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Evaluation of left and right ventricular myocardial function after lung resection using speckle tracking echocardiography

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Abstract

The impact of major lung resections on myocardial function has not been well-investigated. We aimed to identify this impact through the use of speckle tracking echocardiography (STE) to evaluate the right and left ventricular myocardial function in patients who underwent lung resections.

Thirty patients who had lung resections were recruited for this study. Ten patients who underwent pneumonectomies were matched by age and sex, with 20 patients who underwent lobectomies. STE was performed on both right and left ventricle (RV and LV). Strain values of pre and postlung resections were compared in both the pneumonectomy group and the lobectomy group. Comparison between the pneumonectomy group and the lobectomy group was also studied.

Left ventricular ejection fraction remained normal (>55%), but significantly decreased after lung resection in both the pneumonectomy group and the lobectomy group. An accelerated heart rate was observed in both groups after lung resection, with the pneumonectomy group demonstrating extra rapid heart rate ($P < 0.05$). Strain values in the RV and LV decreased in both groups after lung resection, with the pneumonectomy group exhibiting a further decrease in longitudinal strain in LV and RV when compared with the lobectomy group ($P < 0.05$).

Right and left ventricular dysfunction can occur after lung resection regardless of pneumonectomy or lobectomy, and lobectomy may have a less significant impact on myocardial functions. This study demonstrated that STE is able to detect acute cardiac dysfunction after lung resection.

Abbreviations: AF = atrial fibrillation, ASE = American Society of Echocardiography, CMR = cardiac magnetic resonance, CS = circumferential strain, CT = computed tomography, EF = ejection fraction, HR = heart rate, ICC = intraclass correlation coefficient, LS = longitudinal strain, LV = left ventricle, LVEF = left ventricular ejection fraction, ROI = region of interest, RS = radial strain, RV = right ventricle, SD = standard deviation, STE = speckle tracking echocardiography, SV = stroke volume, TDI = Tissue Doppler imaging.

Keywords: left ventricular function, lobectomy, lung resection, pneumonectomy, right ventricular function, speckle tracking echocardiography

Editor: JianJun Yuan.

Author contributions: ZW: concept/design, image acquisition, statistics, data analysis/interpretation, drafting article; JY: concept/design, data analysis/interpretation, critical revision of article, approval of article; WC: image acquisition, statistics, data analysis/interpretation, initial editing, proofreading; YK: image acquisition, statistics, data analysis/interpretation, proofreading; XZ: concept/design, data analysis/interpretation, critical revision of article, approval of article. All the authors take full responsibility for all aspects of the reliability and freedom from bias of the data presented and their discussed interpretation.

The authors report no conflicts of interest.

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Medicine (2016) 95:31(e4290)

Received: 27 April 2016 / Received in final form: 7 June 2016 / Accepted: 26 June 2016

http://dx.doi.org/10.1097/MD.0000000000004290

1. Introduction

Cardiac dysfunction can occur in lung resection patients due to primary respiratory diseases or surgical procedures.[1–3] Atrial fibrillation (AF) was reported as the most frequent cardiac complication during the early postoperative period of pulmonary resection,[4,5] but AF is transient in most cases.[6] Previous studies have shown that patients can be limited by the cardiovascular system during exercise after extensive lung resection; and the anatomical changes associated with pneumonectomy may reduce maximal cardiac output and attenuate heart function.[7,8] Assessing heart function after lung resection is of significant value in patient management and clinical decision-making.

Echocardiography is the primary imaging method used to monitor cardiac dysfunction caused by surgical trauma. Traditionally, clinical management and intervention decision-making regarding myocardial dysfunction has mostly relied on the measuring ejection fraction (EF). However, the EF is not sensitive enough to detect subtle myocardial dysfunction. Myocardial strain/strain rate has been widely used in exploring the subtle changes of cardiac dysfunction and has reported better sensitivity than left ventricular EF (LVEF).[9] Tissue Doppler imaging (TDI) allows quantification of myocardial tissue velocities, from which strain/strain rate can be obtained, but TDI is limited due to the Doppler angle dependency.[10] Speckle tracking echocardiography (STE) based on tracing acoustic markers within the myocardium on standard 2-dimensional (2D) images provides strain parameters, which overcomes the limitation of TDI and has proven to be valuable in evaluating cardiac function.[11–13] To date, no study has assessed myocardial strain after major lung resection. In particular, the different impact of pneumonectomy and lobectomy on myocardial function has not been studied. Therefore, we evaluated myocardial strain using STE in patients who underwent lung resection and studied different impacts of pneumonectomy and lobectomy on heart function.

Table 1

Basic patient clinical information.

	Pneumonectomy	Lobectomy
Age, y/o	53.1±10.7	57.0±11.4
Sex, M/F	7/3	15/5
SBP, mm Hg	114±6.1	116.3±6.8
DBP, mm Hg	74.6±5.4	71.3±4.9
BMI, kg/m^2	21.7±3.0	22.7±2.5

BMI = body mass index, DBP = diastolic blood pressure, SBP = systolic blood pressure.

2. Methods

2.1. Subjects

This study was approved by the institutional review board and was conducted in compliance with the institutional human research policy of The People's Hospital of Zhengzhou University. All subjects gave written informed consent before image acquisitions. From March 2015 to September 2015, 30 patients who had undergone lung resections were recruited for this study, including 10 patients (7 males, 3 females; mean age 53±10 years) who underwent pneumonectomy (5 left lung, 5 right lung) and 20 patients (15 males, 5 females; mean age 57±11 years) who underwent lobectomy (7 right superior lobe, 3 right middle and inferior lobes, 5 left superior lobe, 5 left inferior lobe) (Fig. 1 and Table 1). The age and sex of the patients in the pneumonectomy group matched with those in the lobectomy group. Exclusion criteria included: existing arrhythmia before and after surgery, pericardial effusion, baseline pulmonary hypertension, congestive heart failure, lung failure, diagnosed hypertension, diabetes, cardiomyopathy, and coronary artery disease. The pathology diagnoses of lung diseases within the subjects were as follows: 1 case of pulmonary lymphangioleiomyomatosis, 1 case of tuberculosis (TB), 3 cases of lung abscess, and 25 cases of pulmonary carcinoma (including 12 cases of lung adenocarcinoma, 3 cases of small cell carcinoma, and 11 cases of squamous cell carcinoma).

2.2. Image acquisitions

All patients underwent complete 2D and Doppler echocardiographic examinations according to American Society of Echocardiography (ASE) recommendations[14] using a Vivid E9 Digital Ultrasound System (GE Healthcare, Horten, Norway) equipped with a M5S transducer with a frequency of 1.7 to 3.4 MHz. Image loops were acquired 1 or 2 days before the surgery and a week after the surgery. Two-dimensional recordings were collected with frame rates ranging from 50 to 80 frames/s during a brief breath hold. Three consecutive cardiac cycles were recorded for further image analysis.

2.3. Image analysis

Left ventricular diastolic diameter was measured at parasternal long-axis view. Stroke volume (SV) and LVEF were calculated from apical 4 and 2-chamber views using Simpson method. Right ventricular diameter was measured at a right ventricle (RV)-focused apical 4-chamber view by tilting the transducer laterally or medially.[14] Pulmonary artery diameter, pulmonary artery velocity, and pulmonary artery systolic pressure were measured at parasternal short-axis views at the aortic valve level. Continuous-wave Doppler was used to measure the pulmonic and tricuspid transvalvular maximal velocity.

Speckle tracking echocardiography was performed to assess myocardial strain during systole. Off-line analyses of strain values from archived image loops were performed using commercially available analysis software (Echopac, GE Vingmed). The region of interest (ROI) of the RV and left ventricle (LV) was defined by tracking the endocardial and epicardial borders (Fig. 2). The ROI width was adjusted as needed to fit the wall thickness, as previously described.[15–17] The tracking quality of each segment was indicated by the software, and the segments with insufficient tracking quality were excluded. Peak strain values at each segment and global strain were acquired. Myocardial strain values were

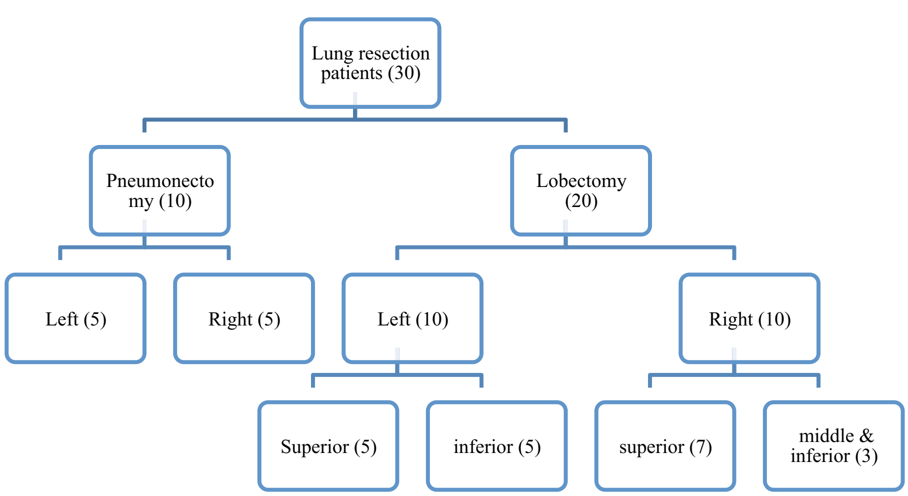

Figure 1. Patient recruitment flow chart.

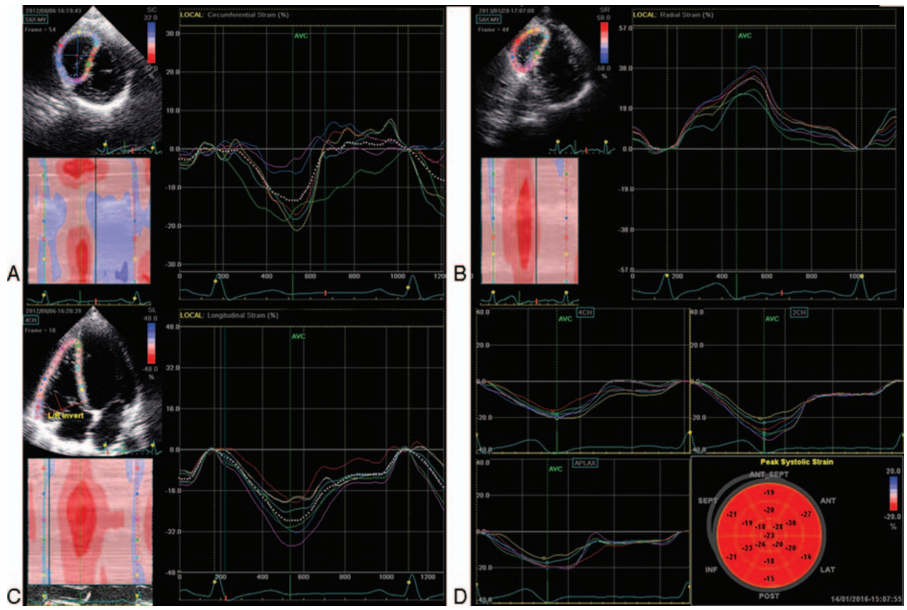

Figure 2. Two-dimensional speckle tracking for strain values at both right and left ventricles. A, Circumferential strain derived from mitral valve level of right ventricle; B, radial strain derived from mitral valve level of right ventricle; C, longitudinal strain derived from apical 4-chamber view of right ventricle; D, longitudinal strain curves derived from apical 4 and 2-chamber view and apical long-axis view of left ventricle.

analyzed by a single observer blinded to the clinical findings and other echocardiographic measurements. Right ventricular free wall and septal circumferential strain (CS) and radial strain (RS) were calculated from average value of different levels of short-axis views (Fig. 2A and B). Right ventricular free wall and septal longitudinal strain (LS) values were calculated from an average of 3 segments (basal, mid, and apical) at apical long-axis views (Fig. 2C). Left ventricular LS values were acquired from average values of apical long-axis view, and apical 4 and 2-chmaber views (Fig. 2D). CS and RS of LV were acquired from average values of different levels in short-axis views, whereas twist was calculated from the difference in rotation at apical and basal short-axis views.

2.4. Statistical analysis

Data are expressed as mean ± standard deviation (SD). All data before surgery (preop) was compared with that obtained from data after the surgery (postop) using a paired *t* test. Comparison between the pneumonectomy group and the lobectomy group preop and postop were analyzed using simple *t* test. All data were graphed and analyzed in Microsoft Excel (Microsoft Corporation, Redmond, WA) and SPSS (13.0 SPSS Inc., Chicago, IL). Significance levels were defined at $P < 0.05$.

Global CS (GCS) and global LS (GLS) derived from RV and LV were used for intra and interobserver analysis. Intraobserver analyses were conducted 2 months after completion of the initial measurements. For interobserver variability, a second observer analyzed 20% of the images. Intraobserver variability and interobserver variability were assessed using the intraclass correlation coefficient (ICC).

3. Results

3.1. Basic demographic and echocardiographic data

There were no differences for age, sex, body mass index (BMI), and blood pressure between the pneumonectomy group and the lobectomy group (Table 1). For baseline echocardiography, there were no differences between the pneumonectomy group and the lobectomy group in ventricular diameters and pulmonary velocities at preop and postop conditions. LVEF remained normal (>55%) in both the pneumonectomy group and the lobectomy group after lung resection, but significantly decreased ($P < 0.05$) when compared with the preop values. Both the pneumonectomy group and the lobectomy group demonstrated elevated heart rate (HR) postop. In addition, the HR in the pneumonectomy group accelerated more than that in the lobectomy group (Table 2). Preop echocardiography between the pneumonectomy and the lobectomy groups did not show statistical differences with respect to pulmonary artery pressure. However, patients in the pneumonectomy group demonstrated significantly higher pulmonary artery pressure ($P < 0.05$; Table 2).

3.2. Right ventricular strain values

Since strain values are strongly affected by the HR, all of the comparisons were analyzed using HR as a covariance. LS, CS, and RS demonstrated decreased absolute values in the pneumonectomy group after lung resection ($P < 0.05$; Table 3).

In the lobectomy group, the absolute values of LS, CS, and RS were reduced after lung resection ($P < 0.05$; Table 3). In addition, the lobectomy group showed less reduction in LS values than the pneumonectomy group after lung resection ($P < 0.05$; Table 3).

3.3. Left ventricular strain values

The pneumonectomy group and the lobectomy group both demonstrated decreased LS after lung resection in all apical views ($P < 0.05$; Table 4). When compared with the pneumonectomy group, LS derived from the lobectomy group showed less reduction after lung resection ($P < 0.05$; Table 4), whereas only the pneumonectomy group demonstrated a statistical decrease in terms of CS, RS, and twist after lung resection ($P < 0.05$; Table 4);

Table 2

Traditional echocardiographic measurements of patients' pre and postlung resection.

Groups	Conditions	LVDd, mm	SV, mL	LVEF, %	RVDd, mm	PA-D, mm	PV-Vmax, m/s	PAP, mm Hg	HR, beats/min
Pneumonectomy (10)	Preop	42.83±4.45	77.31±37.27	66.64±7.54	32.0±4.5	19.6±1.2	0.85±0.51	21.4±7.3 (7)	70.50±18.46
	Postop	38.96±3.80	62.57±26.54	57.15±6.52*	28.1±3.8	21.3±1.7	0.83±0.13	28.8±10.6* (6)	105.17±12.12*
Lobectomy (20)	Preop	42.43±3.02	75.41±18.43	68.69±4.22	31.4±3.5	21.1±1.5	1.00±0.17	20.3±6.7 (16)	70.08±15.14
	Postop	43.11±3.91	72.22±26.41	63.28±3.95*	29.2±4.1	22.0±1.9	0.99±0.12	24.2±9.1† (15)	87.86±18.54*,†

HR = heart rate, LVDd = left ventricular diastolic diameter, LVEF = left ventricular ejection fraction, PAP = pulmonary artery pressure (cases of measurable PAP), PV-D = pulmonary artery diameter, PV-Vmax = maximal velocity across pulmonary valve, RVDd = right ventricular diastolic diameter, SV = stroke volume.

* Comparison between preop and postop within the pneumonectomy group and within the lobectomy group ($P < 0.05$).

† Comparison between the pneumonectomy group and the lobectomy group ($P < 0.05$).

the lobectomy group showed less decrease of RS when compared with the pneumonectomy group after lung resection ($P < 0.05$; Table 4).

3.4. Interobserver variability and intraobserver reproducibility

Excellent correlation coefficients were found between the initial measurements and values generated from the same observer 2 months later with high R values for both right ventricular and left ventricular global strain analysis ($P < 0.05$; Table 5). ICC between initial values and reanalyzed values demonstrated good reproducibility of strain analysis. Interobserver analyses demonstrated excellent correlations between 2 observers' measurements. ICC between 2 observers' measurements demonstrated good agreements (Table 5).

4. Discussion

We have demonstrated that there was significant change of the left ventricular and right ventricular function using STE after lung resectionz.

(1) Even within a normal clinical range, LVEF decreased after lung resection in both the pneumonectomy group and the lobectomy group.
(2) An accelerated HR was observed in both the pneumonectomy group and the lobectomy group after lung resection, with the pneumonectomy group demonstrating further rapid HR.
(3) Right ventricular strain values decreased in both the pneumonectomy group and the lobectomy group after lung resection, with the pneumonectomy group exhibiting further reduction in LS when compared with the lobectomy group.
(4) Left ventricular LS values were decreased in both the pneumonectomy group and the lobectomy group after lung resection, whereas the pneumonectomy group demonstrated advanced reduction; left ventricular circumferential and RS and twist values were decreased in the pneumonectomy group after lung resection, especially RS values, which were significantly lower in the pneumonectomy group when compared with that in the lobectomy group after lung resection.

In summary, biventricular dysfunctions were detected using echocardiography and STE after lung resection, and the pneumonectomy group demonstrated further deterioration than the lobectomy group.

Lung cancer is the most common indication for major lung resection and is rarely associated with pulmonary hypertension.[2,18,19] Lung resection has a significant impact on vital organ function, such as heart and lung; therefore preoperative evaluation of operation risk and postoperative prediction of cardiac and respiratory function are of the same significance. It has been recognized that echocardiographic assessment of the ventricular function can improve the perdition of atrial arrhythmias after elective lung resection.[4–6]

Numerous studies have investigated changes in the ventricular function after lung resection, though many of them only studied the hemodynamics of the RV,[2,18–20] and few studies accessed left ventricular function.[3,6] Previous studies have validated the accuracy of speckle tracking in the assessment of RV,[21,22] despite the well acceptance of STE in left ventricular strain

Table 3

Strain values derived from right ventricle preop and postop of lung resection.

Groups (n)	Strain	Conditions	Right ventricular free wall	Septum	Global
Pneumonectomy (10)	LS (%)	Preop	−30.86±5.88	−17.51±7.11	−24.56±5.32
		Postop	−11.77±4.14*	−10.1±5.92*	−12.04±5.33*
	CS (%)	Preop	−14.69±5.44	−16.34±7.52	−15.01±7.98
		Postop	−4.43±3.56*	−5.06±3.83*	−4.13±2.86*
	RS (%)	Preop	33.86±17.06	31.27±17.78	32.56±17.42
		Postop	11.36±4.95*	11.23±4.87*	11.29±4.91*
Lobectomy (20)	LS (%)	Preop	−29.7±6.23	−19.88±5.92	−25.69±4.71
		Postop	−18.03±8.06*,†	−15.65±6.40*,†	−17.07±5.26*,†
	CS (%)	Preop	−14.30±9.43	−14.34±9.92	−14.13±10.12
		Postop	−7.11±4.84*	−6.54±4.50*	−6.35±4.85*
	RS (%)	Preop	32.71±16.44	28.98±15.15	30.8±15.80
		Postop	18.14±9.31*	16.10±10.12*	17.12±9.71*

CS = circumferential strain, LS = longitudinal strain, RS = radial strain.

* Comparison between preop and postop within the pneumonectomy group and within the lobectomy group ($P < 0.05$).

† Comparison between the pneumonectomy group and the lobectomy group ($P < 0.05$).

Table 4

Left ventricular myocardial strain preop and postop of lung resection.

Groups (n)	Conditions	LS			CS	RS	Twist
		Lax	4-ch	2-ch			
Pneumonectomy (10)	Preop	−21.12±2.63	−21.05±2.13	−22.36±3.18	−21.55±3.26	41.56±10.11	15.12±5.48
	Postop	−12.54±5.14*	−11.48±2.51*	−12.97±4.35*	−16.65±4.46*	28.37±11.23*	9.52±4.12*
Lobectomy (20)	Preop	−22.89±2.15	−21.95±2.46	−23.72±3.31	−20.70±3.81	40.60±15.44	14.23±4.88
	Postop	−18.47±5.02*,†	−17.06±3.34*,†	−18.61±5.56*,†	−18.22±4.25	37.85±10.21†	11.78±3.47

2-ch=2-chamber view, 4-ch=4-chamber view, CS=circumferential strain, Lax=apical long-axis view, LS=longitudinal strain, RS=radial strain.
* Comparison between preop and postop within the pneumonectomy group and within the lobectomy group ($P<0.05$).
† Comparison between the pneumonectomy group and the lobectomy group ($P<0.05$).

analysis. To the best of our knowledge, this study is the first to assess the biventricular myocardial strain using STE in patients who underwent lung resection. STE is a promising and appropriate diagnostic tool to predict with great sensitivity the development of postoperative cardiac dysfunction after lung resection.

The occurrence of postoperative nonfatal morbidity after pneumonectomy varies up to 15%,[23] and lobectomy is at the same level, but with a relatively lower right heart pressure.[18] In our study, both right ventricular and left ventricular strain values were decreased in the pneumonectomy group and the lobectomy group, with the pneumonectomy group demonstrating further decrease ($P<0.05$). The marked reduction of the pulmonary vascular bed after lung resection led to pulmonary artery hypertension and subsequently to right heart failure. It was reported that resections not exceeding 1 lobe, leading to very little permanent functional deficit, whereas pneumonectomies caused a permanent deficit for pulmonary function.[24] The dramatic anatomical changes associated with pneumonectomy in the thoracic cavity can alter the normal heart position; in addition, the intraoperative hemorrhage or nerve injuries can affect cardiac performances resulting in an alteration of the cardiac morphology and function, reduction of maximal cardiac output, and left ventricular function.[25,26] Our findings of alterations in pulmonary artery pressure, rather, and EF of lung resection patients agree with other studies on the decrease of cardiac function. The increase in the dead space to the alveolar space ratio, reduction of the effective diffusion surface, and the mechanical limitation of the chest movement associated with lung resection will induce rapid cardiopulmonary responses to oxygen demand and cause a temperate increase of cardiac and pulmonic burden, resulting in a decrease of myocardial strain values. Given that the postop strain values were more than 50% less than the preop values, despite LVEF also slightly decreasing, the significant drop of strain values is a remarkable indicator of cardiac dysfunction.

The comparison between the pneumonectomy group and the lobectomy group in this study is the first attempt to evaluate the different impacts of 2 surgical procedures on cardiac function at the myocardial level. Studies have demonstrated that incidence of combined morbidity and mortality did not differ between the 2 groups[18,23]; however, our results provided a detailed evaluation of myocardial deformation of the LV and RV. The differences in myocardial strain values are worthy of more thorough investigation to gain awareness of the distinct cardiac dysfunction after pneumonectomy and lobectomy. The interobserver and intraobserver analysis (all ICC >0.8) of this study demonstrated good reproducibility and small variability of STE on evaluating cardiac function.

It is important to acknowledge the limitations of this study. First, this study included a small number of patients undergoing lung resection, with a large percentage of patients suffering from lung carcinoma. The impact of carcinoma on ventricular function is unclear before lung resection. Second, there was more than 50% drop in strain values after lung resection, especially in the pneumonectomy group. This significant drop can be a rapid response to dramatic functional and anatomical changes of thoracic cavity after lung resection. The heart position changed after lung resection, especially in the pneumonectomy group. Also, the image acquisition and analysis are more difficult than preop; therefore the primary cardiac dysfunction and the challenge of strain analysis can both contribute to the dramatic decreases of strain values. A larger sample size of patients with similar primary pathology needing lung resection is necessary to study the impact of lung resection on cardiac function. In addition, this study was a single-institution clinical study, which restricts our ability to generalize the results while only a short postoperative period was studied. We believe the acute decrease of strain values in RV and LV may recover to some extent over a long period of time, so further long-term follow-up studies are necessary.

Table 5

Inter and intraobserver analyses for strain values from right and left ventricles.

Variables		*R*	Bias	LOA	ICC
Interobserver	RV-GLS	0.76	−2.27	−6.88 to 4.15	0.842
	LV-GLS	0.81	2.07	−4.44 to 4.58	0.897
Intraobserver	RV-GLS	0.78	1.41	−5.92 to 3.75	0.874
	LV-GLS	0.82	−1.50	−4.31 to 3.32	0.863

ICC=intraclass correlation coefficient, LOA=limit of agreement, LV-GLS=global longitudinal strain derived from left ventricle, RV-GLS=global longitudinal strain derived from right ventricle.

5. Conclusions

Right and left ventricular dysfunction can occur after lung resection, regardless of pneumonectomy or lobectomy, and lobectomy may have a less significant impact on heart functions. Despite the aforementioned limitations, this study demonstrated that STE is able to detect the distinct acute myocardial dysfunctions after pneumonectomy and lobectomy; the long-term impact of lung resection on heart functions is worthy to study in the future.

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