Original Article

Comparison of Changes in Hemodynamics between Unilateral and Bilateral Lung Volume Reduction for Pulmonary Emphysema

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This study was aimed to compare changes in hemodynamics between unilateral (UL) or simultaneous bilateral (BL) lung volume reduction surgery (LVRS) for chronic obstructive lung disease. Sixteen patients underwent LVRS by stapler resection with neodymium: yttrium-alminum-garnet (Nd: YAG) laser ablation; five underwent BL-LVRS (four by median sternotomy and one by thoracoscopy) and 11 underwent UL-LVRS by thoracoscopy. Four patients had multiple bullae within pulmonary emphysema. At preoperation and 6, 12, 24, and 48 hours postoperatively, hemodynamics and right ventricular performance were evaluated. UL- and BL-LVRS reduced afterload of the right and left ventricle postoperatively. Although the pulmonary arterial resistance increased after surgery, the total pulmonary resistance decreased (p=0.001) in association with the reduced systemic vascular resistance (p=0.001). These reductions improved cardiopulmonary circulation, resulting in increased stroke volume and cardiac output (p=0.003). The right ventricular ejection fraction showed minimal change 48 hours postoperation. Two patients died of pneumonia caused by persistent air leakage. In conclusion, both the UL- and BL-LVRS showed similar effectiveness in terms of improvement in the systemic and cardiopulmonary circulation after LVRS, if there were no postoperative complications. We concluded that we had to reduce and repair the persistent air leakage after LVRS. (Ann Thorac Cardiovasc Surg 2001; 7: 266–72)

Key words: pulmonary emphysema, lung volume reduction, hemodynamics, right ventricular ejection fraction

Introduction

A partial lung resection (lung volume reduction surgery: LVRS) has been performed to reduce hyperinflated lung volume in patients with a chronic obstructive lung disease, particularly in patients with diffuse pulmonary emphysema and/or multiple bullous lung with emphysematous lung parenchyma. LVRS has improved disabling dyspnea and quality of life due to improvement of pulmonary function in patients suffering from pulmonary emphysema with or without multiple bullae.[1-6] Wakabayashi et al.[1,2] reported a thoracoscopic laser pneumoplasty especially for the former and Cooper et al.[3] reported a lung volume reduction surgery for diffuse pulmonary emphysema through median sternotomy. We performed LVRS for the hyperinflated lung parenchyma in 16 patients with diffuse pulmonary emphysema including four patients with multiple bullae and 11 patients without bullae. Several authors reported that LVRS influences cardiopulmonary hemodynamics.[7-10] Therefore, this study was conducted to clarify differences in the change in hemodynamics and right ventricular perfor-

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Table 1. Patients studied (n=16)

	BL (n=5)	UL (n=11)	
Age	65.2 ± 7.6 (64-74)	68.4 ± 4.3 (55-77)	ns
Gender (male / female)	3 / 2	10 / 1	ns
Brinkmann index	1140 ± 581	1145 ± 502	ns
Preopeerative H-J	4.0 ± 0.70	3.92 ± 0.77	ns
HOT	5 / 5	11 / 11	ns

UL: unilateral LVRS; BL: bilateral LVRS; H-J: Hugh-Jones classification of dyspnea; HOT: home oxygen therapy.

mance in terms of surgical approaches, i.e., unilateral approach or simultaneous bilateral approach in 16 patients who underwent partial lung resection by LVRS.

Subjects and Methods

Indications and patients selections

The indication for partial lung resection of a hyperinflated nonfunctioning lung was based on the results of pulmonary function test, pulmonary ventilation and perfusion scintigraphy, presence of disabling dyspnea at rest or on minimal exertion (more than grade III of the Hugh-Jones dyspnea score) and smoking cessation for 6 months or more. (Tables 1 and 3) The degree of hyperinflation was set provisionally based on chest X-ray and pulmonary function test results, i.e., a total lung capacity (TLC) of more than 120% of the predicted value and a residual volume index (RV/TLC) of more than 50%. The degree of obstructive ventilatory disturbances was set at less than 35% of predicted forced expiratory volume in one second (%FEV1.0) and/or less than 1.0 L of forced expiratory volume in one second (FEV1.0). Pulmonary perfusion and ventilation scintigraphy deficits revealed the nonfunctioning area of the lung. The extraindications were as follows: pulmonary hypertension (mean pulmonary artery pressure: mPAP>30 mmHg), hypercapnia ($PaCO_2$>55 torr), and presence of severe ischemic heart disease or advanced malignant disease. Based on the conditions mentioned above, the protocol for this study was established and approved by the Institutional Review Board and informed consent was obtained from all patients before operation. From October 1994 to December 1997, 16 consecutive patients with a mean age of 67 years old (ranging from 55 to 77) were indicated for partial resection of the hyperinflated nonfunctioning lung by LVRS, and finally recommended to undergo LVRS depending on the mental and physical conditions of the patients, all of whom depended on continuous supplemental oxygen inhalation (home oxygen therapy: HOT). There were 13 males and 3 females. Four of the patients had multiple bullae in areas with pulmonary emphysema and 12 had diffuse but heterogeneous pulmonary emphysema. Five patients exhibiting symmetric distribution of perfusion underwent simultaneous bilateral (BL)-LVRS (median sternotomy, 4; thoracoscopy, 1). Eleven patients underwent unilateral (UL)-LVRS by thoracoscopy, because of the presence of asymmetric distribution of perfusion and ventilation deficit.

Surgical technique

Five patients underwent BL-LVRS by stapler resection with 8 watts of neodymium: yttrium-alminum-garnet (Nd: YAG) laser ablation using a contact probe (four by median sternotomy and one by thoracoscopy), and 11 patients underwent UL-LVRS by stapler resection with Nd: YAG laser ablation using a thoracoscope. Thoracoscopic LVRS was performed under general anesthesia using one-lung ventilation. With patients in the lateral decubitus position, four ports (1- to 2-cm-long skin incision to insert the trocar) were made to insert the thoracoscope and endoscopic instruments. Four trocars were each inserted into the sixth intercostal space of the anterior axillary line, the eighth intercostal of the posterior axillary line, the third intercostal space of the anterior axillary line and the fifth intercostal space of the posterior axillary line. One patient who underwent thoracoscopic bilateral partial lung resection was made to change his position contralaterally in a decubitus position after completion of the opposite side. According to preoperative examination of the target area, the nonfunctioning emphysematous lung area was resected partially using a 45-mm and 60-mm endoscopic stapler (Ethicon Endo-Surgery Inc., Cincinnati, OH, and U.S. Surgical Corp. Philadelphia, PA, U.S.A.) without reinforcement with bovine pericardium. After resection of the nonfunctioning emphysematous lung as the target area, additional laser ablation was carried out using Nd: YAG laser with a contact probe. The lung parenchyma was resected 60 g on

Table 2. Surgery and postoperative complications

	Group		Statistics	p value	95% CI
	BL group (n=5)	UL group (n=11)			
Operation time (min)	276 ± 93	247 ± 84	ns	0.53	–71~130
Blood loss (mL)	316 ± 218	89 ± 188	significant	0.05	–2~456
Chest drainage (day)	21 ± 12	8 ± 3	significant	0.004	4~21
Air leakage > 7 days	5 / 5	4 / 10	significant	0.036	

Operation time was longer for UL than for BL, but blood loss was minimal in the case of the unilateral thoracoscopic procedure compared to that of the bilateral procedure (p=0.052, 95% CI: –2.4~456). Values are presented as means ± SD, p: less than 0.05 was considered significant.

average (ranging from 50 to 70 g) for one lung and reduced around 20% to 30% of the hyperinflated lung. After resection of the lung, additional stitches and fibrin glue were applied to prevent air leakage from the stapled and stitched line.

Hemodynamics and right ventricular performance

The hemodynamics and right ventricular ejection fraction (RVEF) were measured at preoperation and 6, 12, 24, and 48 hours postoperatively using a Swan-Ganz EF thermodilution catheter (model 93A-431 H-7.5F) and model REF-1 cardiac output computer (Baxter Health Care Corporation, Edward's Critical-Care Division, Irvine, CA, U.S.A.). The postoperative pulmonary function test was conducted for 3 months on average, except in two patients who died of pneumonia on the 41st and 45th postoperative day.

Postoperative management

In order to reduce postoperative pain, epidural analgesia was administered to all the patients. Oxygen was supplied to all patients continuously after surgery to maintain the arterial blood gas values at levels higher than the preoperative value. As a postoperative medical care of cardiopulmonary circulatory conditions, 0.25 mg/day of Digoxin and 40 mg/sheet/day of isosorbide dinitrate were administered after surgery. The patients were followed up as out-patients for an average of 12 months ranging from 1.5 to 60 months postoperatively.

Statistical analyses

Analyses were performed using the software package of Stat View 5.0 (SAS Inc., Cary, NC, U.S.A.). Two-factorial analysis of variance was used for analysis of hemodynamic changes. If it showed significance, further analysis was performed using Bonferoni's t-test for multiple pairwise comparisons. The relationship between two parameters was analyzed using linear regression analysis. Since the findings showed a normal distribution, a parametric test was applied for statistical analysis of age, clinical outcome and changes in hemodynamics. Mean values were compared using a Student's t-test for comparison of two groups. The Fisher exact test was used to compare proportions. The Mann-Whitney rank sum test was performed for comparison of two groups with respect to the preoperative Hugh-Jones dyspnea score, gender and cases with 7 days or more of air leakage after surgery. All values were reported as means ± standard deviation (SD). A p-value of less than 0.05 was considered significant.

Results

There were no significant differences in preoperative age, gender, preoperative pulmonary function (%FEV1.0, % TLC, RV/TLC), Hugh-Jones dyspnea score, Brinkmann index and necessity of HOT. Before operation, the Hugh-Jones dyspnea score was as follows: UL group, 3 patients of grade V, 4 of grade IV, 4 of grade III; BL group, 1 of grade V, 2 of grade IV, 2 of grade III. After surgery, 10 out of 11 patients who underwent UL improved and 3 of 5 patients who underwent BL had improved Hugh-Jones dyspnea score. Before surgery, all patients used HOT, but 7 of 11 UL cases and 2 of 5 BL cases no longer used HOT postoperatively.

Morbidity and mortality

The operation time was slightly longer in the case of BL-LVRS compared to that of UL-LVRS, but blood loss was minimal in patients who underwent UL-LVRS compared to those who underwent BL-LVRS (p=0.052, 95% CI: –2.4-456). During the postoperative course, the most frequent complication was persistent air leakage as shown in Table 2. Persistent air leakage for more than 7 days was more frequently observed in the BL group than in the IL group (p=0.036). Two patients died of pneumonia

Table 3. Changes in pulmonary function of patients who underwent BL and UL within 3 months after operation.

Procedure	% FEV1	FEV1 (L)	% TLC	RV / TLC
BL group				
preoperative	32 ± 4	0.75 ± 0.12	139 ± 2	64 ± 2
postoperative	39 ± 3	0.84 ± 0.14	118 ± 7*	60 ± 2
change	+18%	+18%	–15%	–7%
UL group				
preoperative	26 ± 2	0.55 ± 0.04	122 ± 5	67 ± 2
postoperative	32 ± 2*	0.67 ± 0.05*	100 ± 6*	62 ± 2
change	+20%	+22%	–13%	–7%

FEV1: forced expiratory volume in 1 second, % FEV: FEV1 predicted, TLC: total lung capacity, % TLC: TLC predicted, RVI: residual volume index, change: (postoperative value – preoperative value) / preoperative value ×100 (%).

during postoperative hospitalization. A 66-year-old male who underwent UL-LVRS was recommended reoperation for persistent air leakage caused by collapse of visceral pleura by laser ablation with atelectasis. Perforation of lung surface around the coagulation area by laser ablation revealed massive air leakage. Even though the patient was cared for intensively, he died of respiratory failure on the 45th postoperative day due to exacerbated pneumonia and pyothorax. Another 65-year-old male who underwent BL-LVRS by median sternotomy died of pneumonia on the 41st postoperative day caused by bronchial obstruction with abundant intrabronchial sputum retention. Five patients (2 of 12 in the IL group, and 3 of 5 in the BL group) were cared for under mechanical ventilation 48 hours or more postoperatively. Their FEV1 was from 0.39 to 0.54 L with a mean of 0.54 L.

Pulmonary function

Before operation the mean FEV1 was 0.75 L or 32% of predicted in the BL group and was 0.55 L or 26% of predicted in the UL group. Changes in pulmonary function in patients who underwent UL- and BL-LVRS are shown in Table 3. This study showed less improvement in pulmonary function compared to that reported by other authors. There were no significant differences between the two groups.

Hemodynamics and right ventricular performance (Table 4)

Before operation the mPAP was 23±3 mmHg in the BL group and was 22±5 mmHg in the UL group. No patient showed a mPAP higher than 35 mmHg. After operation both group of patients who underwent UL and BL exhibited a reduction in ventricular afterload 48 hours postoperation, compared to that at preoperation. Systemic vascular resistance index (SVRI) was reduced from 6 to 48 hours postoperation, associated with reduction in the total pulmonary resistance index (TPRI), even though the pulmonary arterial resistance index (PARI) was slightly elevated 48 hours postoperation. There was a significant linear correlation between change in pre- and postoperative values for the right ventricular end-diastolic volume index (RVEDVI) and stroke volume index (SI) 48 hours postoperation (R=0.746: p=0.0009) (Fig. 1). Reduction in SVRI correlated significantly with an increase in the cardiac index (CI) 48 hours postoperation (R=0.760: p=0.0006) (Fig. 2). The RVEF changed minimally 48 hours postoperation, compared to that at preoperation, followed by an increase in SI. RVEDVI increased in both the UL and BL groups through 24 hours postoperation. The patients who underwent UL showed minimal change in blood pressure compared to the BL group whose blood pressure decreased. In contrast, the patients who underwent BL showed deterioration of mean arterial blood pressure (mBP) and increase in heart rate (HR) to more than 120% compared to the preoperative value. The left ventricular stroke work index (LVSWI) increased in the patients who underwent UL-LVRS, from 6 to 48 hours postoperation. In the patients who underwent BL-LVRS, it tended to decrease until 48 hours postoperation.

Discussion

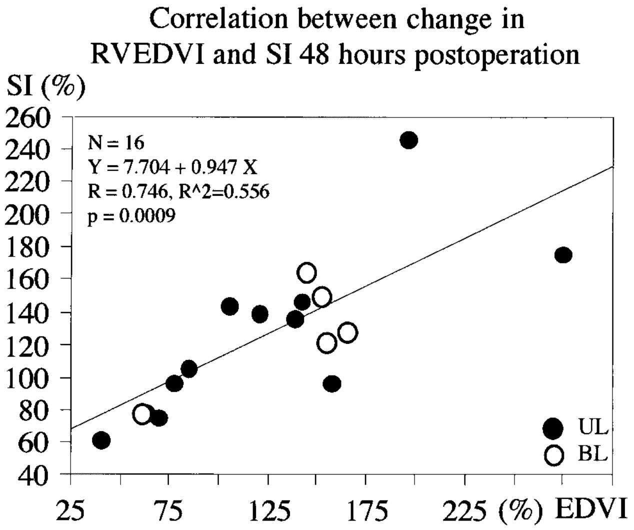
In the present study, even though the total number of patients was small, significant reduction in the ventricular afterload of both lungs was observed in patients who underwent UL- and BL-LVRS. Effectiveness of LVRS

Table 4. Pre- and postoperative hemodynamics and right ventricular performance

	Preoperation		6 hours		12 hours		24 hours		48 hours	
	UL	BL	UL	BL	UL	BL	UL	BL	UL	BL
n	n=11	n=5	n=11	n=5	n=11	n=5	n=11	n=5	n=11	n=5
HR (bpm)	81 ± 10	86 ± 21	87 ± 14 a	118 ± 25	94 ± 16 b	119 ± 13	97 ± 17	112 ± 25	94 ± 19	105 ± 21
mBP (mmHg)	91 ± 15	90 ± 9	83 ± 15 c	72 ± 12	91 ± 18 d	70 ± 10	92 ± 14 e	72 ± 9	86 ± 14	78 ± 6
mPAP (mmHg)	22 ± 5	23 ± 3	23 ± 4	21 ± 8	23 ± 3	21 ± 9	23 ± 4	21 ± 7	22 ± 8	23 ± 12
PCWP (mmHg)	12 ± 4	13 ± 2	7 ± 2	8 ± 1	9 ± 3	10 ± 8	8 ± 4	10 ± 7	8 ± 5	8 ± 4
RAP (mmHg)	10 ± 2	12 ± 2	4 ± 2	5 ± 2	6 ± 3	5 ± 4	5 ± 2	7 ± 3	6 ± 3	6 ± 4
RVEDVI (l/m^2)	120 ± 36	95 ± 37	136 ± 32 f	98 ± 35	155 ± 74	110 ± 31	158 ± 51	118 ± 31	140 ± 53	120 ± 36
RVESVI (l/m^2)	83 ± 28	60 ± 25	92 ± 26	71 ± 21	120 ± 60	76 ± 25	111 ± 47	81 ± 23	96 ± 45	77 ± 31
RVEF (%)	31 ± 5 i	37 ± 7	33 ± 7	32 ± 4	28 ± 7	30 ± 6	31 ± 8	32 ± 5	32 ± 7	37 ± 7
SI (ml/m^2)	36 ± 12	36 ± 13	44 ± 13	35 ± 13	43 ± 13	33 ± 19	46 ± 11	38 ± 10	43 ± 12	47 ± 7
CI (l/min)	2.8 ± 0.8	3.1 ± 1.4	3.8 ± 1.1	4.0 ± 1.5	4.0 ± 0.9	3.8 ± 0.6	4.3 ± 0.9	3.2 ± 1.9	3.8 ± 1.0	4.4 ± 0.8
LVSWI (g·m/m^2)	77 ± 30	85 ± 39	101 ± 20 g	65 ± 14	96 ± 32 j	63 ± 29	102 ± 21 h	74 ± 35	94 ± 36	92 ± 27
RVSWI (g·m/m^2)	13 ± 9.5	12.8 ± 7.8	22.2 ± 6.2	15.4 ± 6.6	21.0 ± 8.9	17.0 ± 11.6	22.0 ± 5.5	15.8 ± 11.3	18.8 ± 104	21.6 ± 12.7
TPRI (dyne·sec·cm-5·m^2)	656 ± 169	674 ± 244	518 ± 135	472 ± 266	502 ± 136	461 ± 214	450 ± 148	430 ± 188	488 ± 259	426 ± 236
PARI (dyne·sec·cm-5·m^2)	295 ± 126	257 ± 73	366 ± 132	301 ± 225	307 ± 120	239 ± 122	289 ± 105	210 ± 114	313 ± 173	276 ± 164
SVRI (dyne·sec·cm-5·m^2)	2452 ± 968	2333 ± 889	1973 ± 574	1520 ± 682	1783 ± 616	1407 ± 476	1692 ± 604	1285 ± 271	1775 ± 703	1328 ± 320

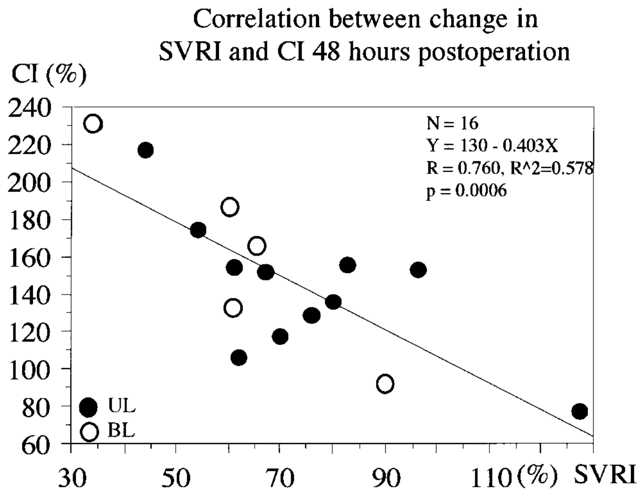
UL: unilateral lung volume reduction, BL: bilateral lung volume reduction, HR: heart rate, mBP: mean arterial pressure, mPAP: mean pulmonary arterial pressure, PCWP: pulmonary capillary wedge pressure, RAP: right atrial pressure, RVEDVI: right ventricular endo-diastolic volume index, RVESVI: right ventricular endo-systolic volume index, RVEF: right ventricular ejection fraction, SI: stroke volume index, CI: cardiac index, LVSWI: left ventricular stroke work index, RVSWI: right ventricular stroke work index, TPRI: total pulmonary resistance index, PARI: pulmonary artery resistance index, SVRI: systemic vascular resistance index, UL vs BL: p value; a=0.008, b=0.002, c=0.01, d=0.03, e=0.01, f=0.02, g=0.003, h=0.06 (95%CI: 0.15-13.7), j=0.069 (95%CI: –69-3), k=0.065 (95%CI: –14-0.4).

was considered to depend on the reduction in elevated TPRI which is followed by a reduction in SVRI. Kubo et al.[9] reported on the improvement of peripheral pulmonary circulation after LVRS for severe pulmonary emphysema. They mentioned that LVRS improved peripheral pulmonary circulation, because CI increased after LVRS. The mPAP and the pulmonary capillary wedge pressure (PCWP) before LVRS increased both at rest and during exercise. They concluded that elevated PCWP during exercise before LVRS is probably related to mechanical lung abnormalities. This suggests that peripheral pulmonary circulation might be affected in the hyperinflated lung. In this study, minor differences were noted in terms of changes in LVSWI, which increased in patients who underwent UL-LVRS compared to patients who underwent BL-LVRS. Thurnheer et al.[10] reported that LVRS did not result in serious changes in pulmonary pressure in terms of pulmonary hypertension in patients who are good candidates for LVRS. Furthermore, Oswald-Mammosser et al.[11] attempted to assess the pulmonary hemodynamics and gas exchange at rest and during exercise after LVRS. They emphasized that LVRS itself does not impair pulmonary hemodynamics in spite of a decrease in vascularity following LVRS. These reports seem to indicate the improvement of peripheral pulmonary circulation after LVRS. Concerning postoperative management, Cooper,[12] Kellar,[13] and Naunheim[6] emphasized that postoperative complication is a serious problem in postoperative care. Cooper warned thoracic surgeons that prolonged air leakage and atelectasis would cause serious problems in the pulmonary circulation that would particularly result in a decrease in the venous blood return to the left ventricle. In the present study, although we used polyglycolic acid fabric, teflon felt strips as reinforcement for the stapler line, the patients who underwent BL-LVRS tended to suffer from persistent air leakage compared to those who underwent UL-LVRS. It was concluded that it is hard to completely control air leakage with or without polyglycolic acid fabric, teflon felt strips and to avoid perforation of the lung surface a few days after surgery, where it was ablated by Nd: YAG laser. Two patients died of pneumonia caused by persistent air leakage with atelectasis on the 41st and 45th postoperative day. In such patients, postoperative hemodynamic changes showed re-elevation in TPRI and SVRI associated with a marked decrease in SI and CI, which are in agreement with those mentioned by Cooper. The patients studied could not have achieved improvement



Significant linear correlation was shown between change in pre- and postoperative values for the RVEDVI and SI 48 hours postoperation.

Fig. 1. Correlation between the change in RVEDVI and the change in SI 48 hours postoperation.
A positive linear correlation was observed between the change in RVEDVI and the change in SI 48 hours postoperation in all cases.
RVEDVI: right ventricular endo-diastolic volume index, SI: stroke volume index.
Change = Post / Pre ×100 (%)



Significant linear correlation was shown between change in pre- and postoperative values for the SVRI and CI 48 hours postoperation.

Fig. 2. Correlation between the % change in CI and the % change in SVRI 48 hours postoperation.
CI: cardiac index, SVRI: systemic vascular resistance index. Positive linear correlation was observed between the % change in SVRI and the % change in CI 48 hours postoperation in all patients.
Change = Post / Pre ×100 (%)

in pulmonary function compared to those reported by other authors.[1-7] We concluded that the high incidence of air leakage in the present study must have affected the improvement in pulmonary functions after LVRS.

Patients with a chronic obstructive pulmonary disease (COPD) tended to suffer from an increased RVEDVI with a decrease in RVEF. Brent et al.[14] and Burghuber and Bergman [15] mentioned that a decrease in RVEF in severe patients correlated with the right ventricular afterload and emphasized the benefit of administration of various vasodilators to reduce the right ventricular afterload in COPD patients. In contrast, patients who underwent LVRS showed a significant increase in RVEDVI associated with an increase in SI and CI. RVEF did not show a significant change associated with an increase in RVEDVI, RVESVI and SI postoperatively. Even though it is unclear what factors contributed to the reduction in SVRI and TPRI, reduced intrapleural pressure and intensive care might improve laborious breathing immediately after surgery. These reductions in both SVRI and TPRI might contribute to the reduction in ventricular afterload of both lungs resulting in an increase in ventricular forward flow. In contrast, in the patients with postoperative complications, both PARI and TPRI tended to increase compared to those in patients showing an uneventful postoperative course. Furthermore, RVEDVI tended to increase in association with the significant decrease in RVEF (p=0.023) and LVSWI (p=0.012) in patients with postoperative complications compared to the patients showing an uneventful postoperative course. In the present study, changes in hemodynamics and right ventricular performance showed similar values for both UL and BL groups postoperatively, except for HR, mBP and LVSWI.

In conclusion, LVRS for hyperinflated pulmonary emphysema reduced the ventricular afterload of both lungs 48 hours postoperation. This suggested that LVRS can reduce elevated intrapleural pressure, which contributes to an increase in the endo-diastolic volume associated with an increase in cardiac output. This improved performance is considered to be a beneficial aspect of LVRS for hyperinflated pulmonary emphysema. Both the UL- and BL-LVRS approaches showed similar effectiveness in terms of improvement in the systemic and cardiopulmonary circulation after LVRS, if there were no postoperative persistent air leakage. Therefore, we concluded that persistent air leakage must be avoided and repaired quickly in the early postsurgical period.

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