Improvements in Thoracic Movement Following Lung Volume Reduction Surgery in Patients with Severe Emphysema

Keisaku Fujimoto, Keishi Kubo, Masayuki Haniuda*, Yukinori Matsuzawa, Takeshi Yamanda* and Yuichiro Maruyama**

In twelve patients with severe emphysema who underwent lung volume reduction surgery (LVRS), we assessed the results of dyspnea scale, pulmonary function, 6-minute walk distance (6MD), and thoracic movement prior to and 6 months following LVRS. Postoperatively, forced expiratory volume (FEV₁), maximum inspiratory mouth pressures (MIP), maximum expiratory mouth pressures (MEP), maximum voluntary ventilation (MVV), diffusing capacity for carbon monoxide (DLco), partial pressure of oxygen (PaO₂) and 6MD were significantly increased with the decrease in dyspnea scale and lung hyperinflation. Thoracic movement, as assessed by the bilateral lung area ratio of the mid-sagittal dimension of dynamic magnetic resonance imaging (MRI) at full inspiration to that at full expiration, was significantly increased. The improvement in thoracic movement was significantly correlated with the increases in FEV₁, MVV, and MIP, and with the decrease in residual volume (RV), and with the improvement in the dyspnea scale. These findings suggest that LVRS is an effective procedure for improving not only the airflow limitation and gas exchange but also the thoracic movement in severe emphysema, and these improvements may contribute to an increase in exercise performance and relief of dyspnea.

(Internal Medicine 38: 119-125, 1999)

Key words: respiratory muscle dysfunction, diaphragmatic excursion, Medical Research Council (MRC) dyspnea scale, chest wall, respiratory muscle strength, airway collapsibility

Introduction

Patients with severe emphysema have a limited exercise performance as a result of airflow limitation reducing their ventilatory reserve, respiratory muscle dysfunction associated with hyperinflation, exercise-induced hypoxemia, and cardiac dysfunction (1–3). The hyperinflation of the lung impairs the efficiency of the muscles of the chest wall and diaphragm by placing them at mechanical disadvantage, and limits diaphragmatic excursion (4). The adverse effects of hyperinflation on diaphragmatic function include the foreshortening of the diaphragm precontraction length (5–7), decreased area of apposition of the costal part with the chest wall (8, 9), increased radius of curvature (5), impaired blood flow and decreased insertional action of the rib cage (10), and increased internal elastic inspiratory load (4).
patients improves breathing patterns and diaphragmatic function (16–20). In the present study, to investigate the effects of LVRS on the thoracic mechanics, we evaluated the thoracic movement of patients with severe pulmonary emphysema while they inhaled and exhaled slowly and maximally, with the use of fast spoiled-gradient-recalled (SPGR) magnetic resonance imaging (MRI) (21, 22) before and 6 months after LVRS. The thoracic movement was assessed by the lung area ratio of the bilateral mid-sagittal plane from dynamic MRI at full inspiration to that at full expiration (I/E ratio), and the contribution of the changes in the thoracic movement following LVRS to the improvements in dyspnea, lung function, and exercise performance was examined.

Methods

Subjects

Thirteen patients with severe pulmonary emphysema and without giant bullae underwent LVRS at the Shinshu University Hospital between March 1995 and July 1997. Twelve of these patients participated in this study, one patient moved to another hospital after the surgery, and could not participate in the study. All patients, diagnosed by a clinical history of exertional dyspnea and smoking and the clinical features of irreversible airway obstruction, lung hyperinflation, decrease in diffusing capacity for carbon monoxide (DLco), and anatomic emphysema on computed tomography (CT) scanning of the chest, were selected in accordance with the 9 criteria for surgery from Cooper’s laboratory (23–25): 1. Age ≤75 years. 2. Abstinence from cigarette smoking (>6 months). 3. Marked restriction in the activities of daily or social living due to severe fixed expiratory obstruction despite maximal medical therapy including physical therapy. 4. Ability to undergo a vigorous pulmonary rehabilitation program. 5. Anatomic emphysema with marked hyperinflation and presence of heterogeneous disease distribution with target areas for resection on high-resolution CT scanning of the chest and ventilation/perfusion lung scanning. 6. Normal left heart function. 7. Partial pressure of carbon dioxide (PaCO2) under breathing room air at rest <55 mmHg. 8. Mean pulmonary arterial pressure at rest <35 mmHg. 9. No coexisting major medical problems that would significantly increase the operative risk. The characteristics of the patients before the surgery are summarized in Table 1. All of the patients were males with clinically severe emphysema in its stable phase without an α1-antitrypsin deficiency. All patients complained of marked limitation in the activities of daily living or social living due to chronic exertional dyspnea (grade III to V dyspnea on the Hugh-Jones scale). Nine patients required supplemental oxygen with exertion, and six of these also required supplemental oxygen at rest. All of the patients showed severe airflow obstruction, hyperinflation, and a decrease in DLco. All patients gave written consent after being informed about the risk, benefit, and procedure of the surgery, and their participation in this study.

Study design

The preoperative phase of pulmonary exercise rehabilitation began as soon as the patient was accepted for LVRS. The rehabilitation was continued for a minimum of 6 to 8 weeks before surgery with the goal of obtaining optimal exercise endurance and pulmonary hygiene. The assessment of dyspnea, lung function, 6-minute walk test, and the chest wall and diaphragmatic movement determined by fast SPGR MRI was conducted immediately prior to and approximately 6 months following the surgery.

Operative technique

All patients underwent stapled LVRS via median sternotomy according to the method of Cooper and colleagues (11, 23, 26). Visually the most distended, destroyed, emphysematous areas that were previously targeted by the preoperative CT lung scan and ventilation/perfusion lung scanning were excised, and linear staple lines were reinforced with bovine pericardium to minimize air leaks. The excised regions were mainly the bilateral upper lung lobes in 9 patients, the bilateral lower lung lobes in two patients, and a unilateral lower lung lobe in one patient.

Quantification of dyspnea

A modified Medical Research Council (MRC) Dyspnea Scale was used to quantify the degree of dyspnea (23, 27).

Pulmonary function test

The spirometry was performed with a water spirometer (Godart Exprograph, Godart-Statham, Bilthoven, Holland). The vital capacity (VC), forced vital capacity (FVC), forced expiratory volume in one second (FEV1), FEV1% (FEV1/FVC), and maximum voluntary ventilation (MVV) were calculated. Functional residual capacity (FRC) was measured in a body plethysmography system (model 1085/D; MedGraphics Co., St. Paul MN, USA), and total lung capacity (TLC) and residual volume (RV) were calculated from this lung volume. DLco was measured by the single-breath method (Pulmocorder, model

| Table 1. Preoperative Characteristics of Patients with Pulmonary Emphysema |
|------------------|------------------|------------------|
| Age (yr)         | 65 ± 2           | (54–75)          |
| Sex (M/F)        | 12/0             |                  |
| BMI (kg/m²)      | 19.4 ± 0.7       | (15.7–23.9)      |
| %VC (%)          | 80.0 ± 4.3       | (61.8–103.0)     |
| %FEV1 (%)        | 29.7 ± 3.2       | (17.5–52.0)      |
| FEV1% (%)        | 33.1 ± 2.3       | (23.1–48.8)      |
| %RV (%)          | 344.9 ± 13.2     | (264.1–421.4)    |
| %DLco (%)        | 45.9 ± 4.8       | (14.1–67.8)      |
| PaO2 (mmHg)      | 63.9 ± 3.2       | (45.6–83.7)      |
| PaCO2 (mmHg)     | 43.6 ± 1.7       | (34.3–51.8)      |

Values are expressed as mean ± SEM. BMI: body mass index, %VC: percentage of predicted vital capacity, %FEV1: percentage of predicted forced expiratory volume (FVC) in 1 second, FEV1/FVC, %RV: percentage of predicted residual volume, %DLco: percentage of diffusing capacity for carbon monoxide.
Six-minute walk test

Exercise performance was assessed by the 6-minute walk test according to standard procedures (11, 31). The 6-minute walk distance (6MD) was measured while the patient breathed supplemental oxygen through a nasal tube to avoid extreme hypoxemia, with SpO2 monitored by a pulse oxygen saturation monitor (Pulsox-8; Teijin Ltd., Osaka). The test was of the distance the patient could walk in 6 minutes in a measured corridor. Patients were allowed to rest when necessary, but were encouraged to complete as many lengths of the corridor as possible.

Assessment of thoracic movement by fast SPGR MR imaging

The technique we used for the dynamic MR imaging of the chest was based on the protocol used by Shellock et al (21) and Gierada et al (22). We used a body coil, fast SPGR (spoiled-gradient-recalled acquisition in the steady state) pulse sequence with a 30° flip angle, repetition time of 15.9 msec, echo time of 4.2 msec, receiver bandwidth of 8 kHz, field of view of 24×48 cm, section thickness of 7 mm, 128×256 matrix (sagittal), field of view of 36×48 cm, section thickness of 7 mm, 192×256 matrix (coronal) and one signal acquired (1.5-T Signa MR imager; GE Medical Systems, Milwaukee, WI). With this technique, we obtained 18 sequential 1.1-second images during one to three uninterrupted respiratory cycles (6–18 images per cycle) at the sagittal imaging level. While in the supine position, patients inhaled and exhaled slowly and maximally following verbal cues during image acquisition. The respiratory rates were 3–9 cycles per minute. Images were played and recorded as cine loops for analysis and comparison. The mid-sagittal plane of each right and left chest were chosen for the assessment of thoracic movement. The sequential movements of the chest wall and diaphragm at the mid-sagittal image of each side while 10 breaths were recorded, and the lung areas of the bilateral mid-sagittal dimensions at each full inspiratory and full expiratory image through the sequential acquisition were calculated at each breathing. The thoracic movement was assessed by the bilateral lung area ratio at full inspiration to that at full expiration (I/E ratio) (Fig. 1). The highest values of I/E ratio during 10 breaths was accepted. As a control study, the I/E ratio was also measured in 6 healthy volunteers, who gave written informed consent.

Statistical analysis

All data are presented as means ± standard errors (SEM). Comparisons of variables were made by paired t-test. If the two-tailed test results were p<0.05, significance was accepted. The correlation between variables was examined by calculating Pearson’s product correlation coefficient. A p value of less than 0.05 was considered significant.

Results

Dyspnea, pulmonary function, and exercise performance

The results of the dyspnea score, lung function data and arterial blood gas analysis, and 6-minute walk test after LVRS are summarized in Table 2. The MRC scores were improved in all but two of the 12 patients by 1–3 grades on the MRC scale at 6 months after the surgery. After LVRS, the FRC, RV, and RV/TLC values were significantly decreased, and the FEV1 and MVV were significantly increased (Fig. 2). There was a significant positive correlation between the increases in FEV1 and the decreases in FRC (r=0.79, p<0.01). The V50 and V25 values were significantly increased, and the difference between VC and FVC was significantly decreased from 0.44 ± 0.07 to 0.17 ± 0.07 l (p<0.01). The respiratory muscle strength, especially inspiratory muscle strength (MIP), was significantly increased from the values obtained after the preoperative rehabilitation. The patients’ decreased DLCO and partial pressure of oxygen (PaO2) were significantly increased, and the gas exchange also...
improved. The 6MD values were significantly increased. The improvement in the exercise performance had a tendency to be positively correlated with the increases in FEV$_1$, but there was no significant correlation ($r=0.54$, $p=0.07$).

**Thoracic movement**

Before the LVRS, the sequential bilateral mid-sagittal dynamic MRI showed a flattened diaphragm at end-inspiration and an outward-bowed anterior chest wall; the upward and downward movement of diaphragm during full respiration ("diaphragmatic excursion") was markedly limited (Fig. 3, top row), and the I/E ratio was markedly low (1.17 ± 0.03) compared with the values in the healthy volunteers (I/E: 1.82 ± 0.07) (Fig. 4). At 6 months after LVRS, the lung areas at the bilateral mid-sagittal dimension were reduced, the diaphragm was curved at end-expiration and the diaphragmatic excursion was improved (Fig. 3, bottom row). The I/E ratios of the patients were significantly increased (1.38 ± 0.06), although they did not reach the values of the healthy controls. There was no difference in the improvement in I/E ratio between the patients who received LVRS of the upper lobes and LVRS of the lower lobes. The percentage of increase in the I/E ratio was positively correlated with the decrease in RV ($r=0.71$, $p<0.01$) and with the increase in MIP ($r=0.66$, $p<0.05$) (Fig. 5), and also it was significantly correlated with the increases in FEV$_1$ ($r=0.64$, $p<0.05$) and MVV ($r=0.64$, $p<0.05$). There was no significant correlation between the improvement in thoracic movement and exercise performance ($r=0.46$); however, a significant positive correlation with the improvement in the MRC dyspnea scale was obtained ($r=0.73$, $p<0.01$) (Fig. 6).

**Discussion**

Dynamic MR imaging has been useful for evaluating diaphragmatic motion (32, 33). With conventional spin-echo imaging, the necessary imaging time is long, and cardiac and respiratory motion artifacts result in inadequate temporal resolution for a dynamic evaluation of thoracic movement. Fast SPGR pulse sequences greatly reduce these problems and allow for improvement in the evaluation of diaphragmatic movement (22). In the present study, a mid-sagittal plane was chosen for the evaluation of chest wall and diaphragmatic movement, because partial volume averaging of the posterior diaphragm with the lung in the coronal plane makes the identification of the diaphragmatic margin difficult, and outward movements of the chest wall displace the dome of the diaphragm into or out of the

| Table 2. Dyspnea Scale, Pulmonary Function and Arterial Blood Gas Analysis, 6-minute Walk Distance (6MD) before and 6 Months after Lung Volume Reduction Surgery |
|---------------------------------|-----------------|
|                                 | before          | after           |
| MRC scale                       | 3.1 ± 0.3       | 2.0 ± 0.3**     |
| FVC (L)                         | 2.22 ± 0.17     | 2.53 ± 0.19*    |
| FEV$_1$ (L)                     | 0.73 ± 0.08     | 1.03 ± 0.11**   |
| FRC (L)                         | 6.68 ± 0.23     | 5.08 ± 0.26**   |
| RV (L)                          | 5.55 ± 0.21     | 4.03 ± 0.29**   |
| RV/TLC (%)                      | 67.9 ± 1.8      | 60.1 ± 3.0**    |
| $\dot{V}_{20}$ (L/sec)          | 0.30 ± 0.05     | 0.56 ± 0.08**   |
| $\dot{V}_{25}$ (L/sec)          | 0.18 ± 0.02     | 0.33 ± 0.04**   |
| $\Delta N_2$ (%)                | 1.81 ± 0.10     | 1.86 ± 0.12*    |
| DLco (ml/min/mmHg)              | 11.2 ± 1.1      | 14.5 ± 1.32*    |
| MVV (L/min)                     | 27.6 ± 3.7      | 36.3 ± 3.8**    |
| MIP (cmH$_2$O)                  | 52.4 ± 4.2      | 70.3 ± 6.5**    |
| MEP (cmH$_2$O)                  | 61.4 ± 5.4      | 76.3 ± 6.1*     |
| PaO$_2$ (mmHg)                  | 63.9 ± 3.2      | 71.7 ± 3.5**    |
| PaCO$_2$ (mmHg)                 | 43.6 ± 1.7      | 41.0 ± 1.7      |
| 6MD (m)                         | 306 ± 37        | 398 ± 36*       |

Values are expressed as mean ± SEM. MRC Scale: Modified Medical Research Council of Great Britain Dyspnea Scale, $\dot{V}_{20}$, $\dot{V}_{25}$: flow at 50% and 25% of the FVC, $\Delta N_2$: $N_2$ slope of the alveolar plateau, MVV: maximum voluntary ventilation, MIP, MEP: maximum inspiratory and expiratory mouth pressure, 6MD: 6-minute walk distance. *p<0.05, **p<0.01 vs. values before lung volume reduction surgery.

**Figure 2. FEV$_1$ and FRC responses in individual patients with emphysema at 6 months after lung volume reduction surgery (LVRS) (n=12).** **p<0.01 vs. values before LVRS.**
Lung Volume Reduction in Emphysema

Figure 3. Left mid-sagittal plane of dynamic MRI at end-inspiration (left-hand panels) and end-expiration (right-hand panels) obtained before (top row) and 6 months after (bottom row) lung volume reduction surgery (LVRS). Before surgery, the diaphragm was flattened at end-inspiration, and the excursion was markedly limited. After surgery, the diaphragm was curved at end-expiration and the diaphragmatic excursion was markedly improved.

Figure 4. Comparison of the bilateral lung area ratio of the mid-sagittal dimension of dynamic MRI at end-inspiration to that at end-expiration (I/E ratio) in healthy controls (n=6) and in patients with emphysema before and 6 months after lung volume reduction surgery (LVRS) (n=12). **p<0.01 vs. healthy controls. +p<0.05 vs. values before LVRS.

In all patients, the anterior chest wall was bowed outward and the diaphragm was positioned lower and flattened compared to the healthy state. The diaphragmatic excursion was markedly limited, and the I/E ratio was markedly decreased before LVRS. Under these conditions, the inspiratory musculature, mainly the diaphragm, undergoes a diminution in strength, efficiency, and endurance (4–10), which may reflect the decrease in MIP. After LVRS, the reduction of the intra-thoracic volume had the result of showing the diaphragm as curved, and significant increases in its excursion and the I/E ratio. The MIP was significantly increased, corresponding with the improvement of the thoracic movement. It has recently been reported that patients with severe emphysema who underwent LVRS showed improvement in inspiratory muscle function by the measurement of MIP, sniff nasal inspiratory pressure, diaphragmatic function as assessed by transdiaphragmatic pressure, and breathing pattern monitored with respiratory inductive plethysmography (16–19). From our dynamic MRI findings, the improvement in diaphragmatic configuration and movement due to decreased hyperinflation following LVRS may result in the increase in these diaphragmatic functions and an improved breathing pattern. It is interesting whether or not the difference of the resected lung areas is related to the improvement of thoracic movement after the LVRS. However, in this study, there was no difference in the improvement in I/E ratio between the patients who received the LVRS of upper lobes and LVRS of lower lobes. Although it is difficult to compare because the number of patient who had lower lung lobes resected was too small, there may be no relation between the resected region of lungs and the improvement of thoracic movement following LVRS.

The exercise performance assessed by the 6-minute walk distance and dyspnea score was significantly improved following LVRS. As factors limiting exercise performance in severe emphysema, airflow limitation, respiratory muscle dysfunction associated with hyperinflation, exercise-induced hypoxemia, and cardiac dysfunction have been proposed (1–3); the decreased ventilatory capacity due to airflow limitation and respiratory muscle dysfunction associated with hyperinflation is the most significant limiting factor for exercise capacity (1). The LVRS resulted in a 42.3 ± 10.5% increase in FEV₁, correlated with a 23.8 ± 3.1% decrease in FRC. The V₅₀ and V₂₅ values were also significantly increased, and the difference between
VC and FVC was also significantly decreased, which may reflect the improvement of airway collapsibility. The improvement in expiratory airflow limitation after LVRS has been suggested to be primarily attributed to the increase in the driving pressure and transmural pressure distending intraparenchymal airways, as a result of the increased lung elastic recoil by the resection of high-compliance regions (13–15). The LVRS also improved gas exchange, based on the findings that the DLco and PaO₂ were significantly increased. Therefore, it is suggested that the improvement in airflow limitation and gas exchange following LVRS contributed to the increased exercise performance. Benditt et al (20) reported that LVRS improved maximal ventilation dependent on the increase in tidal volume, thereby improving maximal exercise performance; their results also suggested the increased use of the diaphragm, based on the measurements of transdiaphragmatic pressure at rest and during maximum exercise. In the present study, the thoracic movement assessed by dynamic MRI was significantly improved following the LVRS, and the improvement was significantly correlated with the relief of dyspnea, however, a significant correlation with the exercise performance assessed by the 6-minute walk distance could not be obtained. One reason may be that the increased exercise performance is suggested to result from not only the improvement in thoracic movement, but also the improvement in airflow limitation and gas exchange. Another reason may be that the thoracic movement during exercise is not same as that during a deep and slow breathing at rest because a dynamic hyperinflation by air-trap is an important factor which limits thoracic movement during exercise in emphysema (34). However, it is speculated that the dynamic hyperinflation may have also been improved because the airflow limitation or airway collapsibility was significantly improved following the LVRS. Also, the MVV was significantly increased with a significant correlation with the improvement in I/E ratio. It is suggested that the improvement in thoracic movement due mainly to the relief of limited diaphragmatic excursion following LVRS, as well as the improvements in airflow limitation and gas exchange, are importantly influence on the increase in exercise capacity by increasing the ventilatory capacity and the relief of dyspnea.

In summary, LVRS improves the airflow limitation, gas exchange, and thoracic movement as a result of a decrease in lung hyperinflation following the resection of higher-compliance regions in severe emphysema patients. These changes may contribute to the improvements in exercise performance and dyspnea.

References

1) Carlson DJ, Ries AL, Kaplan RM. Prediction of maximum exercise
Lung Volume Reduction in Emphysema


Internal Medicine Vol. 38, No. 2 (February 1999)