±4.6	37.7±6.7	<0.001	0.029
Left atrial diameter (mm)	38.6±8.5	40.7±6.6	0.340	34.8±5.0	38.1±5.4	0.001	0.097
Left atrial diameter (mm) E/E'	11.8±1.8	12.9±2.2	0.049	10.6±2.0	10.9±1.9	0.341	0.031
Left atrial diameter (mm) strain (%) (n=49) *	-25.8±5.4	-19.9±2.5	0.001	-29.1±5.0	-29.5±4.9	0.722	0.042
Right ventricular basal diameter (mm)	35.1±2.7	33.3±2.4	0.004	34.8±3.4	32.5±2.3	<0.001	0.771
Right ventricular free wall thickness (mm)	9.6±1.2	8.1±1.2	<0.001	9.1±1.3	7.7±1.0	<0.001	0.192
Right ventricular fractional area change (%)	36.3±6.5	41.7±3.2	0.003	36.8±5.2	41.5±2.6	<0.001	0.738
Tricuspid annular plane systolic excursion (mm)	1.9±0.2	2.0±0.4	0.250	2.0±0.3	2.0±0.2	0.217	0.204
Right ventricular E/E'	8.2±1.6	7.8±1.6	0.388	8.5±2.0	7.7±1.9	0.029	0.587
Right ventricular strain (%) (n=49) *	-15.5±4.3	-18.7±1.9	0.021	-15.5±2.1	-17.8±2.2	<0.001	0.958
Cardiopulmonary exercise test							
Peak oxygen consumption (mL/min/kg)	17.6±4.1	14.5±6.9	0.046	14.5±5.3	16.9±4.8	0.003	0.999
Predicted oxygen consumption (%)	47.5±23.0	62.0±15.1	0.019	44.0±17.9	56.5±14.1	<0.001	0.504
Slope of the ratio of minute ventilation to carbon dioxide	42.4±14.0	35.4±5.5	0.053	36.6±8.9	35.4±5.4	0.484	0.048

* We could obtain LV and RV strain information in 49 patients (71% of cohort).

† p values associated with the difference of pre-lung transplant echo parameters between the groups by Student's unpaired t-test.

Table 4

Univariate and multivariate logistic analysis of pre-lung transplant factors associated with post-transplant decrease in left ventricular ejection fraction.

Variables	Univariate			Multivariate		
	OR	95% CI	p value	OR	95% CI	p value
Days from Lung transplant to post-Lung transplant echo (days)	0.999	0.996–1.000	0.1553			
Age (years)	1.045	1.002–1.102	0.0385	1.039	0.987–1.104	0.1426
Gender (male=1, female=0)	0.808	0.280–2.321	0.6897			
Body mass index (kg/m ²)	1.018	0.900–1.154	0.7808			
Type of Lung transplant (double =1, single=0)	0.341	0.092–1.253	0.1036			
Mean aortic pressure (mmHg)	1.009	0.956–1.061	0.7424			
Mean right atrial pressure (mmHg)	0.942	0.817–1.070	0.3727			
Mean pulmonary artery pressure (mmHg)	0.999	0.929–1.063	0.9693			
Pulmonary capillary wedge pressure (mmHg)	1.033	0.931–1.148	0.5308			
Cardiac index (L/min/m ²)	0.783	0.206–2.621	0.6962			
Trans-pulmonary gradient (mmHg)	0.982	0.898–1.054	0.6268			
Pulmonary vascular resistance (wood)	0.927	0.651–1.162	0.5495			
Systemic vascular resistance (dyne*sec*cm ⁻⁵)	1.000	0.998–1.001	0.7532			
Right ventricular stroke work index (g·m ² /beat)	1.010	0.886–1.129	0.8565			
Pulmonary hypertension (yes=1, no=0)	1.801	0.629–5.291	0.2730			
Post-capillary pulmonary hypertension (y=1, no=0)	3.667	0.733–20.27	0.1137			
Left ventricular end-diastolic diameter (mm)	1.052	0.945–1.176	0.3508			
Left ventricular end-systolic diameter (mm)	0.948	0.820–1.087	0.4475			
Interventricular septum wall thickness (mm)	1.258	0.819–1.968	0.2973			
Posterior wall thickness (mm)	1.026	0.728–1.404	0.8728			
Left ventricular ejection fraction (%)	1.119	1.024–1.235	0.0126	1.536	0.890–4.039	0.1226
%Fractional shortening (%)	1.109	1.010–1.231	0.0297			
Left atrial diameter (mm)	1.095	1.009–1.199	0.0288	1.062	0.951–1.202	0.2942
Left ventricular E/E'	1.349	1.028–1.814	0.0300	1.381	1.010–1.947	0.0433
Left ventricular strain (%) (n=49) *	1.145	1.008–1.324	0.0372			
Right ventricular basal diameter (mm)	1.025	0.867–1.210	0.7668			
Right ventricular free wall thickness (mm)	1.321	0.873–2.034	0.1873			

Variables	Univariate			Multivariate		
	OR	95% CI	p value	OR	95% CI	p value
Right ventricular fractional area change (%)	0.984	0.896–1.083	0.7339			
Tricuspid annular plane systolic excursion (mm)	0.288	0.037–1.895	0.1967			
Right ventricular E/E'	0.922	0.683–1.228	0.5790			
Right ventricular strain (%) (n=49) *	0.993	0.791–1.240	0.9568			
Peak oxygen consumption (mL/min/kg)	1.0001	0.910–1.094	0.9986			
Predicted oxygen consumption (%)	0.9932	0.886–1.111	0.5001			
Slope of the ratio of minute ventilation to carbon dioxide	1.0494	1.000–1.108	0.0506	1.020	0.963–1.083	0.4971

* LV and RV strain information were obtained from a subset of 49 patients; therefore these parameters were not included in the multivariate analysis.