Thoracoscopic Lung Volume Reduction Surgery for Pulmonary Emphysema Patients With Severe Hypercapnia

Objectives: **We assessed whether hypercapnia patients with an extremely high level of $PaCO_2$ • •60 mmHg were suitable candidates for lung volume reduction in the treatment of severe pulmonary emphysema.** ***Methods:*** **Of 65 patients undergoing lung volume reduction surgery between May 1993 and August 1997, 6 (9.23%) who had a preoperative rest room air blood gas level of $PaCO_2$ • •60 mmHg were selected for study. All patients underwent video-assisted thoracoscopic surgery. Of the 6 with severe hypercapnia, 5 underwent the unilateral procedure and 1 the bilateral procedure.** ***Results:*** **All severe hypercapnia patients showed significant clinical improvement. When assessed at 3 to 6 months after lung volume reduction surgery, significant improvements were seen in mean forced expiratory volume in 1 second (preop: 0.44 ± 0.04 L; postop: 0.74 ± 0.20 L; $p < 0.01$), for a magnitude improvement of 69.8%, and in trapped gas volume (preop: 3.28 ± 1.11 L; postop: 1.61 ± 1.02 L; $p < 0.05$). Arterial blood gas analysis showed significant improvement in PaO_2 from 51.1 ± 6.68 mmHg to 69.8 ± 7.87 mmHg ($p < 0.001$) with a decrease in $PaCO_2$ from 70.4 ± 9.41 mmHg to 46.9 ± 3.44 mmHg ($p < 0.01$). Postoperative follow-up averaged 55 months (43–69 months). All but 1 patient remain alive and well.** ***Conclusion:*** **Patients with severe pulmonary emphysema accompanied by hypercapnia can gain relief and a better quality of life through volume reduction surgery and should not be excluded from surgical treatment simply based on this condition. Selection should involve a comprehensive view of the patient's condition that includes criteria such as the results of radiographic diagnosis and detailed pulmonary function tests. (JJTCVS 2001; 49: 481–488)**

Key words: lung volume reduction surgery, pulmonary emphysema, hypercapnia

Kazuhiro Mitsui, MD, Yoshimochi Kurokawa, MD, Yoshihiro Kaiwa, MD, Kenjiro Ando, MD, Hajime Kurosawa, MD,* Wataru Hida, MD,* and Susumu Satomi, MD.

A general consensus has been reached that lung volume reduction surgery (LVRS) conducted on patients with severe pulmonary emphysema improves pulmonary function, exercise performance, and overall quality of life (QOL).[1–6] Brantigan et al.[7–8] first advocated this procedure about 40 years ago; however, due to its high mortality, this treatment did not gain favor at the time, only coming back into use in 1991 when Wakabayashi et al.[1] combined thoracoscopy and laser treatment to reduce lung volume in emphysema patients, markedly improving postoperative pulmonary function. The report by Cooper et al.[2] in 1995 on "bilateral pneumectomy" marked the start of widespread utilization of LVRS.

Many hospitals and institutions now conduct this procedure, each based on its own patient selection criteria and risk factors, so a uniform selection procedure remains to be established.[6,9–11] Patients with hypercapnia are excluded at most institutions and, according to Weinmann et al.,[12] those with $PaCO_2 > 50$ mmHg are commonly excluded.[4,13–16] Although reports of success with patients with hypercapnia have appeared,[17–20] some have also reported no improvement in patients undergoing LVRS.[3,13,14,21]

We studied the effectiveness of LVRS in treating

From the Second Department of Surgery and the *First Department of Internal Medicine, Tohoku University School of Medicine, Sendai, Japan.

Received for publication September 11, 2000.
Accepted for publication April 19, 2001.

Address for reprints: Kazuhiro Mitsui, MD, Second Department of Surgery, Tohoku University School of Medicine, 1–1 Seiryomachi, Aoba-ku, Sendai 980–8574, Japan.

Table I. *Selection criteria for thoracoscopic LVRS*

Inclusion Criteria
a. Diagnostic criteria for patients with pulmonary emphysema
b. Hyperinflation documented by chest radiograph and pulmonary function
c. Fletcher, Hugh-Jones dyspnea scale above grade III
d. Marked restriction in activities of daily living despite maximal medical therapy
e. Heterogenous distribution demonstrated by lung computed tomography (CT) and radionuclide ventilation/perfusion lung scans
f. Absence of significant cardiovascular and pulmonary disease
h. Smoking cessation for over 6 months
Relative exclusion criteria
a. Malnutrition (body mass index (BMI) < 16 kg/m^2)
b. Pulmonary hypertension (mean pulmonary arterial pressure above 35 mmHg)
c. Neoplastic disease and pulmonary tuberculosis
d. Patients aged 80 years or older
e. Continued cigarette smoking
f. Psychological dysfunction

patients with pulmonary emphysema accompanied by severe hypercapnia and $PaCO_2$ • •60 mmHg.

Subjects and Methods

Between May 1993 and August 1997, LVRS was conducted on 65 patients with pulmonary emphysema, 64 men and 1 woman aged 45–80 years (mean: 67.0 ± 7.45 years) at Tohoku University Hospital. Preoperative rest blood gas analysis was conducted and results compared by dividing them into a hypercapnia group (n = 6), i.e. those with severe hypercapnia of $PaCO_2$ • •60 mmHg, and an others group (n = 59), i.e. those with mild hypercapnia or who are nonhypercapnic with $PaCO_2$ < 60 mmHg. All underwent pulmonary function tests and blood gas analysis 3 to 6 months postoperatively and results were retrospectively compared and evaluated.

Criteria for diagnosing of patients with pulmonary emphysema were based on the chronic obstructive pulmonary disease (COPD) diagnostic criteria of the Japanese Respiratory Society, i.e., (1) forced expiratory volume in 1 second as percent- predicted (FEV1%) • •55%; (2) RV/TLC • •45% (gas dilution); (3) static lung compliance (Cst) • •0.3 L/cmH_2O; and (4) percentage of single-breath diffusing capacity (DLCO) of predicted (% DLCO) • •70%.

According to this standard, to be diagnosed with emphysema, patients must meet 3 of the 4 criteria and show low attenuation areas (LAA) on computed tomography (CT) scans.

Those meeting these criteria were then selected based on the additional criteria in Table I. Lung CT patterns showed diffuse but heterogeneous emphysema; patients with giant bullae were excluded. We included patients with hypercapnia or too weak to undergo preoperative rehabilitation, e.g., bedridden or ventilator-dependent.

Radiologic evaluation consisted of routine chest radiography with posteroanterior and lateral views and lung CT and radionuclide lung ventilation/perfusion scans. Chest radiography showed hyperexpansion of the thorax with flattening or inversion of diaphragmatic domes. Lung CT scans showed diffuse but heterogeneous emphysema, and target areas were defined by LAA on CT and radionuclide lung ventilation/perfusion scans.

Out of the 65 patients who underwent LVRS, all but one were male and heavy smokers. We selected as candidates those who had stopped smoking for 6 months or longer and who were receiving maximum medical therapy and measured 3 or higher on the Fletcher, Hugh-Jones dyspnea scale (F, H-J dyspnea scale).[22] The most commonly used dyspnea scale in Japan and similar to the Modified Medical Research Council Dyspnea Scale,[23] it has the following classifications: Grade 1. Not troubled by shortness of breath except in strenuous exercise; Grade 2. Troubled by shortness of breath when hurrying on the level or walking up a slight hill or stairs; Grade 3. Walks slower than people of the same age on the level due to shortness of breath or stops for breath when walking 1 mile at own pace on the level; Grade 4. Stops for breath after walking about 100 yards or after a few minutes on the level; Grade 5. Too short of breath to leave home, or becomes short of breath when dress-

Table II. *Number of surgical procedures in hypercapnia and others groups*

	Hypercapnia (*n* = 6)	*Others* (*n* = 59)
Unilateral procedure	5	31
laser ablation	1	5
laser ablation with staple excision	3	21
staple excision	1	5
Bilateral procedure		
staple excision	1	28

ing or undressing.

Pulmonary rehabilitation was conducted for about a month prior to surgery depending on the patient's condition, but participation or completion of this program was not considered a criterion for surgery.

Pulmonary function tests were conducted at evaluation for surgery and between 3 and 6 months postoperatively.

All patients underwent room air blood gas analysis (Model 213; Instrumentation Laboratories, Lexington, MA, USA), spirometry (Fudac-70S, Fukuda, Tokyo, Japan), and lung volume and single-breath diffusing capacity (DLCO) based on American Thoracic Society guidelines. Lung volume was measured by helium gas dilution and body plethysmography (Gould 2800J, Dayton, Ohio, USA) but data in this paper is taken from the results of body plethysmography because this measures lung volume most accurately. Since ventilation does not occur in the target area where emphysematous and bullous changes are most apparent, the area in which air trapping occurs cannot be measured using gas dilution. Body plethysmography enable actual lung volume to be estimated by measuring intrathoracic volume that includes emphysematous changes.

Functional residual volume is measured by either body plethysmography or gas dilution, and the difference between the 2 is defined as trapped gas volume:[24,25] Trapped gas volume = {FRC (box) — FRC (gas)} L. This term refers to an emphysema lesion in which air trapping occurs that results in respiratory unevenness. Excision of the lesion, or target area, by LVRS reduces trapped gas volume.

Data is expressed as the mean (± SD) except where noted otherwise. Statistical analysis was conducted via the 2-tailed paired t test, the Wilcoxon signed-rank test, and Fisher's exact probability test where $p < 0.05$ was considered statistically significant.

Surgical procedure. All patients underwent video-assisted thoracoscopic LVRS. When we first began using LVRS in 1993, Japan had no established guidelines for perioperative management. We began by following Wakabayashi's[26] method of conducting the unilateral procedure. In 1995, we started bilateral procedures after determining their greater effectiveness.

LVRS was conducted under general anesthesia supplemented by thoracic epidural anesthesia. A left-sided double lumen endotracheal tube was used to provide one-lung ventilation during surgery.

Patients were placed in the lateral decubitus position, and for bilateral procedures, this position was reversed after 1 side was completed. For unilateral procedures, the side with the larger target area was selected after evaluation of chest radiography, lung CT scans, and radionuclide lung ventilation/perfusion scans. If no difference could be discerned through radiologic assessment, the right side, which has a larger lung capacity, was selected. Patients who had a target area on only 1 side underwent the unilateral procedure. Although 15–30% of the lung was generally removed, this amount differed from patient to patient due to target area variation.

Of the 65 patients undergoing LVRS, 36 underwent unilateral and 29 bilateral procedures.

In the unilateral procedure, 3 techniques were used: laser ablation alone, laser ablation with staple excision, and staple excision alone. In the laser ablation, a neodymium-yttrium-aluminum-garnet (Nd: YAG) laser (SLT Japan, Tokyo, Japan) was applied to small bullae < 3 cm and for areas showing clear emphysematous changes, identified by distention due to airway obstruction. The Nd: YAG laser was applied at 8 to 10 W using a contact probe to shrink pleura. An Endo linear stapling device was used to excise relatively large target areas such as bullae • •3 cm in a single movement. Laser ablation with staple excision combined the above 2 techniques. Bilateral procedures excised the target area using the Endo linear stapling device.

Although we did not use a buttress at the beginning

Table III. *Baseline characteristics in hypercapnia and others groups*

	Hypercapnia (*n = 6*)	*Others* (*m = 59*)	*p value*
Ages (yrs)	62.0 ± 9.19	67.5 ± 7.13	NS
F, H-J dyspnea scale	4.67 ± 0.52	3.71 ± 0.73	NS
Body mass index (kg/m^2)	18.8 ± 4.01	18.6 ± 2.48	NS
Smoking history (pack/yr)	70.0 ± 36.3	60.5 ± 28.1	NS
Steroid dependent (n)	4	13	< 0.05
O2 required at rest (n)	6	28	< 0.05
Ventilator dependent (n)	1	1	NS

Table IV. *Baseline comparison of hypercapnia and others groups*

	Hypercapnia (*n = 6*)*(*n = 5*)	*Others* (*n = 59*)	*p value*
VC (l)	1.44 ± 0.31	2.52 ± 0.65	< 0.05
(% predicted)	(42.3 ± 10.1)	(75.6 ± 17.7)	(< 0.005)
FEV1 (l)	0.44 ± 0.04	0.78 ± 0.30	< 0.05
(% predicted)	(17.1 ± 2.85)	(32.8 ± 12.1)	(< 0.005)
TLC (l)	8.58 ± 1.65	7.84 ± 1.15	NS
(% predicted)	(155 ± 31.0)	(141 ± 18.0)	(NS)
FRC (l)	7.28 ± 1.21	6.00 ± 1.08	NS
(% predicted)	(180 ± 35.8)	(144 ± 24.1)	(NS)
RV (l)	6.65 ± 1.14	5.21 ± 1.10	NS
(% predicted)	(339 ± 52.8)	(252 ± 52.4)	(< 0.05)
FRC (box-gas)* (l)	3.28 ± 1.11	1.22 ± 1.08	NS
RV/TLC (%)	77.9 ± 6.35	66.1 ± 7.67	< 0.005
% DLCO (%)	35.8 ± 11.4	37.6 ± 16.0	NS
PaO_2 (mmHg)	51.1 ± 6.68	68.8 ± 8.30	< 0.005
$PaCO_2$ (mmHg)	70.4 ± 9.41	42.0 ± 8.88	< 0.001

to prevent air leakage, we used bovine pericardial strips (Peri-Strips; Bio-Vascular, Inc, St. Paul, MN, USA) or felt-like bioabsorbable prostheses (polyglycolic acid sheet; Neovail; Gunze, Kyoto, Japan) attached to the Endo linear stapling device during the last 9 bilateral lung excisions.

Among the severe hypercapnia patients, 5 underwent the unilateral procedure and 1 underwent the bilateral procedure. In the others group, 31 underwent the unilateral procedure and 28 the bilateral procedure (Table II).

After surgery was completed, extubation was conducted and patients taken to the intensive care unit (ICU) for 24 hours, after which they were transferred to a regular ward.

Results

A comparison of preoperative profiles of patients in the 2 groups showed no significant differences for the following factors: average age, dyspnea scale, body mass index, and smoking history. The 2 factors necessitating supplementary oxygen at rest and steroid dependence were significantly higher in the hypercapnia group.

One patient in each group was preoperatively ventilator-dependent (Table III). No examples were seen of α1-antitrypsin deficiency.

Table IV compares baseline pulmonary function test results and blood gas analysis. Vital capacity (VC) was 1.44 ± 0.31 L vs. 2.52 ± 0.65 L and forced expiratory volume in 1 second (FEV1) was 0.44 ± 0.04 L vs. 0.78 ± 0.30 L, with the hypercapnia group significantly lower. Although the difference was not statistically significant for total lung capacity (TLC), functional residual capacity (FRC) and residual volume (RV) measured by body plethysmography, the residual volume of % predicted value (% RV) showed a significant correlation, 339 ± 52.8% vs. 252 ± 52.4%. RV/TLC was 77.9 ± 6.35% vs. 66.1 ± 7.67%, reflecting significantly greater hyperinflation in the hypercapnia group. No significant difference was observed for trapped gas volume {FRC (box-gas)} or % DLCO. PaO_2 was 51.1 ± 6.68 mmHg vs. 68.8 ± 8.30 mmHg,

Table V. *Comparison of pulmonary function in hypercapnia group before and after LVRS*

(*n* = 6, **n* = 5)	*before*	*after*	*p value*
VC (l)	1.44 ± 0.31	2.37 ± 0.43	< 0.01
(% predicted)	(42.3 ± 10.1)	(68.7 ± 16.1)	(< 0.01)
FEV1 (l)	0.44 ± 0.04	0.74 ± 0.20	< 0.01
(% predicted)	(17.1 ± 2.85)	(29.2 ± 9.01)	(< 0.05)
TLC (l)	8.58 ± 1.65	7.41 ± 1.28	< 0.05
(% predicted)	(155 ± 31.0)	(135 ± 25.4)	(< 0.05)
FRC (l)	7.28 ± 1.21	5.68 ± 1.10	< 0.05
(% predicted)	(180 ± 35.8)	(147 ± 32.7)	(< 0.05)
RV (l)	6.65 ± 1.14	5.26 ± 1.09	< 0.05
(% predicted)	(339 ± 52.8)	(266 ± 54.2)	(< 0.01)
FRC (box-gas)* (l)	3.28 ± 1.11	1.61 ± 1.02	< 0.05
RV/TLC (%)	77.9 ± 6.35	70.5 ± 6.82	< 0.05
% DLCO (%)	35.8 ± 11.4	49.5 ± 22.6	NS
PaO_2 (mmHg)	51.1 ± 6.68	69.8 ± 7.87	< 0.001
$PaCO_2$ (mmHg)	70.4 ± 9.41	46.9 ± 3.44	< 0.01

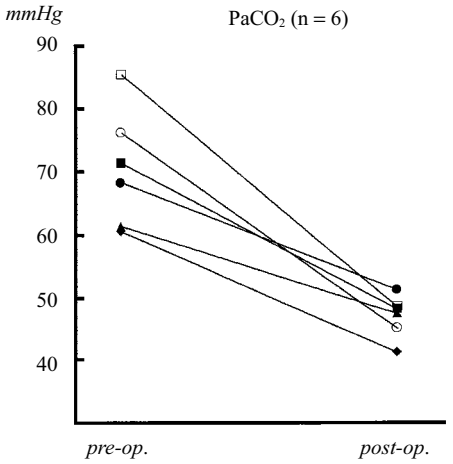

Fig. 1. Effects of LVRS on $PaCO_2$ among hypercapnic patients.

indicating significant hypoxemia in the hypercapnia group, and $PaCO_2$ was 70.4 ± 9.41 mmHg vs. 42.0 ± 8.88 mmHg, significantly higher than in the others group.

Severe hypercapnia patients with $PaCO_2$ • •60 mmHg showed postoperative improvement in pulmonary function tests 3 to 6 months after surgery (Table V). Significant improvement was seen in increased VC and FEV1. The mean FEV1 improved by 69.8% compared to the preoperative value. Values for lung volume (TLC, FRC and RV) all significantly decreased. Trapped gas volume was reduced by half. Blood gas analysis showed that PaO_2 increased significantly and $PaCO_2$ decreased significantly. Scores on the F, H-J dyspnea scale improved from 4.67 ± 0.52 to 3.00 ± 0.63 ($p < 0.05$).

Pre- and postoperative $PaCO_2$ for the 6 patients are shown in Fig. 1. The maximum change was 43% ($PaCO_2$: 85.3 → 48.6 mmHg) and the minimum change 22.9% ($PaCO_2$: 61.2 → 47.2 mmHg) with an average decrease of 32.6%.

Table VI presents results of pulmonary function tests and rest blood gas analysis for patients in the others group (n = 51) 3 to 6 months after surgery. No significant difference was found for VC or % DLCO while FEV1, lung volume (TLC, FRC, and RV), and rest blood gas improved significantly. Mean FEV1 improved by 49.0%. On the F, H-J dyspnea scale scores improved significantly from 3.67 ± 0.77 to 2.82 ± 0.71 ($p < 0.001$).

Although all 6 patients with severe hypercapnia required oxygen supplementation at rest preoperatively, 3 were weaned postoperatively and 1 of the 4 on steroids was able to overcome steroid dependence after treatment. One patient preoperatively ventilator-dependent was weaned postoperatively. Two confined to wheelchairs as well as 2 bedridden, and 1 ventilator-dependent who were unable to walk due to severe dyspnea recovered well enough after surgery to walk unassisted.

Table VII compares postoperative complications between the 2 groups. The period of air leakage was 19.8 ± 14.1 days vs. 18.2 ± 14.4 days, not statistically significant. Fisher's exact probability test was used to compare postoperative complications between groups. No significant difference was found for prolonged air leakage, extended periods of mechanical ventilation,

Table VI. *Comparison of pulmonary function in others group before and after LVRS*

(*n = 51*)	*before*	*after*	*p value*
VC (l)	2.54 ± 0.67	2.61 ± 0.59	NS
(% predicted)	(76.4 ± 18.2)	(79.3 ± 15.9)	(NS)
FEV1 (l)	0.79 ± 0.31	1.13 ± 0.43	< 0.0001
(% predicted)	(33.0 ± 12.6)	(47.4 ± 17.6)	(< 0.0001)
TLC (l)	7.66 ± 1.20	6.73 ± 1.07	< 0.0001
(% predicted)	(139 ± 17.8)	(124 ± 20.5)	(< 0.0001)
FRC (l)	5.80 ± 0.95	4.83 ± 0.96	< 0.0001
(% predicted)	(141 ± 22.9)	(117 ± 21.7)	(< 0.0001)
RV (l)	4.97 ± 0.92	3.96 ± 0.84	< 0.0001
(% predicted)	(339 ± 52.8)	(266 ± 54.2)	(< 0.01)
FRC (box-gas) (l)	1.01 ± 1.09	0.62 ± 0.72	< 0.05
RV/TLC (%)	64.7 ± 7.65	58.9 ± 7.95	< 0.0001
% DLCO (%)	39.8 ± 16.7	38.7 ± 15.7	NS
PaO_2 (mmHg)	68.8 ± 8.33	74.6 ± 9.85	< 0.0001
$PaCO_2$ (mmHg)	41.9 ± 5.66	40.0 ± 4.61	< 0.05

Table VII. *Comparison of major complications and mortality between hypercapnia and others groups*

	Hypercapnia (*n = 6*)	*Others* (*n = 59*)	p value
air leakage (days)	19.8 ± 14.1	18.2 ± 14.4	NS
prolonged air leakage (over 3 weeks) (n)	2	16	NS
mechanical ventilation (over 7 days) (n)	1	7	NS
pneumonia (n)	0	3	NS
bronchial bleeding (n)	0	3	NS
reoperation (n)	0	3	NS
mortality (3 years) (n)	0	11	NS

pneumonia, or bronchial bleeding, reoperation as a result of postoperative hemorrhages and uncontrolled air leakage, or 3- year mortality. Also, 3- year mortality was 0 for the hypercapnia group.

Severe hypercapnia patients were followed up postoperatively for an average of 55 months (43–69 months). One patient died 3 years and 7 months after surgery from respiratory failure due to multiple rib fractures probably due to long-term steroid use, but others are doing well with much improved QOL.

Discussion

Indices for measuring the degree of severity in pulmonary emphysema include progression of dyspnea, hypoxemia, hypercapnia, malnutrition, progression of hyperinflation of the lung, decrease in FEV1, and decrease in VC. Hypercapnia is defined as the end stage of respiratory failure in emphysema. Table IV makes a baseline comparison of severe hypercapnia and those without patients who underwent LVRS. $PaCO_2 > 50$ mmHg is usually regarded as a relative exclusion criterion,[3,12] whereas $PaCO_2 > 50$ mmHg or 55 mmHg as an absolute exclusion criterion.[4,13–16]

Few studies have been made of LVRS focusing on hypercapnia. Argenziano et al.[17] reported significant improvement in 9 cases with $PaCO_2 > 55$ mmHg and Wisser et al.[18] concluded that hypercapnia alone should not be considered a contraindication for LVRS. O'Brien et al.[19] comparatively studied a hypercapnia group and controls, finding no significant difference in morbidity or mortality between groups, with QOL greatly improved postoperatively in both. Our results confirm this (Table V). No statistically significant difference was seen in the frequency of postoperative complications between groups (Table VII).

Through volume reduction of target areas, trapped gas volume decreased, ventilation/perfusion (V/Q) matching improved, and movement of respiratory muscles such as the diaphragm improved, with amelioration of hypercapnia.

The 1 severe hypercapnia patient who was ventilator-dependent prior to LVRS was weaned postoperatively and showed sufficient improvement in pulmo-

nary function to return to work. As reported by Criner et al.,[27] ventilator dependence is not a contraindication for LVRS. Four of the 6 severe hypercapnia patients either wheelchair-bound or bedridden recovered to where they could walk unassisted and return to work and home.

We believe that patients with severe pulmonary emphysema accompanied by severe hypercapnia are good candidates for LVRS. Trapped gas volume appears to be a reliable indicator of ventilatory unevenness. Patients with severe hypercapnia accompanied by a large increase in trapped gas volume showed improved pulmonary function and blood gas status after LVRS. We believe that hypercapnia per se should not be a contraindication to LVRS.

An objective, comprehensive evaluation of the patients must be conducted by carefully reviewing results of pulmonary function tests, and of lung hyperinflation, blood gas, CT scan, and radionuclide lung ventilation/perfusion scans before reaching a final decision on surgery.

Conclusion

Severe hypercapnia patients with $PaCO_2$ • •60 mmHg, apparent hyperinflation, a large amount of ventilatory unevenness (trapped gas volume), and clearcut target areas should not be excluded as candidates for LVRS simply because of these conditions, and will benefit positively from this procedure.

REFERENCES

1. Wakabayashi A, Brenner M, Kayaleh RA, Berns MW, Baker SJ, Rice SJ, et al. Thoracoscopic carbon dioxide laser treatment of bullous emphysema. Lancet 1991; 337: 881–83.
2. Cooper JD, Trulock EP, Triantafillou AN, Trianafillou AN, Patterson GA, Pohl MS, et al. Bilateral pneumectomy (volume reduction) for chronic obstructive pulmonary disease. J Thorac Cardiovasc Surg 1995; 109: 106–19.
3. Keenan RJ, Landreneau RJ, Sciurba FC, Ferson PF, Holbert JM, Brown ML, et al. Unilateral thoracoscopic surgical approach for diffuse emphysema. J Thorac Cardiovasc Surg 1996; 111: 308–16.
4. Little AG, Swain JA, Nino JJ, Prabhu RD, Schlachter MD, Barcia TC. Reduction pneumonoplasty for emphysema: early results. Ann Surg 1995; 222: 365–74.
5. Gelb AF, Brenner M, McKenna RJ, Zamel N, Fischel R, Epstein JD. Lung function 12 months following emphysema resection. Chest 1996; 110: 1407–15.
6. Cooper JD, Patterson GA, Sundaresan RS, Trulock EP, Yusen RD, Pohl MS, et al. Results of 150 consecutive bilateral lung volume reduction procedures in patients with severe emphysema. J Thorac Cardiovasc Surg 1996; 112: 1309–30.
7. Brantigan OC, Mueller E. Surgical treatment of pulmonary emphysema. Am Surg 1957; 23: 789–804.
8. Brantigan OC, Mueller E, Kress MB. A surgical approach to pulmonary emphysema. Am Rev Respir Dis 1959; 80: 194–202.
9. Szekely LA, Oelberg DA, Wright C, Johnson DC, Wain J, Trotman-Dickenson B, et al. Preoperative predictors of operative morbidity and mortality in COPD patients undergoing bilateral lung volume reduction surgery. Chest 1997; 111: 550–8.
10. McKenna RJ, Brenner M, Fischel RJ, Singh N, Yoong B, Gelb AF, et al. Patient selection criteria for lung volume reduction surgery. J Thorac Cardiovasc Surg 1997; 114: 957–67.
11. Fujita RA, Barnes GB. Morbidity and mortality after thoracoscopic pneumonoplasty. Ann Thorac Surg 1996; 62: 251–7.
12. Weinmann GG, Hyatt R. Evaluation and research in lung volume reduction surgery. Am J Respir Crit Care Med 1996; 154: 1913–8.
13. Miller JI, Lee RB, Mansour KA. Lung volume reduction surgery: lessons learned. Ann Thorac Surg 1996; 61: 1464–9.
14. Kotloff RM, Tino G, Bavaria JE, Palevsky HI, Hansen-Flaschen J, Wahl PM, et al. Bilateral lung volume reduction surgery for advanced emphysema: a comparison of median sternotomy and thoracoscopic approaches. Chest 1996; 110: 1399–406.
15. Daniel TM, Chan BBK, Bhaskar V, Parekh JS, Walters PE, Reeder J, et al. Lung volume reduction surgery: case selection, operative technique, and clinical results. Ann Surg 1996; 223: 526–33.
16. Bingisser R, Zollinger A, Hauser M, Bloch KE, Russi EW, Weder W. Bilateral volume reduction surgery for diffuse pulmonary emphysema by video-assisted thoracoscopy. J Thorac Cardiovasc Surg 1996; 112: 875–82.
17. Argenziano M, Moazami N, Thomashow B, Jellen PA, Gorenstein LA, Rose EA, et al. Extended indications for lung volume reduction surgery in advanced emphysema. Ann Thorac Surg 1996; 62: 1588–97.
18. Wisser W, Klepetko W, Senbaklavaci O, Wanke T, Gruber E, Tschernko E, et al. Chronic hypercapnia should not exclude patients from lung volume reduction surgery. Eur J Cardio-Thorac Surg 1998; 14: 107–12.
19. O'Brien GM, Furukawa S, Kuzma AM, Cordova F, Criner GJ. Improvements in lung function, excercise, and quality of life in hypercapnic COPD patients after lung volume reduction surgery. Chest 1999; 115: 75–84.
20. Snade D Jr, Cordova F, Lando Y, Travaline JM,

Furukawa S, Kuzma AM, et al. Relationship between resting hypercapnia and physiologic parameters before and after lung volume reduction surgery in severe chronic obstructive pulmonary disease. Am J Respir Crit Care Med 1999; 159: 1405–11.

21. Albert RK, Benett JO, Hildebrandt J, Wood DE, Hlastala MP. Lung volume reduction surgery has variable effects on blood gases in patients with emphysema. Am J Respir Crit Care Med 1998; 158: 71–6.
22. Fletcher CM, Elmes PC, Fairbairn AS, Wood CH. The significance of respiratory symptoms and the diagnosis of chronic bronchitis in a working population. Br Med J 1959; 2: 257–66.
23. Task Group on Screening for Respiratory Disease in Occupational Settings. Official Statement of the American Thoracic Society. Am Rev Respir Dis 1982; 126: 952–6.
24. Criner GJ, Cordoba FC, Leyenson V, Roy B, Travaline JM, Sudarshan S, et al. Effect of lung volume reduction surgery on diaphragm strength. Am J Respir Crit Care Med 1998; 157: 1578–85.
25. Kaiwa Y, Kurokawa Y, Kenjiro A, Nakagawa A, Mitsui K, et al. Correlation of unilateral lung volume reduction with improvement in lung function and exercise performance in patients with severe pulmonary emphysema. Jpn J Surg 1999; 29: 718–23.
26. Wakabayashi A. Thoracoscopic laser pneumoplasty in the treatment of diffuse bullous emphysema. Ann Thorac Surg 1995; 60: 936–42.
27. Criner GJ, O'Brien G, Furukawa S, Cordova F, Swartz M, Fallahnejad M, et al. Lung volume reduction surgery in ventilator-dependent COPD patients. Chest 1996; 110: 877–84.