BILATERAL VOLUME REDUCTION SURGERY FOR DIFFUSE PULMONARY EMPHYSEMA BY VIDEO-ASSISTED THORACOSCOPY

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We prospectively studied the surgical aspects, functional results, and complications of video-assisted bilateral thoracoscopic volume reduction surgery in patients with severe diffuse pulmonary emphysema. *Methods:* Fifteen men and five women with a mean age of 64 years (range 42 to 78 years) whose daily activity was substantially impaired by severe airflow obstruction and hyperinflation underwent thoracoscopic volume reduction surgery. The prospective preoperative assessment and postoperative assessment at 3 months included (1) pulmonary function studies, (2) grading of dyspnea, and (3) exercise performance; pulmonary function tests were also performed immediately before discharge from the hospital. *Results:* There was no perioperative mortality. All patients left the hospital after a median stay of 15 days (6 to 27 days). Only seven patients had a prolonged chest tube drainage time (>7 days). At 3 months the mean ($\pm$ standard deviation) forced expiratory volume in 1 second had improved by 42% ($\pm 3.8\%$), from 0.80 L (± 0.23) to 1.09 L (± 0.28) ($p < 0.001$); residual volume had decreased from 5.8 L (± 1.5) to 4.4 L (± 1.0) ($p < 0.001$). Shortly before discharge the forced expiratory volume in 1 second was already 1.10 L (± 0.26). The median 12-minute walking distance increased from 495 m (35 to 790 m) to 688 m (175 to 1035 m) ($p < 0.001$) and the mean maximal oxygen consumption from 10 ml/kg per minute (± 2.5) to 13 ml/kg per minute (± 2.3) ($p < 0.0005$). The patients reported a substantial relief of dyspnea with a mean decrease in the Medical Research Council score from 3.4 to 1.8. (J Thorac Cardiovasc Surg 1996;112:875-82)

Resection of large bullae, either unilaterally by thoracotomy or bilaterally by median sternotomy, has been performed with good functional results for many years by numerous groups.¹⁻⁶ Resection of large bullae, that is, bullae along with at least one third of a hemithorax and minimal or moderate remaining emphysematous lung tissue, resulted in the most impressive improvement.⁶

A totally different concept was pioneered by Brantigan, Mueller, and Kress⁷ more than 30 years ago. Their procedure consisted of multiple wedge resections of emphysematous lung tissue through a standard thoracotomy. Their goal was to reduce lung volumes, hence improving radial traction on the airways.⁷⁻⁹ A high perioperative mortality of 16%, the lack of appropriate functional documentation of the patients, and prejudices discouraged other physicians from following this approach. Cooper and associates¹⁰ resumed Brantigan's concept and performed bilateral lung volume reduction surgery (VRS) in patients who had grossly hyperinflated lungs because of severe diffuse pulmonary emphysema. They used median sternotomy as a surgical approach. Because of our experience and good results with video-assisted thoracoscopy (VAT) for a variety of indications, we prospectively studied the surgical problems, complications, and functional results of VRS performed by this approach. We expected to obtain functional improvements comparable with those obtained with median sternotomy.

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Table 1. Emphysema severity scores assessed by computed tomography

Patient	Left lung*			Right lung*			Total score	Emphysema type†
	UL	Lingula	LL	UL	ML	LL		
1	1.5	1.0	1.5	1.5	0.5	0.5	6.5	Uniform
2	3.0	0.5	1.0	3.0	1.0	0.0	8.5	UL
3	3.0	3.0	3.0	3.0	2.0	2.5	16.5	Uniform
4	0.5	2.5	3.0	0.5	2.5	3.0	12.0	LL
5	3.5	4.0	1.0	4.0	3.5	0.5	16.5	UL
6	2.0	0.0	0.5	3.5	0.0	0.5	6.5	UL
7	3.0	1.5	3.5	3.0	0.5	1.5	13.0	Asymmetric
8	3.0	3.0	2.0	3.0	2.0	1.5	14.5	Asymmetric
9	3.0‡	2.5	2.5‡	3.0‡	2.5‡	2.5§	16.0	Uniform
10	1.0	2.5	1.5	1.0	2.5	1.5	10.0	ML/lingula
11	3.5	1.5	2.0	3.5	1.0	2.0‡	13.5	UL
12	2.5	2.0	1.5	2.5	1.5	2.5‡	12.5	Uniform
13	0.5‡	1.5	2.5‡	0.5‡	0.5	1.0‡	6.5	Asymmetric
14	2.5	3.5	3.5	2.5	2.5	3.5	18.0	Uniform
15	1.0	0.5	3.5	1.0	2.0	3.5	11.5	LL
16	1.0	1.0	1.0	2.0	1.0	2.0§	8.0	Uniform
17	3.5	2.0	2.0	3.5§	2.5	3.5	17.0	Asymmetric
18	1.0	1.0	2.0	2.0	1.0	2.0	9.0	Uniform
19	1.0	2.5	3.5	2.0	2.5	2.0§	13.5	Asymmetric
20	3.5	2.0	2.0	3.5	0.5	2.5	14.0	UL

UL, Upper lobe; LL, lower lobe; ML, middle lobe. The extent of emphysematous changes of each individual lobe is scored for both panlobular and centrilobular emphysema according to the following scheme: 0, no emphysematous changes; 1, emphysematous changes involving <30% of lobar parenchyma; 2, involving 30%-60% of lobar parenchyma; 3, involving 60%-90% of lobar parenchyma; 4, >90% of lobar parenchyma.

*Severity score for each individual lobe is calculated by adding 100% of the score for panlobular and 50% of the score for centrilobular emphysema, respectively.

†The emphysema type is determined by the distribution of the severity scores in the individual lobe. *Uniform*, Lobar scores evenly distributed, the difference being ≤ 1 ; *UL/LL/ML/Lingula*, bilateral predominance of the emphysema in the lobe indicated; *Asymmetric*, the lobar scores are unevenly distributed, there being no clear symmetric lobar predominance.

‡Bulla <2cm.

§Bulla 2-5 cm.

Methods

Patient selection. Patients were referred from the German and Italian speaking parts of Switzerland (population 5.28 million) and gave informed consent to be included in this prospective study of VAT-VRS performed by the same surgeon (W.W.). They were selected according to the following criteria:

Inclusion criteria

- Severe obstruction (forced expiratory volume in 1 second [FEV₁] < 1.2 L/sec) without significant improvement by the usual antiobstructive pharmacotherapy, including a prolonged trial with systemic corticosteroids
- Smoking cessation (carboxyhemoglobin < 2.0%)
- High motivation and acceptance of an increased perioperative mortality (estimated as being up to 10%) or morbidity, or both
- Severe hyperinflation (total lung capacity [TLC] > 130% of predicted)
- Severe emphysema of the diffuse bilateral type with no isolated bullae occupying more than 20% of the volume of either hemithorax (according to Table 1)
- Dyspnea at rest or at minimal physical activity resulting in severe limitation of daily activity and an impaired quality of life

Exclusion criteria:

- Significant coronary artery heart disease ($\geq 50\%$ diameter reduction of $\geq$ one coronary artery)
- Mean pulmonary arterial pressure greater than 35 mm Hg
- Carbon monoxide diffusing capacity (DLCO) less than 20% of predicted or hypercapnia with an arterial carbon dioxide tension (Paco₂) greater than 55 mm Hg
- Active bronchopulmonary infection
- Neoplastic disease with a life expectancy of less than 2 years
- Addiction to alcohol or drugs; psychiatric disturbance (e.g., panic disorder)
- Serum creatinine level of 150 μ g/ml or more; history of gastrointestinal bleeding in the previous year; abnormal results of liver function tests; active inflammatory bowel disease
- Oral corticosteroids at a dose of more than 15 mg of prednisone equivalent

Patient population. Within 1 year (from August 1994 to August 1995) 60 patients were referred for evaluation. Twenty-nine patients were excluded from this study for the following reasons: unwilling to accept an increased

risk, 12; obvious gross bullous lung disease, 2; no hyperinflation, 2; DLCO less than 20% of predicted, 1; severe coronary artery disease, 9; bronchial carcinoma, 2; drug addiction, 1.

Twenty-five patients were accepted and six are being evaluated. Twenty were operated on and had 3 months' follow-up at the end of September 1995. The mean age of the 15 men and six women was 64 years (range 42 to 78 years). Their mean body mass index was 21.5 kg/m² (range 15.5 to 31.5 kg/m²). Twenty were former smokers, and two had α_1 -antitrypsin deficiency (ZZ, homozygosity for the allele Z). Seven patients were receiving long-term home oxygen therapy.

Functional assessments. Measurements were performed within 2 weeks before the operation, before discharge, and 3 months after the intervention.

Lung volumes were measured according to standard criteria^{11, 12} using the SensorMedics 66200 Autobox device (SensorMedics Corp., Yorba Linda, Calif.). Results are expressed as the best values after inhalation of two puffs of salbutamol.

DLCO was measured with the 66200/SensorMedics equipment. Reference values were according to the criteria of the European Community for Steel and Coal.¹³

Arterial blood gases were analyzed with an AVL 995-S device (AVL Medical Instruments, Schaffhausen, Switzerland) and oxygen saturation and carboxyhemoglobin with a Co-Oximeter device (IL 482, Radiometer A/S, Copenhagen, Denmark).

Exercise was evaluated by the 12-minute walking distance. The patients walked along the same hospital hallway without oxygen supplementation, monitored by pulse oximetry, accompanied and encouraged by a technician.^{14, 15}

Cardiopulmonary stress tests were performed by the SensorMedics 2900 metabolic measurement cart on an electronically braked cycle ergometer (Bosch; Medicare AG, Zurich, Switzerland). After 2 minutes of unloaded cycling at 50 rpm, the workload was increased by 5 W/min according to a ramp protocol until the patient was unable to continue. Maximal values for cardiorespiratory variables were taken at the highest oxygen uptake. Predicted maximal heart rate was 215 beats/min minus age (years).

Right heart catheterization was performed in all patients. Coronary angiography was performed in 14 patients in whom coronary artery heart disease was suspected.

Dyspnea was rated according to the American Thoracic Society's modified Medical Research Council score¹⁶ and Mahler and associates' baseline and transition dyspnea index.¹⁷

High-resolution computed tomographic scanning was performed by a Somatom plus 4 device (Siemens AG-Bereich Medizinische Technik, Erlangen, Germany). Each patient's scan was scored independently by two experienced readers blinded for clinical and functional data, according to an emphysema severity score that was defined beforehand (see legend to Table I).

A lung perfusion scan was performed with a Siemens gamma camera (150 mBq technetium 99m-labeled macroalbumin particles).

Anesthesia and postoperative management. A combination of continuous thoracic epidural anesthesia and

total intravenous anesthesia was used. A left-sided double-lumen endotracheal tube was placed for one-lung ventilation. Controlled ventilation was performed with a Servo 900C ventilator (Siemens, Life Support Systems, Solna, Sweden). Extubation was performed in the operating theater. Local anesthetics (Bupivacaine 0.25%) were given continuously through the epidural catheter. Perioperative antibiotics were administered for 3 to 5 days.

Surgical technique. Patients with emphysema localized predominantly to the upper or middle lobe, or both, were placed supine and the less-affected side was operated on first. If the resection was planned in the lower lobes or posteriorly, the patient was placed laterally and the position changed after completion of the first side. Three 11.5 mm trocars (Thoracoport trocar, Auto Suture Company Division, United States Surgical Corporation, Norwalk, Conn.) were placed in the seventh or eighth intercostal space and a 5.5 mm trocar in the fourth intercostal space. A 10 mm rigid, 25-degree angled thoracoscope (OTV-SX, digital 3 CCD, Olympus America, Inc., Melville, N.Y.) was used. The resection was planned by using computed tomographic scans and perfusion scintigraphy to identify the most severely destroyed tissues. The lack of resorption atelectasis was also helpful in identifying target areas for resection. In addition, "palpation" with an endoscopic lung forceps (Ethicon Endo-Surgery, Inc., Cincinnati, Ohio) was useful. Successive applications of endoscopic staplers (3.5 mm; Endo-GIA 30/60 mm staplers; Auto Suture) and more recently a 45 mm thoracoscopic endoscopic linear cutter (Ethicon Endo-Surgery) were used to resect approximately 20% to 30% of lung volume. At intervals, the lung was reinflated to assess whether further resections were tolerable. The staplers were not buttressed with xenopericardium. Pleural abrasion, pleural tent, and talc poudrage were not performed. Adhesions were dissected with endoscopic shears. Two drainage tubes were placed on each side and inserted through the trocars, applying suction of 10 to 20 cm H₂O.

Statistical analysis. The data were checked for the type of distribution and the parameters were compared for paired samples by means of Student's *t* test or the Wilcoxon paired-sample test, accordingly. Correlation and standard linear regression were calculated between different parameters. Significance levels were *p* < 0.05.

Results

Perioperative and postoperative course and complications. Ten patients were operated on in the supine position and 10 in the lateral position with an intraoperative position change. Two patients had severe and six had minor adhesions. One patient had a tension pneumothorax during the operation, and this side was operated on subsequently. Cardiopulmonary instability developed in two patients. Because the risk of operating on the other side was considered to be too high, only one side was resected. The mean duration of the operations was 154 minutes (± 61) with a minimum of 65 minutes and a maximum of 290 minutes. All patients were

Table II. Spirometry and lung volumes

	Before the operation: mean $\pm$ SD (range)	Before discharge: mean $\pm$ SD (range)	After 3 months: mean $\pm$ SD (range)
FEV ₁ (L)	0.82 $\pm$ 0.25 (0.46-1.34)	1.09 $\pm$ 0.34† (0.53-2.08)	1.09 $\pm$ 0.31† (0.53-1.76)
% Predicted	29 $\pm$ 7.4 (18-49)	39 $\pm$ 10.5 (23-64)	39 $\pm$ 9.7 (24-60)
FVC (L)	2.54 $\pm$ 0.80 (1.47-4.33)	2.95 $\pm$ 0.81* (1.76-5.24)	3.27 $\pm$ 0.62† (2.11-4.51)
% Predicted	70 $\pm$ 16 (47-99)	84 $\pm$ 16 (58-116)	94 $\pm$ 13 (67-116)
TLC (L)	8.78 $\pm$ 1.43 (6.3-12.0)	6.8 $\pm$ 1.40‡ (5.0-9.9)	7.34 $\pm$ 1.23* (5.9-9.9)
% Predicted	145 $\pm$ 21 (98-185)	123 $\pm$ 21 (87-160)	129 $\pm$ 20 (87-169)
IVC (L)	3.03 $\pm$ 1.02 (1.04-4.77)	2.84 $\pm$ 0.95 (1.19-4.36)	3.51 $\pm$ 0.86* (1.13-4.82)
RV (L)	5.6 $\pm$ 1.3 (4.0-10.4)	4.15 $\pm$ 0.9‡ (2.3-5.8)	4.3 $\pm$ 0.9‡ (2.5-6.0)
% Predicted	256 $\pm$ 71 (154-432)	195 $\pm$ 48 (114-276)	197 $\pm$ 51 (120-300)
RV/TLC (%)	0.64 $\pm$ 0.09 (0.48-0.87)	0.57 $\pm$ 0.07† (0.45-0.71)	0.55 $\pm$ 0.07‡ (0.42-0.68)

SD, Standard deviation; FEV₁, forced expiratory volume in the first second; FVC, forced vital capacity; IVC, inspiratory vital capacity; TLC, total lung capacity; TV, residual volume.

* $p < 0.05$ compared with preoperative value.

† $p < 0.01$ compared with preoperative value.

‡ $p < 0.001$ compared with preoperative value.

extubated immediately at the end of the operation. In one patient endotracheal reintubation was necessary 30 minutes later because of severe alveolar hypoventilation with a PaCO₂ rising to 80 mm Hg. He was successfully extubated 20 hours later.

Twelve of the 20 patients had an uneventful perioperative and postoperative course. The remaining eight had one or two of the following complications. Six had bacterial pneumonia, which was successfully treated by antibiotics. Despite a lack of previous air leaks, a pneumothorax occurred during chest physiotherapy in two patients after the chest tubes had been removed. One patient required rethoracoscopy on the sixteenth postoperative day, although no air leak could be identified. A pleural abrasion was performed. The median chest tube drainage time was 6.5 days (range 3 to 19 days). In seven patients drainage time was prolonged (i.e., more than 7 days). The median stay in the hospital was 15 days, ranging from 7 to 26 days.

No early or late deaths occurred. Two patients had prolonged chest pain at the operation port. They had clinical signs of rib fractures caused by severe osteoporosis after long-term corticosteroid

therapy. Three patients had an incomplete unilateral pneumothorax between 6 and 8 weeks after discharge from the hospital. In two patients the pneumothorax occurred spontaneously and in one as a complication of an intercostal nerve blockade. All were treated by simple thoracic tube drainage and no further events occurred.

Functional results. The preoperative and postoperative functional data are summarized in Tables II to IV. The mean increase in FEV₁ was 42%. The full gain in FEV₁ was reached before discharge (Table II). In four patients the changes in FEV₁ were less than 150 ml, but none showed worsening of FEV₁ or vital capacity compared with preoperative values. In eight patients the increase in FEV₁ was more than 300 ml, in one patient FEV₁ improved by 740 ml, and in another by 830 ml. Residual volume (RV) decreased by a mean of 1.45 L. In three patients the reduction of RV was less than 0.5 L, but in 11 patients RV declined by more than 1 L from the preoperative measurement. The mean difference in TLC was 1.0 L. In four patients the difference in TLC from baseline was 0.5 L or less. Accordingly, the mean RV/TLC ratio had decreased 3 months after the operation (see Table II).

Table III. Gas exchange and pulmonary hemodynamics

	Before the operation: mean $\pm$ SD (range)	After 3 months: mean $\pm$ SD (range)	<i>p</i> Value
PaO ₂ (mm Hg)	67 $\pm$ 8.7 (54-90)	71 $\pm$ 9.6 (54-98)	<i>p</i> < 0.05
Paco ₂ (mm Hg)	37 $\pm$ 4.2 (28-46)	35 $\pm$ 3.9 (27-42)	<i>p</i> < 0.05
D(A-a)PO ₂ (mm Hg)	28 $\pm$ 10.7 (7-44)	29 $\pm$ 8.9 (11-42)	NS
DLCO _{SB} (% pred)	41 $\pm$ 10.0 (24-58)	44 $\pm$ 9.1 (28-61)	NS
PAPs (mm Hg)	30 $\pm$ 4.6	—	—
PAPd (mm Hg)	12 $\pm$ 2.9	—	—
PAPm (mm Hg)	19 $\pm$ 3.1	—	—
PCPm (mm Hg)	8 $\pm$ 3.3	—	—
CO (L/min)	4.6 $\pm$ 0.75	—	—
PVR (dyn $\cdot$ sec $\cdot$ cm ⁵)	210 $\pm$ 89	—	—

SD, Standard deviation; PaO₂, arterial oxygen tension; Paco₂, arterial carbon dioxide tension; D(A-a)PO₂, alveolar-arterial oxygen pressure gradient; DLCO_{SB}, single-breath carbon monoxide diffusing capacity; PAPs, systolic pulmonary artery pressure; PAPd, diastolic pulmonary artery pressure; PAPm, mean pulmonary artery pressure; PCPm, mean pulmonary capillary pressure; CO, cardiac output; PVR, pulmonary vascular resistance; NS, not significant.

None of our patients had a DLCO above 60% of predicted before the operation. No significant changes were observed after VRS (see Table III). In three patients the arterial oxygen tension (PaO₂) at rest was below 60 mm Hg and in two of them it was lower than 55 mm Hg. Three months after VRS we found a mild but significant increase in the mean PaO₂ of 4 $\pm$ 0.71 mm Hg (*p* < 0.01). There was also a small but significant drop in the mean Paco₂. This explains why the alveolar-arterial oxygen pressure gradient remained unchanged (see Table III). In only one of the three patients who had a PaO₂ below 60 mm Hg before the operation, the PaO₂ increased relevantly from 54 to 69 mm Hg (at rest). The hemodynamic data of the right heart catheterizations are presented in Table III. One patient had mild pulmonary hypertension with a mean pulmonary artery pressure of 25 mm Hg.

Both exercise capacity and the 12-minutes walking distance were significantly better after VRS. Three months after the operation, maximal minute ventilation was higher by a mean of 8 L/min.

Except in one patient, a clear relief of dyspnea occurred after VRS. Three of the patients in whom the FEV₁ did not improve significantly (i.e., an increase <0.15 L) reported a clear subjective improvement. The Medical Research Council dyspnea score diminished from a mean of 3.9 ($\pm$ 0.67) to 1.8 ($\pm$ 0.90). Breathlessness, as assessed by Mahler's dyspnea transition index,¹⁷ decreased in 15 of the 20 patients at least moderately ($\geq$ +2). In the one patient who reported no subjective amelioration, the

change in FEV₁ was only 0.13 L. In contrast, three patients in whom neither a significant improvement of FEV₁ nor a reduction of hyperinflation could be documented reported a mild subjective benefit (+1 Mahler's dyspnea transition index).

Taking the changes in Medical Research Council dyspnea scores as dependent and changes in FEV₁ and RV as independent variables, we found moderate correlations between the improvement in dyspnea and the reduction in air flow obstruction (*r* = 0.44; *p* < 0.01), as well as in the decrease of hyperinflation (*r* = 0.42; *p* < 0.001). Furthermore, we found a good correlation between the reduction in dyspnea score (Medical Research Council) and the improvement in exercise capacity (*r* = 0.73; *p* < 0.01). The improvement in dyspnea achieved by VRS correlated only with the preoperative degree of airflow obstruction (FEV₁; *r* = -0.41; *p* < 0.01) but not with the degree of hyperinflation before the operation.

Discussion

Severe forms of chronic obstructive pulmonary disease are characterized by a considerable degree of pulmonary emphysema, which is defined as permanent enlargements of air spaces distal to the terminal bronchioles accompanied by destructions of their walls.¹⁸ In patients with this variety of disease, little or no change in lung function is produced by extensive antiobstructive pharmacotherapy or after pulmonary rehabilitation.¹⁹ For patients with severe impairment who are younger

Table IV. *Cardiopulmonary exercise tests*

	Before the operation: mean $\pm$ SD (range)	After 3 months: mean $\pm$ SD (range)	p Value
Twelve-minute walking distance (*) (m)	495 (35-790)	688 (175-1035)	0.0001
Maximal workload (W)	31 $\pm$ 12 (10-55)	47 $\pm$ 14 (20-70)	0.0001
VO ₂ max (ml/kg/min)	10 $\pm$ 2.5 (5-16)	13 $\pm$ 2.3 (9-18)	0.0005
D(A-a)PO ₂ (mm Hg)	36.2 $\pm$ 9.8 (19.2-56.6)	43.0 $\pm$ 9.9 (14.9 $\pm$ 58.3)	0.01
V _E max (L/min)	29 $\pm$ 9 (18-48)	38 $\pm$ 8 (22-54)	0.0006
Breathing reserve (L/min)	0.1 $\pm$ 5.6 (-12-10)	1.5 $\pm$ 6.7 (-9-16)	0.44
Heart rate max (beats/min)	123 $\pm$ 18 (98-167)	132 $\pm$ 15 (101-158)	0.04

VO₂max, Maximal oxygen uptake; D(A-a)PO₂, alveolar-arterial oxygen pressure gradient at maximal exercise; V_Emax, maximal minute ventilation. (FEV₁ $\times$ 37)-VE max.

*Median.

than 60 years, single or double lung transplantation remained until recently the only promising therapeutic option.^{20, 21}

Cooper and associates¹⁰ published impressive improvements in dyspnea and pulmonary function by bilateral surgical lung volume reduction in 20 patients with severe diffuse pulmonary emphysema. Since then this group has accumulated extensive experience with more than 100 patients. Many other groups in the United States and Europe are now performing VRS and have presented their preliminary results at international meetings.

The degree of functional impairment of our study population (see Tables II to IV) is comparable with that of Cooper's patients.¹⁰ The mean FEV₁ of 0.77 L, mean RV of 5.9 L, mean TLC of 8.5 L, and mean Pao₂ of 64 mm Hg of their patients are almost identical to our measurements. Their patients had a mean age of 56 years, somewhat younger than the mean age of 64 years of our patients. We are not able to compare the morphologic type and the distribution of pulmonary emphysema between Cooper's and our groups, because there is no generally accepted radiologic classification and grading system for emphysema. Nevertheless, as can be seen in Table I, all our patients had pulmonary emphysema of the diffuse type and none of the bullous type.

In contrast to Cooper and coworkers,¹⁰ who used median sternotomy, we performed VRS by VAT. In two patients we decided not to resect the other lung, because the condition of the patients became unstable during the operation. However, the postopera-

tive course in both patients was without complication. Although we did not use pericardial strips to buttress the stapler lines,²² our experience is comparable with the results of Cooper's group,¹⁰ who reported prolonged air leaks in 11 of their 20 patients. This low complication rate is also reflected in a median hospital stay of 15 days, comparable with the hospitalization time reported by Cooper's group. In our study population, selected by previously defined stringent criteria, we had no early or late mortality.

The improvements of pulmonary mechanics achieved by VAT-VRS were highly significant and of clinical relevance. However, in contrast to Cooper's group,¹⁰ which obtained a mean increase in FEV₁ of 82% from 0.77 to 1.4 L by performing VRS by sternotomy, we obtained a mean increase of 42% (from 0.8 to 1.1 L). The reduction in hyperinflation in our study group was also somewhat less than after VRS by sternotomy.¹⁰ Our smaller gains in FEV₁ may be due to several factors. We had a smaller number of patients with predominant upper lobe emphysema, those believed to profit most from VRS. However, our small series does not allow us to draw any reliable conclusions about a correlation between the type of emphysema and the degree of postoperative functional benefit. In addition, two patients did not undergo resection on both lungs as planned because of cardiopulmonary instability. However, it is obvious that functional improvements after bilateral resection are better than after unilateral VRS. Furthermore, it is possible that more

emphysematous lung tissue was removed by sternotomy than by VAT. The results of pulmonary function tests immediately before discharge were similar to functional data at 3 months. This has not been observed after VRS by sternotomy, in which maximal improvements in pulmonary function are reached between 3 and 6 months after the operation.¹⁰ Whether this early functional recovery is due to the thoracoscopic approach remains speculative, because no data are available regarding pulmonary function measurements early in the postoperative course after sternotomy. We decided to perform VRS by VAT for the following reasons. VAT provides a good view and access to all parts of the lungs, including the posterior and inferior aspects. It allows precise dissection of adhesions even in those areas that are difficult to reach through a sternotomy. Adhesions were observed in almost half of our patients. Their dissection can lead to air leaks. Wedge resection by VAT can be performed in any region without overly manipulating the lungs by mobilizing them into the operative field. Furthermore, we consider the inability of manual palpation to select areas of resection unimportant, because we primarily use imaging modalities such as computed tomographic and perfusion scans to identify target areas for resection. However, we encountered some difficulties in recognizing and localizing air leaks, if present, at the end of the procedure.

We found no changes in DLCO (see Table III), a parameter believed to reflect the amount of pulmonary gas exchange surface.²³ These findings are a strong argument that we did not remove relevant quantities of tissue, which contributed to gas exchange. Ventilation-perfusion mismatch is another cause of hypoxemia in patients with chronic obstructive pulmonary disease and emphysema. It is therefore conceivable that the improvements in pulmonary mechanics are accompanied by a rise in P_{aO_2} . Cooper and associates¹⁰ observed a slight increase in the mean P_{aO_2} of their patients, the P_{aCO_2} remaining unchanged. We too found a small but significant rise in the mean P_{aO_2} in our study population. In contrast, the mean P_{aCO_2} in our patients decreased significantly (see Table III). Hence the alveolar-arterial oxygen gradient remained unchanged and the increase in P_{aO_2} might be attributed to a slightly augmented alveolar ventilation.

Pulmonary function does not improve after pulmonary rehabilitation. In contrast, rehabilitation may increase walking distance, maximal workload,

and endurance time in severely impaired but highly motivated patients.¹⁹ This was the case in Cooper's patients, who underwent a structured rehabilitation program before VRS or lung transplantation.¹⁰ The improvement in 12-minute walking distance of our patients was moderate. Our findings are difficult to compare with those of Cooper's group,¹⁰ who assessed physical performance by measuring the 6-minute walking distance. We are not able to compare our improvements, documented by standardized cardiopulmonary exercise tests, with the findings of others, because results of exercise tests after VRS have not yet been published. Since only two of our patients underwent a rehabilitation program after the operation, we believe that the mean improvement in exercise performance of our study population is mainly due to changes in lung mechanics.

The relation between breathlessness and parameters such as dynamic expiratory flow rates, static lung volumes, and arterial blood gases overlap widely.²⁴ We found moderate correlations between the improvements in shortness of breath and alterations in lung mechanics achieved by VRS. Even patients who showed no objective changes, as assessed by conventional pulmonary function tests, reported a marked subjective benefit. A somewhat better correlation was detected between the reduction in the Medical Research Council dyspnea score and an amelioration in exercise performance. The contribution of a placebo effect in these highly motivated patients cannot be excluded.²⁵ Furthermore, changes in pulmonary mechanics, which are not detected by conventional measurements (e.g., diaphragmatic function and breathing pattern), might play a significant role.

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