Effect of lung volume reduction surgery on pulmonary hemodynamics in severe pulmonary emphysema

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Abstract

Objective: The presence of pulmonary hypertension in severe pulmonary emphysema has been considered a relative contraindication to lung volume reduction surgery (LVRS). There was concern that resection of lung tissue might further increase pulmonary artery pressure. To address this point, the prevalence of pulmonary hypertension in candidates for LVRS was investigated. The changes in pulmonary artery pressures after bilateral videoassisted thoracoscopic resection was studied in patients with homo- and heterogeneously destroyed emphysematous lungs.

Design: The pulmonary arterial pressures by right heart catheterization were prospectively assessed, before and 6 months after LVRS in 21 consecutive patients (15 males, six females, mean (±S.E.) age: 62 ± 1.9, range 42–74 years). All were former smokers and three had ZZ-AT1 deficiency. The inclusion criteria were: (a) severe bronchial obstruction (FEV1 < 35% predicted); (b) pulmonary hyperinflation (RV/TLC ≤ 0.60); and (c) absence of hypercapnia (PaCO2 < 50 mmHg).

Results: The FEV1 had increased from 28 ± 2% to 35 ± 3% of the predicted value (P < 0.05) 6 months after surgery. The RV/TLC had declined from 0.65 ± 0.02 to 0.55 ± 0.02; PaO2 increased (66 ± 1 versus 71 ± 2 mmHg, P = 0.04); PaCO2 (38 ± 2 versus 36 ± 1 mmHg, P = 0.26) did not change. The pulmonary artery mean pressure (PAPmean) remained unchanged (18 ± 1 versus 19 ± 1 mmHg, P = 0.26). In six patients PAPmean was ≥ 20 mmHg (up to 24 mmHg) preoperatively. After 6 months, six patients had a PAPmean ≥ 20 mmHg (up to 31 mmHg).

Conclusions: In patients with severe emphysema who are candidates for LVRS (but have only mild to moderate hypoxemia and a PaCO2 < 50 mmHg) we found no relevant pulmonary hypertension and pulmonary artery pressure did not change significantly after surgery. Therefore, routine right heart catheterization is not mandatory for preoperative evaluation. © 1998 Elsevier Science B.V. All rights reserved.

Keywords: Lung volume reduction surgery; Pulmonary arterial pressure; Pulmonary emphysema

1. Introduction

Lung volume reduction surgery (LVRS) is a novel therapeutic concept which has been successfully applied in patients with airflow obstruction and hyperinflation due to severe pulmonary emphysema—who are severely limited in their daily activity [1–4]. LVRS is performed by median sternotomy [1,2] or by video-assisted thoracoscopic (VAT) [3–5]. For both types of procedures, the patient has to undergo one-lung ventilation. The intra- and postoperative management is a challenge in these patients, who are severely impaired in
their pulmonary function [6]. Pulmonary arterial hypertension may be a risk for pre- and postoperative complications. Furthermore, there has been concern, that the resection of pulmonary vascular bed during LVRS might compromise pulmonary hemodynamics and hence functional improvement. Information on changes in pulmonary hemodynamics and right heart function after LVRS is scarce. Sciurba et al. [7] found an increase of the fractional change in right ventricular area after LVRS by echocardiography. In a preliminary study Kessler et al. [8] measured normal PAPmean at rest in four emphysema patients before surgery. It was found that hemodynamics at rest remained unchanged after LVRS and that the exercise induced rise in PAPmean was even less after surgery.

The goal of this prospective study was to assess the prevalence of pulmonary arterial hypertension in patients with severe pulmonary emphysema—who were selected for LVRS according to published criteria [4]—and to study the effects of LVRS on pulmonary artery pressures 6 months after the procedure.

2. Patients and methods

2.1. Patient selection for LVRS

2.1.1. Inclusion criteria

According to criteria published previously [1,4] potential candidates for LVRS had the following profile: the patient has severe COPD with an FEV1 of less than 35% predicted and is considerably hyperinflated (residual lung volume > 200%, total lung capacity > 130% predicted). Radiological signs of pulmonary emphysema with flat diaphragms are present on conventional chest X-ray. The emphysema is confirmed on a high resolution CT scan. The patient is highly motivated and has stopped smoking for more than 6 months. No further improvements could be achieved by antiobstructive pharmacotherapy including systemic corticosteroids.

2.1.2. Exclusion criteria

Age > 75 years, PaCO₂ > 55 mmHg, diffusing capacity for carbon monoxide (DLCO single breath) < 20% predicted, bronchiectases, acute broncho—pulmonary infection, neoplastic disease with a life expectancy of less than 2 years and psychiatric disturbance. Patients with a previous Q-wave myocardial infarction and/or congestive heart failure were also not considered to be candidates for LVRS.

2.2. Cardiac evaluation

A careful history seeking to identify symptoms of prior right heart failure was obtained. Patients were clinically examined for: (a) elevated jugular vein pressure; (b) ankle edema; and (c) roentgenographic signs of pulmonary hypertension, i.e. a diameter of the right descending pulmonary artery diameter greater than 1.6 cm on conventional p.a. chest X-ray [9] and electrocardiographic features of right ventricular hypertrophy, i.e. right axis deviation greater than +100° and R/S ratio in V₁ > 1 [10].

2.3. Dyspnea score

Dyspnea was assessed by the Medical Research Council (MRC) dyspnea score [11], by which shortness of breath is rated from 0 to 4 according to an increase in symptom severity.

2.4. Functional assessments

Lung volumes were measured according to standard criteria [12,13] using the Sensor Medics 6200 Autobox® (Yorba Linda, Ca USA). Results were expressed as the best values after inhalation of two puffs of salbutamol. Diffusing capacity for carbon monoxide was measured using the 6200®/Sensor Medics equipment which uses methane as inert tracer gas. The reference values were according to the ECCS [14]. The arterial blood gases were analyzed using an AVL 995-S (AVL® Medical Instruments, Schaffhausen, Switzerland) and oxygen saturation (HbO₂) and COHb with a CO-oximeter (IL 482®, Radiometer, Copenhagen). Blood was drawn from a radial artery while the patient was sitting at rest and breathing room air.

2.5. Right heart catheterization

By the femoral approach, a Swan–Ganz catheter 7 F (Criti Cath®, Ohmeda, Singapore) was introduced into the right pulmonary artery. The pressures were recorded in the: (a) right atrium; (b) right ventricle; (c) pulmonary artery; and (d) in pulmonary capillary wedge position. The pressures were measured at FRC and averaged over nine cycles. The zero reference level for vascular pressures was taken as 5 cm below the sternal angle using fluoroscopy while the patient lay supine. Right heart catheterization was performed during the preoperative evaluation period for baseline and 6 months later. The patients were not receiving supplemental oxygen and were awake and not sedated.

2.6. Surgical technique

LVRS was performed in all patients bilaterally by video-assisted thoracoscopy as described previously [4]. Resection was aimed at the most destroyed tissues previously identified by CT scans and perfusion scintigraphy. The excised pieces of lung had an estimated
cumulative volume of approximately 20–30% of the lung volume on each side. The staplers were not buttressed with xenopericard. Extubation was performed in the theater immediately at the end of operation.

2.7. Statistics

Pre- and postoperative values are expressed as means ± S.E. and compared by paired t-test. A probability of less than 0.05 was considered significant. Analysis of variance followed by the Newmann–Keuls multiple comparisons procedure, where appropriate, was performed to detect significant differences in preoperative versus postoperative values within the same group and in values between groups.

3. Results

As shown in Table 1, the patients had the typical functional features of severe pulmonary emphysema. These consisted of severe obstruction to expiratory airflow and considerable hyperinflation. Their MRC dyspnea score was 3.5 ± 0.1. Patients had only mild hypoxemia with a mean PaO2 of 66 mmHg at rest (Table 1). In only three subjects, PaO2 was lower than 60 mmHg, i.e. 57, 54 and 52 mmHg. None of the patients were considerably hypercapnic (PaCO2 > 50 mmHg) since this was an exclusion criterion for surgery. No patient had a history of right heart decompensation or clinical signs of right heart failure—such as ankle edema or an elevated jugular venous pressure. In the preoperative chest x-ray, the mean diameter of the right descending pulmonary artery was 1.2 ± 0.1 cm and was smaller than 1.6 cm in all LVRS candidates. In the preoperative ECG, none of the patients had signs of right ventricular overload. The mean R-axis was 51 ± 49°, the P-axis was 14 ± 13° and the R/S ratio in V1 was 0.6 ± 0.3. A right bundle branch block was not documented in any of the patients.

The pulmonary artery pressures are shown in Table 2 and Fig. 1. There were six patients with a PAPmean of 20 mmHg or greater preoperatively but the PAPmean wasn’t above 25 mmHg in any of the patients (Fig. 1). The six patients with a PAPmean above 25 mmHg did not differ from those with normal PAPmean in respect to: (a) age; (b) gender; (c) preoperative FEV1/% predicted; (d) RV/TLC; (e) arterial PaO2; or oxygen saturation; and (f) PaCO2.

Table 1

Pulmonary function data and gas exchange in emphysema patients before and after LVRS

| Functional data | Before surgery | 6 months postop | Δpostop-preop | Δpostop-preop (%) |
|----------------|----------------|----------------|---------------|------------------|
| FVC (L)        | 2.47 ± 0.15    | 3.15 ± 0.22    | 0.68 ± 0.16*  | 30 ± 7*          |
| FVC (% pred)   | 68.2 ± 3.4     | 87.0 ± 4.78    | 18.8 ± 4.1*   |
| FEV1 (l)       | 0.80 ± 0.05    | 1.03 ± 0.10    | 0.23 ± 0.07*  | 28 ± 8*          |
| FEV1 (% pred)  | 27.7 ± 1.75    | 35.3 ± 2.93    | 8 ± 2*        |
| RV/TLC         | 0.65 ± 0.02    | 0.55 ± 0.02    | −0.09 ± 0.02* | −14 ± 3*         |
| TLC (L)        | 8.85 ± 0.33    | 8.00 ± 0.26    | −0.84 ± 0.22* | −9 ± 2*          |
| TLC (% pred)   | 142.4 ± 4.13   | 129.2 ± 3.55   | −13.9 ± 3.4*  |
| DLCO (% pred)  | 45.2 ± 3.48    | 47.0 ± 3.57    | 0.79 ± 4.8    | 0.8 ± 5          |
| O2-Sat (%)     | 93 ± 0.5       | 94 ± 0.8       | 1.2 ± 0.5     | 1.3 ± 0.6        |
| PaO2 (mmHg)    | 66.0 ± 1.3     | 70.7 ± 2.16    | 4.7 ± 2.1     | 7 ± 3*           |
| PaCO2 (mmHg)   | 38.3 ± 1.58    | 36.3 ± 1.18    | −2.0 ± 1.2    | −4 ± 3           |
| (A-a) O2 gr (mmHg) | 30.1 ± 2.2 | 29.6 ± 3.4 | −1.7 ± 2.8 | −1 ± 9          |

Values are means ± S.E.
* Differences significant at P < 0.05; Δpostop-preop (%), difference in postoperative minus corresponding preoperative value expressed in absolute units (or in percent) of preoperative value; FVC, forced vital capacity; FEV1, forced expiratory volume in 1 s; TLC, total lung capacity; DLCO, diffusing capacity for carbon monoxide; O2-Sat, oxygen saturation of hemoglobin; PaO2, arterial oxygen tension; PaCO2, arterial carbon dioxide tension; (A-a) oxygen-gradient, alveolar–arterial oxygen-gradient.

Table 2

Pulmonary arterial, right atrial and pulmonary capillary wedge pressures before and after bilateral LVRS

| Pressures | Before surgery | 6 Months postop | Δpostop-preop |
|-----------|----------------|----------------|---------------|
| PAPsys (mmHg) | 31 ± 1 | 32 ± 2 | 1.5 ± 2 |
| PAPmean (mmHg) | 18 ± 0 | 19 ± 1 | 1.3 ± 1 |
| PAPdia (mmHg) | 11 ± 1 | 13 ± 1 | 1.2 ± 1 |
| PCWP (mmHg) | 6 ± 1 | 8 ± 1 | 1.2 ± 2 |
| RAP (mmHg) | 2.6 ± 1 | 3.9 ± 1 | 1.3 ± 1 |

Values are means ± S.E., all differences between preoperative and postoperative values are nonsignificant. PAPsys, systolic pulmonary artery pressure; PAPmean, mean pulmonary artery pressure; PAPdia, diastolic pulmonary arterial pressures; PCWP, pulmonary capillary wedge pressure; RAP, right atrial pressure
* Values for 20 of 21 patients.
All patients had an uncomplicated postoperative course. Clinically relevant improvements in pulmonary function tests in respect to airways obstruction and hyperinflation were found, 6 months after surgery (Table 1). The patients were considerably less short of breath: their MRC dyspnea score declined from $3.5 \pm 0.1$ to $1.9 \pm 0.2$ ($P < 0.0001$).

A mild improvement in the PaO$_2$ was noticed but there were no significant changes in PaCO$_2$ and in the alveolar–arterial oxygen partial pressure gradient (Table 1). The lung volume reduction surgery did not change the pulmonary diffusing capacity for carbon monoxide (Table 1). The mean pulmonary artery pressures remained unchanged (Table 2). In three patients with a preoperative PAP$_{\text{mean}} \geq 20$ mmHg, PAP$_{\text{mean}}$ was lower than 20 mmHg after LVRS, whereas in three patients with a normal preoperative PAP$_{\text{mean}}$ higher pressures were found postoperatively. We were unable to explore the effect of LVRS on the postoperative diameter of the right descending pulmonary artery, since p.a. chest-x rays were not performed routinely after surgery. There is have no data on postoperative ECG alterations.

### 4. Discussion

It has been shown that bilateral lung volume reduction surgery improves lung function in selected patients with severe emphysema. However, the preoperative predictors of operative morbidity and mortality are not yet well defined in this population. Since pulmonary hypertension might increase the preoperative risk and compromise the postoperative functional improvement, the prevalence of pulmonary hypertension was assessed. Also studied were the changes in pulmonary artery pressures and gas exchange after videoassisted bilateral thoracoscopic LVRS in patients selected for LVRS according to published criteria [4].

The degree of changes in dyspnea and lung function that were observed 6 months after LVRS were comparable to the results of other groups, who perform this type of surgery bilaterally [1,4,15].

The PAP$_{\text{mean}}$ at rest was not elevated in the patient population and only six patients had mild pulmonary hypertension (PAP$_{\text{mean}} \geq 20 < 25$ mmHg). These results are consistent with the findings of other investigators. They have previously shown, that pulmonary artery pressures are normal or only mildly elevated in patients with COPD and emphysema as long as significant hypoxemia and hypercapnia are not present [16,17].

In a population of COPD patients with a broad range of blood gas abnormalities, a negative correlation between resting pulmonary artery pressures and arterial oxygen saturation [18] as well as a positive correlation between the arterial PaCO$_2$ and pulmonary artery pressures are found [18,19]. The observation, that we were unable to find such a correlation in our patients is most likely due to the fact, that according to the selection criteria for LVRS the range of blood gases was small and only three of the patients showed mild hypoxemia. Based on these findings it is concluded, that in candidates for LVRS, who have only mild to moderate hypoxemia and a PaCO$_2 < 50$ mmHg, no relevant pulmonary hypertension is found. The routine right heart catheterization is therefore not mandatory for preoperative evaluation.

The mean pulmonary artery pressures remained unchanged after LVRS (Fig. 1 and Table 1). In a few patients the PAP$_{\text{mean}}$ even declined after LVRS—
some the pulmonary artery pressures were somewhat higher after surgery. However, in none of the patients the postoperative PAP\textsubscript{mean} was higher than 35 mmHg, which is considered as relevant degree of secondary pulmonary hypertension. The individual changes in resting pulmonary hemodynamics measured after LVRS were not predictable since they did not correlate with alterations in pulmonary function tests or parameters of gas exchange. Also no differences in the pulmonary artery pressures were found after surgery within the three different emphysema morphology groups (homogeneous, intermediately or markedly heterogeneous distribution of emphysema) [20]. Even in patients with completely homogenous emphysema the PAP\textsubscript{mean} remained within normal limits. These findings are consistent with the results of Kessler et al. [8], who also found, that resting pulmonary hemodynamics remained unchanged after this type of surgery. Since the cardiac output was not measured, the pulmonary vascular resistance was unable to be calculated. This might be considered a drawback of this study. A more comprehensive investigation of the pulmonary circulation in emphysema would also include measurements of pressures and cardiac output while the patient is breathing air or oxygen (taking measurements at rest and during mild exercise).

Several groups observed a mild rise in the mean PaO\textsubscript{2} [1,2,5,21,22] and a stable or slight decrease in PaCO\textsubscript{2} [1,5,21,22] after bilateral LVRS. In the first 20 patients described by Cooper [1], 10 of 14 did no longer require supplemental oxygen after surgery. In another 53 patients [21], there was a slight but not statistically significant increase in oxygen tension from 62 to 70 mmHg and a decrease in carbon dioxide tension from 43 to 40 mmHg. In the patients a trend towards a slightly higher PaO\textsubscript{2} was found and a mild decrease of PaCO\textsubscript{2} at 6 months after the LVRS. Since the diffusing capacity for carbon monoxide and the alveolo–arterial oxygen partial pressure gradient remained unchanged, it was speculated, that no significant amount of functionally intact gas exchange surface is removed by this procedure. The different effects of LVRS found on blood gases are most likely due to the fact, that emphysema morphology (i.e. very heterogeneous versus more homogeneous type of emphysema, amount of compression of tissue) varies between the various groups, This impedes a fair comparison between the postoperative results in this regard.

In summary, the findings of unaltered resting pulmonary artery pressures and unchanged gas exchange parameters after LVRS are consistent with the speculation, that by this type of surgery mainly functionally useless parts of the lungs are removed, or that the excision of lung pieces with some gas exchange capacity is offset by recruiting of adjacent compressed and potentially less impaired tissue.

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References

[1] Cooper JD, Trulock EP, Triantafillou AN, Patterson GA, Pohl MS, Deloney PA, Sundaresan RS, Roper CL. Bilateral pneumectomy (volume reduction) for chronic obstructive pulmonary disease. J Thorac Cardiovasc Surg 1995;109:106–19.
[2] Yusen RD, Trulock EP, Pohl MS, Biggar DG. The Washington University Emphysema Surgery Group, results of lung volume reduction surgery in patients with emphysema. Semin Thoracic Cardiovascular Surg 1996;8:99–109.
[3] McKenna RJ Jr., Brenner M, Fischel RJ, Gelb AF. Should volume reduction for emphysema be unilateral or bilateral? J Thorac Cardiovasc Surg 1996;112:1331–9.
[4] Bingisser R, Zollinger A, Hauser M, Bloch KE, Russi EW, Weder W. Bilateral reduction surgery for diffuse pulmonary emphysema by video-assisted thoracoscopy. J Thorac Cardiovasc Surg 1996;112:875–82.
[5] Naunheim KS, Keller CA, Krucylak PE, Singh A, Ruppel G, Osterloh J. Unilateral video-assisted thoracic surgical lung resection. Ann Thorac Surg 1996;61:1092–8.
[6] Zollinger A, Zaugg M, Weder W, Russi EW, Blumenthal S, Zalunardo MP, Stoehr S, Thurnheer R, Stammberger U, Spahn DR, Pasch T. Video assisted thoracoscopic volume reduction surgery in patients with diffuse pulmonary emphysema: gas exchange and aesthesiological management. Anesth Analg 1997;82:845–51.
[7] Sciurba FC, Rogers RM, Keenan RJ, Sivska WA, Gorcsan J, Persson P, Holbert JM, Brown ML, Landreneau RJ. Improvement in pulmonary function and elastic recoil after lung-reduction surgery for diffuse emphysema. N Engl J Med 1996;334:1095–9.
[8] Kessler R, Oswald M, Massard G, Lampert E, Lonsdorfer J, Wihlm JM, Weitzenblum E. Evolution of functional data at rest and exercise in five patients treated by lung volume reduction surgery. Eur Respir J 1996;9:302s.
[9] Matthay RA, Schwarz MI, Ellis JH, Steele PP, Siebert PE, Durrance JR, Levin DC. Pulmonary artery hypertension in chronic obstructive pulmonary disease: determination by chest radiography. Invest Radiol 1981;16:95–100.
[10] Scott RC. The electrocardiographic diagnosis of right ventricular hypertrophy: Correlation with anatomic findings. Circulation 1960;1:161–86.
[11] American Thoracic Society. Surveillance for respiratory hazards in the occupational setting. Am Rev Respir Dis 1982;126:952–956.
[12] American Thoracic Society. Standardization of spirometry. Am Rev Respir Dis 1987;13:287–98 Abstract.
[13] Quanjer PH, Tammeling GJ, Pederson OF, Peslin R, Yernault JC. Report working party standardization of lung function tests European Community for Steel and Coal. Official Statement of the European Respiratory Society, Lung volumes and forced ventilatory flows. Eur Respir J 1993;6(Suppl 16):5–40.
[14] ECCS working party. Standardization fo lung functional tests. Bull Eur Physiopath Respir 1983;19:7–92.
[15] Gelb AF, Brenner M, McKenna RJ Jr., Zamel N, Fischel RJ, Epstein JD. Lung function 12 months following emphysema reduction. Chest 1996;110:1407–15.
[16] MacNee W. Pathophysiology of cor pulmonale in chronic obstructive pulmonary disease—part one. Am J Respir Crit Care Med 1994;150:833–52.

[17] Schulman LL, Lennon PF, Wood JA, Enson Y. Pulmonary vascular resistance in emphysema. Chest 1994;105:798–805.

[18] Harvey R, Ferrer M, Richards DW Jr., Courmand A. Influence of chronic pulmonary diseases on the heart and circulation. Am J Med 1951;10:719–38.

[19] Horizontally, Segal N, Bishop J. The pulmonary circulation in chronic bronchitis at rest and during exercise breathing air and 80% oxygen. Clin Sci 1968;34:473–83.

[20] Weder W, Thurnheer R, Stammberger U, Bürge M, Russi EW, Bloch KE. Radiological emphysema morphology is associated with outcome after surgical lung volume reduction. Ann Thoracic Surg 1997;64:313–20.

[21] Miller JJ Jr., Lee RB, Mansour KA. Lung volume reduction surgery: lessons learned. Ann Thorac Surg 1996;61:1464–9.

[22] Gaissert HA, Trulock EP, Cooper JD, Sundaresan RS, Patterson GA. Comparison of early functional results after volume reduction or lung transplantation for chronic obstructive pulmonary disease. J Thorac Cardiovasc Surg 1996;111:296–305.