The Evaluation and Preparation of the Patient for Lung Volume Reduction Surgery

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Potential candidates for lung volume reduction surgery should undergo extensive evaluation and preparation to minimize perioperative risks and optimize surgical outcomes. Initial screening includes spirometry, diffusion capacity, lung volumes by body plethysmography, and high-resolution computerized tomography scanning. Patients who have been successfully screened must complete a preoperative pulmonary rehabilitation program of 6–10 weeks duration. During the pulmonary rehabilitation program, medical therapy should be maximized. Postrehabilitation studies include cardiopulmonary exercise testing, arterial blood gas analysis, oxygen titration, six-minute walk, and cardiac testing. The evaluation process aims at defining the severity and distribution of emphysema and attempts to eliminate those who do not meet criteria outlined by the National Emphysema Treatment Trial. Optimal candidates have upper-lobe–predominant emphysema and acceptable operative risks.

Keywords: preoperative evaluation; lung volume reduction surgery; emphysema; pulmonary rehabilitation; chronic obstructive pulmonary disease

Lung volume reduction surgery (LVRS) carries substantial risks for mortality and complications (1, 2). The evaluation process and medical preparation of potential candidates for LVRS can minimize those risks and are critical to any successful LVRS program. The goal is to identify patients most likely to have a favorable response to the surgery and then position them to attain a favorable outcome with the help of a pulmonary rehabilitation program and optimization of medical treatment.

The screening and evaluation process and medical preparation recommended for LVRS candidates are based on the processes used in the National Emphysema Treatment Trial (NETT), modified and informed with results from the NETT (3). The NETT selection criteria and results were used by the Centers for Medicare and Medicaid Services (CMS) when formulating their decision to cover LVRS for selected patients (4).

The NETT selection criteria were designed to select patients with severe bilateral emphysema without comorbidities that would preclude surgery. The NETT retrospectively identified five subgroups of patients with different risks and benefits after LVRS. Two subgroups had higher risk of mortality after LVRS compared with medical treatment and had little chance of benefit from LVRS; patients in these subgroups are not candidates for LVRS (2, 3). Patients in the remaining three subgroups identified by the NETT as benefiting from LVRS have improvement in at least one outcome category (survival, exercise capacity, or quality of life) after LVRS compared with medical treatment and are candidates for LVRS (3).

The decision to proceed with LVRS is based on careful weighing of individual risks and benefits and requires comprehensive discussions between patients, family members, and health care providers. The recommendations that follow are based on experience gained through the NETT trial and are consistent with the criteria CMS adopted for payment of LVRS for their beneficiaries.

SCREENING AND EVALUATION

Criteria for distinguishing good and poor candidates for LVRS are shown in Table 1, and the screening and evaluation procedures are listed in Table 2. This initial screen includes important historical information and basic testing. The screening process can eliminate patients as potential candidates but is only the first step of a possible approval process.

The screening process documents the presence of emphysema on clinical, radiological, and pulmonary function criteria and attempts to eliminate patients who would face unacceptable operative risks. Prior LVRS by laser or excision and previous sternotomy or lobectomy are viewed as exclusion criteria because they could significantly increase the risk for pleural adhesions and postoperative air leak. Extensive adhesions are associated with less improvement after LVRS, and air leak is the major contributor to postoperative morbidity. Medical contraindications include any conditions that increase the perioperative risk or predict a short life expectancy due to nonemphysema illnesses. A history of recurrent bronchial infection with clinically significant daily sputum production and/or clinically significant bronchiectasis are also contraindications. Myocardial infarction within 6 months with an ejection fraction less than 45%, congestive heart failure with an ejection fraction less than 45%, or uncontrolled hypertension (systolic $>$ 200 mm Hg or diastolic $>$ 100 mm Hg) are contraindications for LVRS. The presence of significant pleural or interstitial lung disease may also prevent LVRS. Although severe emphysema may preclude surgical resection of a pulmonary nodule, surgical techniques developed for LVRS have allowed resection of lung nodules previously believed to be unresectable because of respiratory limitations (5, 6). Reactive airway disease is not a contraindication for LVRS; however, the presence of significant airway bronchoreactivity suggests that the primary disease process may be more of an inflammatory airway disease and thus less likely to improve after LVRS.

Active or recent smoking not only increases perioperative risks (7); it also increases the chances for postoperative resumption of smoking. Because smoking leads to more rapid

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TABLE 1. CRITERIA FOR DETERMINATION OF CANDIDACY FOR LUNG VOLUME REDUCTION SURGERY

Criteria	Good Candidates	Poor Candidates
History and physical examination	Age $<$ 75 yr	Age $\geq$ 75 yr
	Emphysema by clinical evaluation	History of recurrent bronchial infections with increased sputum production
	Ex-smoker $>$ 4 mo*	Cardiovascular comorbidities including significant coronary artery disease, recent MI, CHF, or uncontrolled hypertension or arrhythmias
	Clinically stable on no more than 20 mg prednisone daily	Pulmonary hypertension at rest
	Significant functional limitation after 6–12 wk of pulmonary rehabilitation on optimal medical therapy	Nonpulmonary comorbidities causing significant functional limitation (morbid obesity†) or that could limit survival (e.g., cancer)
	Demonstrated compliance with medical regimen	History of thoracic surgery or chest wall deformity that could interfere with pulmonary resection
Laboratory evaluation	Post-bronchodilator $FEV_1 \leq 45\%$ predicted for all ages and $\geq$15% if age $\geq$70 yr	$FEV_1 \leq 20\%$ predicted and either $D_{LCO} \leq 20\%$ predicted or homogeneous distribution of emphysema on HRCT scan
	Hyperinflation demonstrated by TLC $\geq$ 100% predicted and RV $\geq$ 150% predicted	Non–upper-lobe distribution of emphysema with high‡ exercise capacity postrehabilitation (demonstrated by maximal achieved cycle ergometry watts)
	Postrehabilitation 6MWD $>$ 140 m	Significant pleural or interstitial changes on HRCT
	Low‡ postrehabilitation exercise capacity (demonstrated by maximal achieved cycle ergometry watts)	
	HRCT demonstrating bilateral severe emphysema, ideally with upper-lobe predominance	

Definition of abbreviations: CHF = congestive heart failure; D_{LCO} = carbon monoxide diffusing capacity; HRCT = high-resolution computerized tomography; MI = myocardial infarction; RV = residual volume; 6MWD = six-minute-walk distance; TLC = total lung capacity.

* Plasma cotinine level $\leq$ 13.7 ng/ml (or arterial carboxyhemoglobin $\leq$ 2.5% if using nicotine products) is considered evidence that the patient is a nonsmoker.

† Body mass index $>$ 31.1 kg/m^2 (men) or $>$ 32.3 kg/m^2 (women) is considered evidence of morbid obesity.

‡ Low exercise capacity is defined as a postrehabilitation maximal workload at or below the sex-specific 40th percentile (25 W for women and 40 W for men); high exercise capacity is defined as a workload above this threshold.

deterioration in lung function, smoking after LVRS would likely lead to more rapid loss of any functional gains. Candidates for LVRS should be nonsmokers for more than 4 months. The 4-month requirement recognizes that all candidates are required to complete 6–10 weeks of pulmonary rehabilitation and must remain nonsmokers through this period. The combined duration of abstinence is therefore at least 6 months, which is consistent with the findings of smoking cessation research that the rate of recidivism does not stabilize until at least 6 months after cessation (8). Documentation of smoking status with plasma cotinine or arterial carboxyhemoglobin levels may be required.

Elevated body mass index (BMI) can limit lung function and may increase postoperative respiratory complications, so patients should be at or below the upper limit of acceptable BMI before surgery (Table 1). The NETT required a BMI of less than 31.1 kg/m^2 for male patients and less than 32.3 kg/m^2 for female patients.

TABLE 2. COMPONENTS OF SCREENING AND EVALUATION PROCESS FOR CANDIDATES FOR LUNG VOLUME REDUCTION SURGERY

Phase I: Screening
- History, physical examination, chest roentgenogram, and basic laboratory studies
- α_1-Antitrypsin testing
- High-resolution computed tomography scan
- Pulmonary function testing: spirometry (pre- and post-bronchodilator), lung volumes (by body plethysomography), carbon monoxide diffusing capacity

Phase II: Formal evaluation—postrehabilitation
- Dyspnea evaluation: University of California, San Diego, Shortness-of-Breath Questionnaire, or Modified Medical Research Council scale
- Arterial blood gas level on room air for 10 min
- Cardiopulmonary exercise testing
- Oxygen titration and six-minute walk
- BODE* score
- Quantitative perfusion nuclear lung scan
- Cardiac evaluation: echocardiogram, dobutamine-radionuclide cardiac scan
- Evaluation by medical team including pulmonologists, surgeon, nursing, and rehabilitation staff

Definition of abbreviation: BODE = Body-mass index, airflow Obstruction, Dyspnea, and Exercise capacity index.

* Mortality risk based on body mass index, airflow obstruction (FEV_1), dyspnea (using the Modified Medical Research Council dyspnea scale), and exercise capacity (measured by six-minute walk).

The screening process attempts to evaluate severity of functional limitation, severity of airflow limitation, and degree of air trapping. As a gauge of functional limitation the NETT required a postrehabilitation six-minute-walk distance of over 140 m. Investigators believed that patients with more severe limitations would face higher operative risks. Pulmonary function testing, including pre- and post-bronchodilator spirometry, lung volumes measured by body plethysmography, and carbon monoxide diffusing capacity, must meet criteria that define severe airflow obstruction and hyperinflation (Table 1). In the NETT, preoperative values for total lung capacity and residual volume were not predictive of differential outcome by treatment.

NETT investigators found that two types of assessments of the distribution of emphysema as seen on high-resolution computerized tomography (HRCT) were predictive of outcome after LVRS (3). Assessment of the heterogeneity of the emphysema is needed; the NETT found that postrehabilitation, post-bronchodilator $FEV_1 \leq 20\%$ predicted, and nonheterogeneous emphysema on HRCT or $D_{LCO} \leq 20\%$ predicted defines a subgroup at high risk of mortality after LVRS (16% 30-d mortality) with little chance of benefit (2). Assessment of the craniocaudal distribution of emphysema also predicts LVRS outcome when combined with postrehabilitation exercise capacity; patients with non–upper-lobe–predominant emphysema and high exercise capacity postrehabilitation have higher mortality after LVRS than those treated with medical therapy only. Many LVRS centers use quantitative perfusion nuclear lung scans, in addition to HRCT, to help gauge emphysema heterogeneity. However, the NETT failed to show any improvement in predictive value using lung perfusion scans to predict outcome.

The screening evaluation should also check for α_1-antitrypsin deficiency. Although α_1-antitrypsin deficiency is not a contraindication for LVRS, NETT data suggest that patients with this enzyme deficiency, especially patients with basilar predominant emphysema, receive limited benefit from LVRS (9).

If screening suggests that a patient may be a potential surgical candidate, additional testing is required. An oxygen requirement at rest or during ambulation exceeding 6 L/minute to keep oxygen saturation at 90% or greater is considered a contraindication for LVRS. Cardiac evaluation includes an echocardiogram and a dobutamine-radionuclide cardiac scan. If peak systolic pulmonary artery pressures (Ppa) on echocardiogram are estimated to be 45 mm Hg or greater, a right heart catheterization is required to rule out significant pulmonary hypertension. Echocardiograms notoriously overestimate the degree of pulmonary hypertension in patients with advanced lung disease (10). In the NETT, echocardiographic estimates did not accurately reflect actual pulmonary pressures (11). Mean Ppa on right heart catheterization greater than 35 mm Hg or peak systolic Ppa greater than 45 mm Hg were viewed as contraindications for LVRS to avoid the development of postoperative pulmonary hypertension. Evaluation by a cardiologist for LVRS should be obtained if the dobutamine-radionuclide cardiac scan indicates coronary artery disease or ventricular dysfunction, if the left ventricular ejection fraction is less than 45%, or significant arrhythmia or ectopy are detected at the time of evaluation.

The NETT used the University of California, San Diego, Shortness-of-Breath Questionnaire as a gauge for dyspnea (12). Although the NETT did not use this questionnaire for patient selection, improving dyspnea is one of the major goals of LVRS and an important criterion to consider. Other investigators have used the Modified Medical Research Council (MMRC) dyspnea scale (Table 3) to evaluate the level of dyspnea (13). Celli and colleagues have described a multidimensional grading system for chronic obstructive pulmonary disease (COPD) severity (i.e., the BODE [body-mass index, airflow obstruction, dyspnea, and exercise capacity] index) (14). It assesses mortality risk based on body mass index, airflow obstruction (FEV_1), dyspnea (using the Modified Medical Research Council dyspnea scale), and exercise capacity (measured by six-minute walk) and has been found to be better than FEV_1 alone in predicting risk of death. Several recent publications have suggested the potential value of the BODE index or a modification of it in assessing and following patients with LVRS (15, 16).

TABLE 3. MODIFIED MEDICAL RESEARCH COUNCIL DYSPNEA SCALE

Grade I: breathless with strenuous exercise
Grade II: short of breath when hurrying on the level or walking up a slight hill
Grade III: walking slower than people of the same age on the level because of breathlessness or having to stop for breath when walking at own pace on the level
Grade IV: stopping for breath after walking about 100 yards or after a few minutes on the level
Grade V: too breathless to leave the house or breathless when dressing or undressing

MEDICAL PREPARATION OF THE CANDIDATE AND FINAL EVALUATION FOR LVRS

If the evaluation suggests that a patient may be a potential LVRS candidate, the patient must complete a preoperative pulmonary rehabilitation program of 6–10 weeks duration. NETT investigators observed significant improvements in exercise capacity, dyspnea, and health-related quality of life after pulmonary rehabilitation (17). By optimizing preoperative physical and emotional function, pulmonary rehabilitation in the NETT helped select appropriate patients for surgery. Approximately 10% of NETT patients improved sufficiently during the rehabilitation program that they became unwilling to accept surgical risks (17). During rehabilitation, other patients who initially seemed appropriate for surgery were too ill or fragile to undergo the procedure. The pulmonary rehabilitation program should include 16 to 20 sessions, each lasting a minimum of 2 hours and including education and exercise components. The program must be consistent with the care plan developed by the treating physician and arranged, monitored, and performed under the coordination of the center where the surgery takes place.

During the pulmonary rehabilitation program, all efforts should be made to maximize medical therapy. Several guidelines are available, including those from the Global Initiative for Chronic Obstructive Lung Disease and the American Thoracic Society and the European Respiratory Society (18, 19). All available guidelines stress the importance of using and potentially combining bronchodilator therapy, preferably long-acting inhaled bronchodilators. Recent data suggest that combining inhaled tiotropium with inhaled salmeterol/fluticasone can be an effective and well-tolerated regimen for advanced COPD (20). Systemic corticosteroids should be weaned off or decreased to the lowest possible tolerated dosage before surgery. Regular systemic corticosteroid therapy seems to be widely used in advanced COPD even though data suggest its only role is for short-course therapy during exacerbations (21). NETT investigators found that systemic corticosteroid use increased postoperative cardiovascular morbidity (odds ratio, 1.72; $P = 0.04$) (1). Therefore, patients should be clinically stable on 20 mg prednisone (or equivalent) or less daily dosing to be considered for LVRS.

By eliminating patients with significant chronic bronchitic, asthmatic, or bronchiectatic components from LVRS consideration, the incidence of acute exacerbations pre- and postsurgery should be limited. However, the risk of exacerbations among patients with COPD increases with an FEV_1 less than 50% (22), a threshold all potential LVRS candidates must meet. Over 24% of patients in the NETT were hospitalized or seen in an emergency ward for a COPD exacerbation in the year before study enrollment, and 19.2% required hospitalization (23). Any exacerbation during evaluation for LVRS should be treated aggressively, and surgery should be delayed at least 4–6 weeks after resolution of the exacerbation to allow stabilization.

Patients should be educated before surgery regarding the postoperative course, including postoperative pain issues, pain control regimens, the need for early mobilization, and the importance of postoperative rehabilitation. Oxygen requirements can transiently increase after LVRS, and patients must understand that this does not reflect surgical failure.

On completion of pulmonary rehabilitation, the postrehabilitation six-minute-walk distance must be greater than 140 m, and patients must be able to complete 3 minutes of unloaded pedaling in exercise tolerance testing. The NETT defined the importance of preoperative, symptom-limited maximal cardiopulmonary exercise testing in the LVRS decision-making process. Exercise capacity is measured by incremental, maximal, symptom-limited exercise with a cycle ergometer using a 5 or 10 W/minute ramp on 30% oxygen after 3 minutes of unloaded pedaling. The NETT defined patients with low exercise capacity as those whose maximal postrehabilitation exercise capacity is no greater than 25 W for women and no greater than 40 W for men (maximal workload at or below the gender-specific 40th percentile). High exercise capacity was defined as a maximal workload above this threshold. Combining results from HRCT and postrehabilitation cardiopulmonary exercise testing allows categorizing potential candidates into subgroups (Table 4).

Upper-lobe, low-exercise patients treated with LVRS have lower mortality, greater exercise, and greater improvement in symptoms compared with those treated with medical therapy.

TABLE 4. EXPECTED RESPONSE AFTER LUNG VOLUME REDUCTION SURGERY COMPARED WITH MEDICAL THERAPY ALONE FOR VARIOUS SUBGROUPS OF NON–HIGH-RISK PATIENTS* IDENTIFIED BY HIGH-RESOLUTION COMPUTERIZED TOMOGRAPHY AND POSTREHABILITATION EXERCISE CAPACITY

Findings on HRCT and Postrehabilitation Exercise Testing	Expected Outcomes after LVRS Compared with Medical Treatment
Upper-lobe emphysema + low exercise capacity†	Improved quality of life, exercise capacity, and survival
Upper lobe emphysema + high exercise capacity	Improved quality of life and exercise capacity
Non–upper-lobe emphysema + low exercise capacity	Improved quality of life‡
Non–upper-lobe emphysema + high exercise capacity	Increased mortality, similar exercise capacity, improved quality of life only first year after surgery

Definition of abbreviations: HRCT = high-resolution computerized tomography; LVRS = lung volume reduction surgery.

* High-risk patients have $FEV_1 \leqslant 20\%$ predicted and $D_{LCO} \leqslant 20\%$ predicted or nonheterogeneous emphysema on HRCT scan.

† Low exercise capacity is defined as a postrehabilitation maximal workload at or below the sex-specific 40th percentile (25 W for women and 40 W for men); a high exercise capacity is defined as a workload above this threshold.

‡ This benefit usually wanes 3 yr after LVRS (24).

Upper-lobe, high-exercise patients have similar mortality but greater exercise capacity and greater improvement in symptoms compared with those treated medically. Non–upper-lobe, low-exercise patients treated with LVRS have similar mortality to medically treated patients and similar exercise capacity, but those after LVRS are more likely to have fewer symptoms in the first 1–2 years after surgery compared with those treated medically. CMS has approved LVRS for patients in all three of these groups; however, longer-term NETT follow-up has revealed that the quality of life benefit in the non–upper-lobe group wanes by 3 years (24). The NETT also found that the lone predictor for increased operative mortality after LVRS was the presence of non–upper-lobe predominant emphysema. Most LVRS centers have tended to only offer LVRS to patients with upper-lobe–predominant disease.

Even if the patient has successfully completed pulmonary rehabilitation and meets all selection criteria, the final decision regarding LVRS requires discussion among the entire LVRS team, the patient, and family members. If the decision is made to proceed to LVRS, several therapeutic interventions could decrease postoperative morbidity. Discontinuing inhaled corticosteroids perioperatively seems prudent because NETT results revealed that preoperative use of inhaled but not oral corticosteroids increased postoperative air leaks (25). Perioperative stress corticosteroid coverage may be needed for patients on chronic systemic corticosteroids. Considering that the incidence of postoperative cardiac arrhythmias of 23.5% (with 8.6% requiring treatment) approaches that seen after coronary bypass surgery, cardiac monitoring for the initial postoperative period should be considered. The use of prophylactic pharmacologic prevention for perioperative cardiac arrhythmias has yet to be studied in this setting.

CONCLUSIONS

Although the NETT has shown that LVRS provides advantages over medical management for selected patients, LVRS carries significant potential risks and, even with the NETT experience to guide practitioners, there are no guarantees of a successful result. Following a careful evaluation process and maximizing medical status before surgery should help minimize postoperative complications and improve the chances of longer-term benefits.

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