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Lung Volume Reduction Surgery

Case Selection, Operative Technique, and Clinical Results

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Objective
A clinical study was undertaken to define optimal preoperative strategies and intraoperative techniques that would result in the least morbidity and maximum physiologic improvement in patients with end-stage emphysema selected for lung volume reduction surgery.

Background
Lung volume reduction surgery recently has been advocated as an alternative or a bridge to lung transplantation for patients with end-stage chronic obstructive pulmonary disease. The risks, benefits, and long-term results have not been clarified.

Methods
Twenty-six patients underwent lung volume reduction surgery with a 3-month follow-up on 17 patients. Preoperative and postoperative changes in pulmonary function parameters, quality of life, and oxygen requirement were analyzed. The value of preoperative localization of diseased lung segments and how this affects intraoperative resection is addressed.

Results
Forty-nine percent improvement in FEV_1 (forced expiratory volume in 1 second) and 23% improvement in FVC (forced vital capacity) were seen after lung volume reduction surgery. Supplemental oxygen requirement was decreased and 79% of patients reported a much better quality of life. Mortality was 3.8% and air leak morbidity was 18%.

Conclusions
Lung volume reduction surgery can predictably improve objective and subjective pulmonary function in selected patients with end-stage emphysema with low morbidity and mortality. Careful patient selection, accurate preoperative localization of diseased target areas, skilled anesthetic technique, meticulous operative approach, and intense postoperative support are essential to achieve favorable results.

Lung volume reduction surgery has recently been advocated as an alternative or a bridge to lung transplantation for patients with severe disabling emphysema.[1] Our institution initiated a clinical study in November 1994, seeking to determine with preoperative and postoperative studies of pulmonary function and anatomic distribution of disease what surgical techniques would give the least morbidity and produce the maximum physiologic improvement.

METHODS

In addition to its disabling pulmonary sequelae, end-stage emphysema has profound effects on patients' emotion, nutrition, and psychosocial behavior. To meet the demands of these patients, it is essential that a multidisciplinary team is dedicated to the lung volume reduction surgery (LVRS) program. Case selection and preoperative preparation by the pulmonologist, the thoracic surgeon, and the nurse practitioner must be well coordinated. A dedicated thoracic anesthesiologist is vital to oversee the often unstable anesthetic induction, placement of a double-lumen endotracheal tube, and accurate insertion of a thoracic epidural catheter. Intense postoperative support by physical therapists, nurses, and physicians is required to care for these patients after surgery when physiologic and psychological stress are at their peak.

In the study period from November 1994 to November 1995, 140 patients were referred to the University of Virginia for evaluation. Twenty-six of these were selected to undergo LVRS. Twenty-five carried the diagnosis of disabling chronic obstructive pulmonary disease (COPD), and 1 patient had alpha-1 antitrypsin deficiency. There were 17 men and 9 women, and the age range was 37 to 72 years with a mean of 62 years. Nine patients required supplemental oxygen at rest, whereas five used supplemental oxygen only with exercise. Preoperative FEV_1 (forced expiratory volume in 1 second) ranged from 0.5 L (15% predicted) to 1.3 L (32% predicted), with a mean of 0.75 L (27% predicted).

Patient selection criteria have evolved as our experience grew. Currently, our inclusion criteria are as follows:

- Diagnosis of COPD
- Smoking cessation more than 1 month
- Age younger than 75
- FEV_1 between 15% and 35% of predicted
- pCO_2 (arterial carbon dioxide) less than 55 mmHg
- Prednisone dosage less than 20 mg/day
- Pulmonary artery systolic pressure less than 50 mmHg by echocardiogram
- No previous thoracotomy or pleurodesis
- Absence of symptomatic coronary artery disease
- Absence of chronic asthma or bronchitis
- Commitment to preoperative and postoperative supervised pulmonary rehabilitation for 6 weeks

Patients who meet the above criteria then undergo a series of physiologic and anatomic studies. Physiologic assessment includes pulmonary function tests with arterial blood gas measurement, a standard 6-minute walk, and a cardiac echocardiogram to exclude significant pulmonary hypertension. Anatomic assessment consists of an inspiratory and expiratory chest radiograph, a contrast-enhanced high-resolution computed tomography (CT) of the chest, a planar ventilation and lung perfusion scan, and a lung perfusion single positron emission CT (SPECT) scan to assess segmental three-dimensional distribution of lung perfusion.

Operative Technique

Skilled intraoperative anesthetic technique and aggressive postoperative pain management are critical to the success of this operation. A thoracic epidural is introduced at T6–T8 level with infusion of one-eighth percent bupivacaine and Dilaudid (Knoll, Whippany, NJ). This regimen is continued after operation. Inhalational anesthetic is performed with isoflurane. Intravenous fentanyl is used initially, but toward the end of the case, systemic narcotic is discontinued to minimize respiratory depression while the epidural infusion is initiated. A left-sided double-lumen endotracheal tube is used to provide isolated ventilation to either lung.

A median sternotomy is made and bilateral pleural tents are created by bluntly dissecting the parietal pleura free from the chest wall. This allows the pleura to drape over the apex of the lung to reduce the incidence of prolonged air leak. Usually, based on preoperative imaging studies, the worst lung is done first. Upon deflating the lung, adhesions are released carefully. Any inadvertent tear of the lung may result in prolonged air leak. The inferior pulmonary ligament usually does not need to be divided. Although the various segments of the upper lobes are readily identifiable, access to the lower lobes can be difficult. This is facilitated by floating the partially inflated lower lobe up with saline, which greatly improves exposure to the posterior and basilar segments (Larry Kaiser, M.D., personal communication, 1995)

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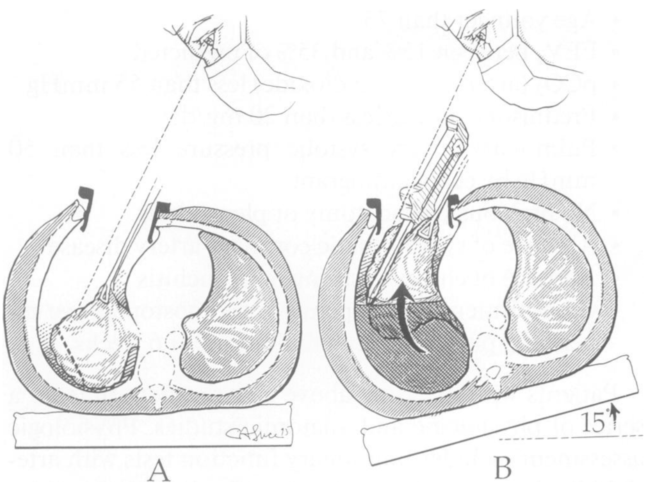

Figure 1. Intraoperative illustration of the saline float technique to facilitate exposure to the basilar segments of the lower lobe.

(Fig. 1). As directed by preoperative SPECT scan, 20% to 30% of each lung then is resected with a linear GIA stapler (U.S. Surgical Corp., Norwalk, CT) buttressed with bovine pericardial strips (Peri-Strips, Biovascular, Inc., St. Paul, MN) as described by Cooper.[2] Sequential applications of the stapler are made often to provide a continuous line of excision (Fig. 2). On completion of each stapled resection, a careful inspection is made for air leaks by flooding the pleural space with saline during lung inflation. Repair of air leaks is best conducted by re-excising the area with the pericardial-buttressed stapler. Two chest tubes are placed in each pleural space, one directed toward the apex and one placed inferiorly along the diaphragm. Chest tubes are inserted through the anterior abdominal fascia rather than through intercostal spaces to minimize postoperative pain. Then chest tubes are connected to water seal or to low suction (0 to 10 cm water) to avoid creating air leaks in these delicate lungs.

Patients are extubated immediately after the procedure to avoid barotrauma and exacerbation of air leaks secondary to positive pressure ventilation. In the recovery room, these patients often exhibit significant, but usually transient, hypercarbia (pCO_2, 45 to 102 mmHg in our series) due to either residual effects of anesthesia or to incomplete analgesia. No patient required reintubation in the recovery room for respiratory insufficiency. Postoperative management primarily involves the judicious use of intravenous fluid, pain control by way of a reliable thoracic epidural, aggressive chest physiotherapy, tireless nursing care, and psychological reassurance.

RESULTS

Twenty-six patients have undergone LVRS. The length of stay in the hospital ranged from 6 to 48 days, with an average of 13.6 days and a median of 9.5 days. There is a 100% follow-up from 1 week to 1 year after operation. A 3-month follow-up evaluation has been performed in 17 patients. Objective data are measured by changes in standard pulmonary function tests, whereas subjective improvement is reflected by a quality-of-life survey.

Results of preoperative and 3-month postoperative lung function parameters are listed in Table 1. Of note,

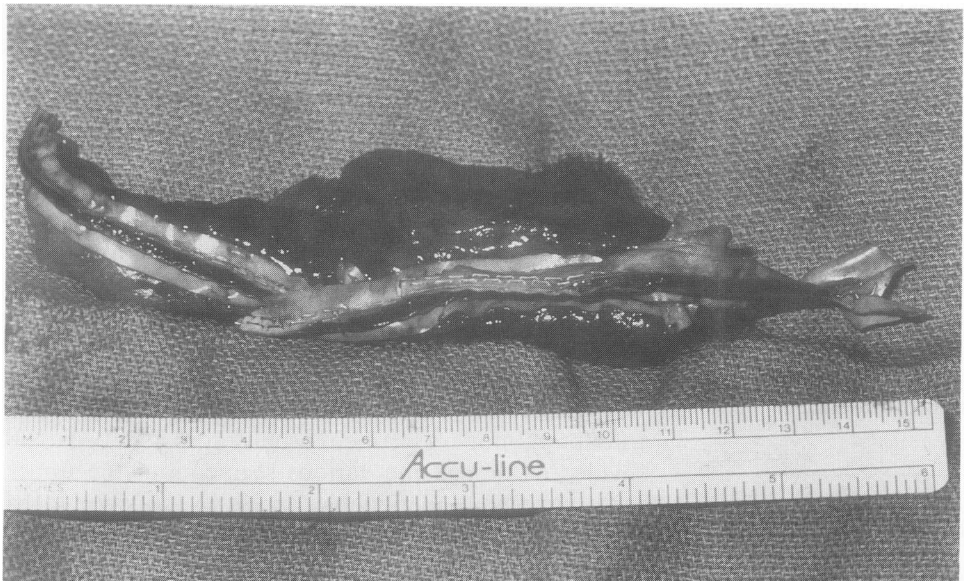

Figure 2. Resected lung specimen showing the continuous pericardial reinforced staple line from sequential applications of a GIA stapler.

Table 1. LUNG VOLUME REDUCTION SURGERY: PRE- AND 3-MONTH POSTOPERATIVE PULMONARY FUNCTION MEASUREMENTS (N = 17)

Parameter (mean)	Preoperative	Postoperative	% Change (mean)	p Value
FEV_1 (L)	0.73	1.02	+49	<0.0001
FVC (L)	2.49	3.00	+23	<0.005
TLC (L)	8.39	7.19	−14	<0.0001
RV (L)	6.1	4.2	−30	<0.0001
PaO_2 (mmHg)	62	66	+6.2	NS
$PaCO_2$ (mmHg)	42	40	−3.6	NS

FEV_1 = forced expiratory volume in first second; FVC = forced vital capacity; TLC = total lung capacity; RV = residual volume; PaO_2 = room air arterial oxygen; $PaCO_2$ = room air arterial carbon dioxide; NS = not significant.

there was a 49% improvement in FEV_1 from a preoperative mean of 0.73 L (25% predicted) to 1.02 L (36% predicted) after operation. Forced vital capacity (FVC) also was significantly improved by 23%. Although there was no significant difference in the preoperative and postoperative room air pO_2 and pCO_2, there was a definite decrease in supplemental oxygen requirement in patients after LVRS. Before operation, seven patients required oxygen continuously and two only with exertion. Eight patients did not require supplemental oxygen. After operation, only one patient required oxygen at rest and six with exercise. Ten are without any oxygen requirement. Thus, more than 85% of all patients who required continuous supplemental oxygen before operation either no longer require oxygen or only use it with exercise. In the quality-of-life survey, 79% of the patients expressed marked improvement in their lifestyle, whereas 17% considered themselves somewhat better, and 4% (one patient) were worse.

Complications in this series are reported for all 26 patients who have undergone LVRS. Air leak and respiratory failure contributed to most of our morbidity. Persistent air leak as defined by chest tube requirement for more than 7 days occurred in two patients. One of these patients was discharged home on day 21 with a Heimlich valve. Two patients required reoperation for massive air leak. One of these patients had a minimal air leak at the end of the original operation. After extubation and transfer to the recovery room, she developed massive bilateral air leaks to such an extent that most of her tidal volume was expelled into her Pleur-evac (Deknatel, Inc., MA). Prompt re-exploration showed rupture of several previously intact bullae. These were excised with the pericardial reinforced stapler. The other patient had a persistent air leak and space problem, necessitating reoperation on postoperative day 10 and closure with pedicled latissimus and serratus muscle flaps. Two patients were reintubated in the first 3 days after operation and subsequently underwent tracheostomy. These and other complications are listed in Table 2. Of note, there was no wound infection or mediastinitis. There was one death on postoperative day 12. This patient was recovering uneventfully when she was found dead in bed. Autopsy was unrevealing. This patient had been re-explored for massive air leak immediately after operation and continued to have a space problem. Removal of too much lung in this case may have been the source of postoperative morbidity.

DISCUSSION

The high prevalence of severe chronic obstructive pulmonary disease and its associated disability have led to a variety of medical and surgical approaches in an attempt to relieve dyspnea in these patients. Many of these procedures have been abandoned because of a lack of proven benefit.[3] Until recently, surgical options to improve pulmonary function in patients with severe emphysema have been limited to two operations. Bullectomy is an accepted procedure for a minority of patients who have giant bullous disease occupying 50% or more of the hemithorax with associated bronchovascular com-

Table 2. LUNG VOLUME REDUCTION SURGERY: MORBIDITY AND MORTALITY (N = 26)

Death	1 (3.8%)
Persistent air leak (>7 days)	2
Reoperation for massive air leak	2
Reoperation for space problem	1
Reintubation	1
Reintubation with tracheostomy	2
Pneumonia	1
Acalculous cholecystitis	1
Myocardial infarction	0
Wound infection/mediastinitis	0

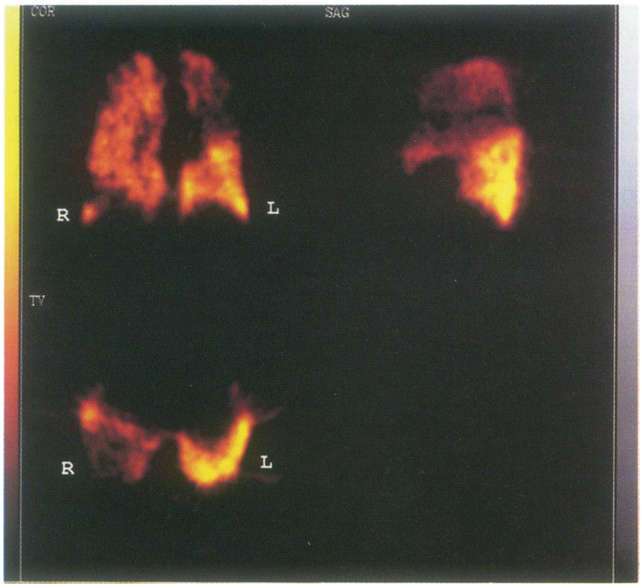

Figure 3. Lung perfusion single positron emission computed tomography scan showing underperfused areas (darkened zones) in the right lower lobe lateral basal segment and in the anterior segment of the left upper lobe. COR = coronal plane; TV = transverse plane; SAG = sagittal plane of left lung.

pression. Symptomatic and functional improvement have been reported in several series.[4,5] Lung transplantation also has become a standard method for end-stage emphysema. The lack of donor lungs and the considerable morbidity associated with transplantation have, however, limited this therapy to a small subset of patients. Furthermore, as a result of chronic rejection and late opportunistic infection, the 5-year survival rate is only 50% to 60%.[6]

In 1994, Joel Cooper at Barnes Hospital, St. Louis, resurrected the concept for emphysema surgery to reduce volume in hyperinflated lung.[1] This was originally introduced in 1959 by Otto Brantigan at the University of Maryland.[7] He proposed that lung volume reduction with multiple-wedge excisions or plications would restore the outward elastic pull on small airways and thus reduce expiratory airway obstruction. After Dr. Cooper's favorable report, LVRS programs have multiplied across the country. Referring pulmonologists and patients have expressed tremendous enthusiasm for the development of this procedure.

Although 140 patients have been referred to the University of Virginia for evaluation, more than 80% were not acceptable candidates for LVRS. Patients with FEV_1 below 15% predicted were considered for lung transplantation, whereas those above 35% of predicted were referred for pulmonary rehabilitation alone. The insistence on no previous thoracotomy or pleurodesis is because the release of pleural adhesions during surgery inevitably causes air leak, which in an ordinary patient would self-seal after surgery. But in these patients with friable lung parenchyma and diffuse blebs, any air leak might persist for weeks. The importance of the patient's commitment to preoperative and postoperative supervised pulmonary rehabilitation for 6 weeks must be emphasized. This requirement not only assesses the patient's motivation, but it also prepares the patient for the intense level of physiotherapy critical to postoperative recovery. Although the underlying pathologic disease is initially confined to the lungs, these patients have been living with the problems of dyspnea, fatigue, and exercise intolerance for years. This often results in secondary deconditioning, which leads to depression, malnutrition, and significant alteration of psychosocial behavior. Several of our patients had episodes of panic attacks after operation because of a constant fear of breathlessness. This again underscores the importance of a multidisciplinary team dedicated to the complicated care of these patients.

The mechanisms by which LVRS results in functional improvement are speculative. Possibilities include the restoration of breathing mechanics from chest wall reconfiguration and improvement in diaphragmatic excursion. Others have proposed that the volume reduction procedure enhances ventilation–perfusion matching by eliminating areas of overly compliant, underperfused lung and also increases the effective recoil of the lung.[1,8]

The absence of anatomic and functional guidelines for resection in these patients with marginal pulmonary and physiologic reserve makes this procedure challenging. In our early experience, the tendency to remove too much lung had resulted in significant morbidity with persistent air leaks and space problems. Patients with severe COPD have diffuse centrilobular emphysematous changes, mostly concentrated in the upper lobes with classic COPD, and lower lobes with alpha-1 antitrypsin. We think that it is essential to localize and resect the least functional areas of the diffusely diseased lung to allow the more healthy areas to function effectively. Accurate "target area selection" should allow us to minimize the amount of functioning lung to be resected and maximize the function of the remaining lung.

Several methods have been advocated for target area selection. Contrast-enhanced high-resolution CT scan accurately delineates focal masses, bullous disease, and lobar anatomy. It has not, however, been uniformly helpful in differentiating specific areas of heterogenous versus homogeneous changes. This is an important issue because patients with heterogeneous distribution of disease are more amenable to LVRS than those with diffuse homogeneous disease.[9] Planar ventilation and lung perfusion scans adequately show abnormal segmental areas, but the overlapping radioactive uptake from the contralateral lungs and the two-dimensional anterior–posterior views do not provide accurate spatial representation of the heterogenous disease, thus limiting the surgeon's choice for specific target zones. Conversely, we have found the lung perfusion SPECT scan to be exceedingly useful in the segmental localization of diseased target areas. The images are viewed in the coronal, sagittal, and transverse planes. The reconstructed three-dimensional images also are viewed in the cine and static modes. Figure 3 shows a SPECT scan localization of underperfused areas in the lateral basal segment of the right lower lobe and in the anterior segment of the left upper lobe. The planar perfusion scan and CT scan were not able to provide this specific information, which subsequently guided our selective resection. Lastly, the intraoperative observation of delayed atelectasis has been described by Cooper as a means to determine the most diseased segments of lung with the greatest degree of air trapping.[1] We have found this to be useful on a lobar basis but not helpful in selecting segments within the lobe to be reduced. Based on preoperative analysis of the SPECT scan, even though most of our patients have classic COPD and should mainly have upper lobe involvement, more than 50% of the patients underwent selective resection of lower lobe segments (Table 3).

We have adopted the St. Louis approach by using a median sternotomy and bilateral lung volume reduction to achieve maximum benefit at one operation with a minimum of overall morbidity. This incision optimizes our exposure to all target areas and also allows accurate identification and repair of any air leaks. Other groups have used video-assisted approaches with laser ablation or stapling or both.[10,11] Staged thoracotomy, staged thoracoscopy, and bilateral thoracoscopic approaches also have been presented at recent national meetings with mixed results.[12,13] Our results compare favorably with data from other centers, showing significantly improved pulmonary function, an air leak morbidity of 18%, and a mortality of 3.8%. The Emory University group recently presented its data on bilateral LVRS with 45 patients.[13] There was significant improvement in pulmonary function parameters, but mortality was 11%. The St. Louis group also has updated its results on 46 patients 6 months after LVRS.[9] The FEV_1 improved by 39%. Forty-five percent of the patients had prolonged air leak for more than 7 days and mortality was 3%.

We acknowledge that LVRS is a palliative operation that will continue to evolve as mechanisms for its efficacy are being studied and long-term data are being collected. It is important that the operative risks be kept low to merit the medical resources and patients' efforts that are required to establish this as an acceptable method to relieve dyspnea in patients with emphysema. Our experience indicates that single-stage, bilateral lung volume reduction surgery can predictably improve objective and subjective lung functions in carefully selected end-stage patients with emphysema with a low mortality and moderate morbidity. Careful patient selection, accurate localization of target areas by SPECT scan, meticulous anesthetic and operative technique, and intense postoperative support are essential to achieve respectable results.

Table 3. LOBAR DISTRIBUTION OF SELECTIVE VOLUME RESECTION AS GUIDED BY PREOPERATIVE SINGLE POSITRON EMISSION COMPUTED TOMOGRAPHY SCAN (N = 26)

Right upper lobe	81
Right middle lobe	27
Right lower lobe	58
Left upper lobe (superior division)	69
Lingula	15
Left lower lobe	50

Values are % of total cases.

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