GENERAL THORACIC SURGERY

THORACOSCOPIC LASER BULLECTOMY: A PROSPECTIVE STUDY WITH THREE-MONTH RESULTS

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One hundred forty-one patients were prospectively enrolled in a study of contact-tip laser bullectomy at four institutions. Ninety-one have had both preoperative and postoperative testing at 3 months. Nonsmoking patients with disabling dyspnea at less than 50 yards and with a forced expiratory volume in 1 second of 35% or less were enrolled. Testing included formal pulmonary function tests, arterial blood gasses, computed tomographic scans, ventilation/perfusion scans, echocardiograms, electrocardiograms, 6-minute walk testing, transdiaphragmatic pressures, and quality of life and dyspnea index questionnaires. A modest 16% improvement was noted in forced expiratory volume in 1 second (0.69 to 0.80 L), and there was a 29% improvement in 6-minute walk distances (655.2 to 846.3 feet). Oxygen use was completely discontinued in 16%. Risk factors for mortality included age, 6-minute walk distances, low diffusing capacity for carbon monoxide, high carbon dioxide tension, and high base excess. Minor improvement was judged from the dyspnea index and the Medical Outcome Study Short Form-36. Preoperative predictors of good outcome included heterogeneous disease, lack of carbon dioxide retention, and no emaciation (weight <40 kg). Comparison of our results with those in the literature suggests that the improvement seen with the contact neodymium:yttrium-aluminum-garnet laser is not as good as that provided by the stapled techniques for volume reduction. (*J Thorac Cardiovasc Surg* 1996;112:319-27)

The American Lung Association estimates that more than 2 million people in the United States had emphysema in 1993 and more than 20,000 deaths were directly attributed to the disorder.¹ Excluding the rare patient with giant bullous emphysema, most patients have been treated nonsurgically in the past. Surgery has been described for patients

with diffuse bullous emphysema, but these efforts have been hampered either by high rates of complications or by the inability to adequately quantitate results.²⁻⁹ In 1991, Wakabayashi and associates¹⁰ began to report success using laser bullectomy for this group of patients with diffuse bullous emphysema. Although their initial results were met with resistance, ultimately a demand was created by this patient population and interest in the thoracic surgical community.

We began our multiinstitutional study in an effort to validate or refute the benefit of this surgical technique and to try to better define the patient population most appropriate for surgical intervention.

Patients and methods

Study methods. One hundred forty-one patients were prospectively enrolled in a study of laser bullectomy at four institutions between October 1993 and September 1994. All patients had a forced expiratory volume in 1 second (FEV₁) of 35% or less and disabling dyspnea at less than 50 yards with maximal medical therapy. Maximal

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Fig. 1. Pedunculated bulla that would be ideal for stapled excision.

Fig. 2. Contact probe for Nd:YAG laser (Surgical Laser Technology, Valley Forge, Pa.) applied to surface of lung.

medical therapy implied the use of metered-dose inhalers, oxygen, and steroids, and all patients were evaluated by a pulmonary medical specialist to ensure that no other medical adjustments were appropriate. Study protocols were approved by the institutional review boards and informed consent was obtained from each patient. Exclusion criteria included ventilator dependency, active malignancy, lack of maximal medical therapy, active infection, morbid obesity (>1.5 times ideal body weight), and pulmonary hypertension (pulmonary artery systolic pressure >60 mm Hg estimated by echocardiography). Pulmonary artery pressures greater than 60 mm Hg were selected to define significant pulmonary hypertension; this was a value arbitrarily selected. All patients underwent preoperative screening, which included formal pulmonary function testing with nitrogen washout, arterial blood gases, computed tomographic (CT) scans with measurement of diaphragmatic heights, ventilation/perfusion scans, echocardiograms and electrocardiograms, 6-minute walk testing, and quality of life and dyspnea questionnaire, in addition to a thorough history and physical examination. All testing was repeated 3 months after laser bullectomy.

Emphysema was due to tobacco abuse in all but two patients (with α_1 -antitrypsin deficiency). Patients with localized bulla filling more than one third of the hemithorax were excluded from this study because they would represent a standard indication for surgical therapy. Statistical analysis was performed with paired *t* tests and multivariate logistic regression analysis.

Surgical technique. Laser bullectomy was performed thoracoscopically with the use of three or four access ports for most cases as previously reported.^{11, 12} Single lung ventilation was achieved with a double-lumen endotracheal tube. The side chosen for bullectomy was determined by the CT scan and the ventilation/perfusion scan. Unless the patient had prior trauma or surgery, the side with the most severe bullous disease on CT scan and worse air trapping on the delayed 5-minute ventilation scan was selected. When no dominant side was found the right side was chosen. After standard techniques were used for access ports, the 10 mm rigid thoracoscope was introduced. Although the exact location of the trocar sites

was dependent on individual findings, in general the thoracoscope was placed low in the chest. Any bullae that were pedunculated were excised by means of the endoscopic stapler (Auto Suture Company Division, United States Surgical Corporation, Norwalk, Conn.) (Fig. 1). With a grasping forceps to manipulate the lung, the neodymium:yttrium-aluminum-garnet (Nd:YAG) laser with a contact probe (Surgical Laser Technology, Valley Forge, Pa.) was applied to the surface of the lung (Fig. 2). Low-power settings (5 to 10 watts) were used and care was taken to keep the lung moist to prevent adherence of the laser probe to the lung with subsequent tearing.

By changing the access sites and manipulating the lung, we "painted" the majority of the surface of the lung with the laser. Bullous tissue readily contracted, effectively shrinking the size of the lung. After completion of the laser treatment a pleurodesis was generally performed either mechanically by abrasion or by the instillation of talc. One or two chest tubes were positioned through the trocar sites and the lung was reexpanded. An attempt was made to look for areas of significant air leak.

The majority of patients were extubated in the operating room or soon thereafter in the intensive care unit. Pain management was geared to control pain without sedation or respiratory depression. Often hypercarbia was seen in the early postoperative period. This was not treated so long as oxygenation was adequate and the patient was alert and breathing comfortably.

Results

One hundred forty-one patients with a mean age of 64.7 ± 7.9 years (40 to 78 years) met the study criteria and 91 patients had complete 3-month follow-up data. Before the operation, oxygen was used in 75% ($n = 106$) and steroids in 42% ($n = 59$). There were no steroid dosages that excluded patients from the study and the range of steroid use was 5 to 40 mg/day. Preoperatively, 50% of patients were limited physically and required a wheelchair if

Fig. 3. Scatter diagram of transthoracic diaphragmatic pressures (Pdi). Regression analysis.

they left home. Results were similar from all participating institutions. For the patients who had a stapled resection of a localized pedunculated bulla, there was no difference in results as compared with the majority of patients who had only laser bullectomy.

Overall median hospital stay was 12.0 days (4 to 193 days), and median stay in the intensive care unit was 1.0 day (up to 70 days). Median duration of chest tube drainage was 9.0 days (1 to 53 days).

Many tests were performed before the operation, with results again obtained in 3 months. Data on these tests are included in the following paragraphs.

CT scans. In addition to the anatomic information provided by CT scans, distances from the apex of the chest to the diaphragm were measured. This measurement was believed to be one method of quantitating thoracic volume. There were 55 patients in whom both preoperative and postoperative volume measurements were obtained. The distance did decrease on inspiration on the operated side (right side, 26.4 cm preoperatively, 23.1 cm postoperatively; left side, 25.0 cm preoperatively, 22.6 cm postoperatively).

Expiratory height decreased significantly ($p < 0.0001$), suggesting volume reduction of the hemithorax had occurred. The mean preoperative height was 25 cm on the right and 23.6 cm on the left, and

Fig. 4. Five-minute washout of ventilation/perfusion scan demonstrating a large degree of air trapping.

at 3 months it had decreased to 22.3 cm on the right and 21.6 cm on the left ($p < 0.0001$).

Pulmonary function tests. Exhaustive pulmonary function tests were performed, with results listed in Table I. The total lung capacity and residual volume were measured by plethysmography. Improvements in FEV₁, although modest, did reach statistical significance, as did decreases in residual volumes. There was a tendency toward lower arterial carbon dioxide tension and increased arterial oxygen tension at 3 months, but these changes were not significant.

Transthoracic diaphragmatic pressures. This pressure proved to be difficult to obtain both before and after the operation because of the inability to pass the catheter or because of poor patient compliance. Only 13 patients had preoperative and 3-month pressure measurements. The mean difference between esophageal and gastric pressures went from a mean preoperative value of 50.87 to 67.24 cm H₂O after the operation ($p < 0.07$). Nine patients had significant improvement in transdiaphragmatic pressures, suggesting improved function. One patient had no change and three had worse transdiaphragmatic pressures (Fig. 3).

Six-minute walk. The mean preoperative 6-minute walk times and distance were 4.5 minutes and 655.2 feet. Three-month testing revealed increases to 5.12 minutes ($p = 0.0017$) and 846.3 feet ($p < 0.0001$).

Ventilation/perfusion scan. Xenon trapping at 5 minutes on the operated side was measured and

Table I. Pulmonary function tests

	Time of test		<i>p</i> Value
	Preop.	3 mo	
FVC	2.29 ± 0.78 (61.5%)	2.61 ± 0.81 (71.1%)	<0.0001
FEV ₁	0.69 ± 0.21 (24.6%)	0.80 ± 0.30 (29.2%)	<0.0001
FEV _{25/75}	0.21 ± 0.07 (7.1%)	0.26 ± 0.17 (9.3%)	0.0004
MVV	26.8 ± 9.1 (27.4%)	31.1 ± 12.1 (23.6%)	<0.0001
TLC	8.25 ± 1.77 (137.5%)	7.71 ± 1.5 (131.8%)	<0.0001
RV	5.72 ± 1.4 (256%)	4.93 ± 1.21 (224%)	<0.0001
FRC PL	6.66 ± 1.5 (188%)	6.05 ± 1.3 (171%)	<0.0001
DLCO	8.12 ± 3.5 (39.5%)	8.56 ± 3.6 (41.9%)	0.0571
DLCO/VA	2.38 ± 0.99 (63.4%)	2.51 ± 2.03 (61.3%)	0.6030
FRC N ₂	4.56 ± 1.1	4.52 ± 1.64	0.6479
PaCO ₂	42.0 ± 6.77 mm Hg	41.1 ± 6.4 mm Hg	0.1171
PaO ₂	64.6 ± 11.2 mm Hg	66.6 ± 18.5 mm Hg	0.1911

FVC, Forced vital capacity; FEV₁, forced expiratory volume in 1 second; FEV_{25/75}, forced expiratory volume 25%/75%; MVV, maximal ventilatory volume; TLC, total lung capacity; RV, residual volume; FRC PL, FRC obtained by plethysmography; DLCO, diffusing capacity for carbon monoxide; DLCO/VA, diffusing capacity for carbon monoxide by alveolar volume; FRC N₂, FRC obtained by nitrogen washout; PaCO₂, arterial carbon dioxide tension; PaO₂, arterial oxygen tension. Figures in parentheses are percent predicted.

demonstrated a decrease from 50.2% to 43.5% ($p = 0.02$). In general the 5-minute washout data along with the perfusion scan were used to select the side of the surgical procedure. Perfusion scans also proved to be significant predictors for improvement in FEV₁ (Fig. 4). Those with localized decreased perfusion of the upper lobe (<25% of unilateral perfusion to upper one third) and more pronounced air trapping had the most improvement.

Oxygen, prednisone requirement, and functional state. Seventy-five percent ($n = 106$) of patients were receiving oxygen before the operation. Overall 16% ($n = 17$) of these patients were able to discontinue supplemental oxygen completely and 21% ($n = 22$) were able to reduce their oxygen needs, whereas 63% ($n = 67$) did not show improvement.

Steroid dependency did not change significantly, going from 42% before the operation to 41% after the operation. Although 50% required a wheelchair before the operation for minimal activity, 26% reported needing a wheelchair 3 months after the operation.

Dyspnea and quality of life assessment. The dyspnea index data are demonstrated in Table II.¹³ For functional improvement, magnitude of task, and magnitude of effort, all demonstrated that more than 70% of patients showed improvement. This amount of change indicated minor improvement, for example, ability to return to work at a reduced pace or resumption of some activities with more vigor than previously because of improvement in shortness of breath.

The medical outcomes study 36-item short form health survey (MOS-36) demonstrated that 80% believed their breathing was improved since the operation.^{14, 15}

Complications. Prolonged air leak (>5 days) was the most frequent complication seen in 85 patients (55%). Thirty-five of those with leaks for more than 5 days had a leak that persisted longer than 2 weeks (23%). Gastrointestinal problems such as ileus were frequently seen and one patient had a cecal perforation. Pneumonia developed in four (28%) and conversion to thoracotomy, usually for large air leaks, occurred in five (3.4%). Two patients had cardiac arrhythmias (1.4%) and nine patients (5%) required a tracheostomy for prolonged ventilatory support.

There were eight (5.7%) hospital deaths (death within 30 days or >30 days and during surgical admission), and five (3.5%) late deaths were noted. Hospital mortality was due to pneumonia and respiratory failure in five, sepsis in two, and ventricular arrhythmia in one. Late deaths were due to unknown cause ($n = 2$), carcinoma ($n = 2$), and progressive respiratory failure ($n = 1$). One patient was identified with mesothelioma at thoracoscopy and died after discharge. One patient had a history of colon cancer, and although a preoperative workup including a bone scan showed no abnormalities, he died with multiple bone metastases and spinal cord compression 2 months after the operation.

Predictors of mortality. Several factors were evaluated as predictors of mortality, including oxy-

Table II. *Laser bullectomy*

	Dyspnea index (n = 58)		
	Worse	No change	Better
Functional impairment	10 (17%)	6 (10%)	42 (72%)
Magnitude of task	8 (14%)	9 (16%)	41 (71%)
Magnitude of effort	8 (14%)	6 (10%)	44 (76%)

gen use, steroid use, age, walk time and distance, forced vital capacity, FEV₁, FEV_{25/75}, maximal ventilatory volume, total lung capacity, residual volume, functional residual capacity, diffusing capacity for carbon monoxide (DLCO), oxygen tension, and carbon dioxide tension. The 6-minute walk distance, DLCO, carbon dioxide tension, base excess, and age all proved to be statistically significant predictors of mortality by multivariate logistic regression analysis (Table III).

Predictors of good results. Defining a good result in these patients is often difficult. For the purpose of this study, we defined an improvement in FEV₁ of greater than 200 ml as a success. This is the definition of success for treatment of persons with asthma adopted by the American Thoracic Society. According to this definition, there were only 24 patients (19%) for whom success was achieved. In evaluating all factors for predictors of success, we found base excess, localized decreased perfusion (<25% perfusion of ipsilateral perfusion to upper one third), and weight to be predictors. Base excess in those with improvement was 1.02 versus 3.6 in those without improvement of FEV₁ ($p = 0.01$). Perfusion scans that demonstrated localized decreased perfusion (<25% of unilateral perfusion) in the upper lobe predicted better results than those with diffuse disease and evenly distributed perfusion. Very low preoperative weights (<40 kg) were associated with worse outcomes with respect to FEV₁.

Discussion

Preliminary reports of success with laser bullectomy by Wakabayashi and associates^{10, 16} served as a stimulus for the multiinstitutional prospective study. Exhaustive preoperative and postoperative testing were performed in an effort to quantify improvement and better select groups of patients who may benefit.

The technique of using the contact-tip Nd:YAG laser was selected because this was the method that was reported as providing the most benefit when this

Table III. *Predictors of mortality*

	Mortality group	Non-mortality group	p Value
Six-minute walk (feet)	356	714	<0.0001
DLCO (% predicted)	26.5%	38.1%	<0.029
PCO ₂ (mm Hg)	48.2	42.5	<0.003
Base excess	7.7	2.9	<0.0006
Age (yr)	68.2	63.8	<0.04

trial was begun.¹⁶ Other methods have been used for bullectomy, including carbon dioxide laser, free-beam Nd:YAG laser, and the argon beam coagulator. Although these energy forms attempt to produce similar effects on the bullous lung tissue, our study cannot be directly compared.

Laser bullectomy was reported in 1991 by Dr. Wakabayashi using the carbon dioxide laser in 22 patients. Only 11 patients had postoperative testing. Benefit was shown in FEV₁ as mean values improved by 43% (0.74 to 1.06 L) and maximal exercise treadmill times also improved (5.4 to 8.0 minutes). There were two deaths (9.1%), one patient required a second thoracoscopy, and three required a thoracotomy. Air leaks were prevalent and the mean duration of chest tube drainage was 13 days.¹⁰

A subsequent report at the American College of Surgeons in 1993 reported on 262 patients treated with the contact-tip Nd:YAG laser, with all but three treated for dyspnea and diffuse bullous emphysema. The mortality rate was reduced to 4.7% and average duration of air leak to 10 days.¹⁷

Data presented at The American Association for Thoracic Surgery in April 1993 by Dr. Wakabayashi demonstrated some objective improvement. Postoperative values were available in 83 patients (out of 283), and the FEV₁ improved from a mean preoperative value of 24.6% of predicted to 32.9% of predicted. Surprisingly the total lung capacity and residual volume did not change very much to suggest volume reduction. Oxygen requirements were decreased, with more than one half of the patients discontinuing oxygen use. Only seven patients needed a wheelchair after the operation compared with 49 before the operation. No exercise testing was reported.¹⁶

Overall our results in terms of pulmonary function testing were not as good as these reports. Although we had statistically significant improvements in forced vital capacity, FEV₁, and maximal ventilatory volume, these changes were of less magnitude. The FEV₁ improved from 24.6% of pre-

dicted to 29.2%. We did, however, see more change in residual volume, suggesting some volume reduction. Similarly, despite very modest improvement in direct pulmonary function data, we were able to wean 16% of the patients completely off oxygen, and functional exercise capacity improved in most patients as evidenced by the 6-minute walk results.

The mechanisms of improvement in patients with diffuse bullous emphysema may be by improved respiratory muscle positioning (i.e., diaphragm) owing to volume reduction, there may be decreased airway resistance owing to decreased intrathoracic pressure, and decreased compression of surrounding lung tissue or increased elastic recoil may play some role. A report from Brenner and associates¹⁸ on carbon dioxide laser bullectomy suggested that more compression predicted better outcome with respect to FEV₁ and improvement was due to the decreased volume of the hemithorax and decreased airway resistance. Our results would support these mechanisms because there was a decrease in volume as measured by residual volumes and the diaphragm was higher at expiration as measured by CT scan. Our patients also demonstrated less air trapping (ventilation/perfusion scan, nitrogen washout,) and improved elastic recoil (functional residual capacity).

The 6-minute walk data demonstrated a statistically significant improvement of 29%. This must be evaluated carefully considering that there was not a rigorous preoperative pulmonary rehabilitation program and improvements in this range have been seen with pulmonary rehabilitation alone.¹⁹ Although pulmonary rehabilitation can improve endurance, it has typically not resulted in improvement in pulmonary function tests such as the FEV₁.

Dyspnea is a very subjective symptom, which we tried to quantitate with the dyspnea index and the MOS SF-36 questionnaire. The dyspnea index demonstrated that more than 70% had less dyspnea since the surgical procedure, however this was graded as a minor improvement. Similarly, the MOS SF-36 questionnaire supported subjective improvement, with 80% of patients indicating their health had improved since the operation.

We attempted to identify preoperative factors that suggested increased risk of surgery. DLCO, age, 6-minute walk, carbon dioxide tension and base excess were the only predictive tests seen using multivariate logistic regression analysis. Brenner and associates¹⁸ also suggested that DLCO was predictive of increased risk and this also has been

shown to be important when other pulmonary resections are evaluated.^{17, 20-22} The 6-minute walk is a good test of the physiologic state of the patient. The better the patient's ability to perform this test, the less likelihood of mortality with the procedure. Both carbon dioxide tension and base excess measure the same parameters. Excessive carbon dioxide retention is associated in our study with mortality. Given our present information, we would recommend that patients with DLCO less than 30%, a carbon dioxide tension greater than 50 mm Hg, or a 6-minute walk distance under 350 feet be considered at high risk. We presently would not offer surgical therapy to these patients but encourage pulmonary rehabilitation.

Defining a successful outcome is difficult in this group of patients. Many had satisfactory outcomes when the dyspnea questionnaires are considered; however, their improvements in other parameters were not as significant. We chose to select an improvement of greater than 200 ml in FEV₁ as a success. Using this criterion, we were able to find several factors that would preoperatively predict a satisfactory outcome. The best predictor has been localized or heterogeneous disease as evidenced by the ventilation and perfusion scans. Decreased perfusion at the apex (excludes the patients with α_1 -antitrypsin deficiency) predicted a good result, as did air trapping on the delayed (5-minute) ventilation scan. Those patients with diffuse disease as evidenced by even distribution of perfusion and air trapping did not demonstrate as much improvement. Elevated base excess also predicted a worse outcome with respect to improvement in FEV₁ and appears to be related to a higher operative mortality and lower chance of obtaining significant improvement, although the precise mechanism is unclear. Severe preoperative emaciation (weight <40 kg) likewise was associated with worse results. These factors may simply identify patients at the extreme end of emphysema, too far along in their disease process to benefit from any surgical intervention.

Given the constellation of variables that predict improvement in FEV₁ and the factors that predict mortality, we can begin to develop a picture of who might be considered an ideal candidate for surgical intervention. Heterogeneous disease in those patients with better endurance characteristics (6-minute walk >350 feet, weight >40 kg, and carbon dioxide tension <50 mm Hg) would appear to be preferred.

Since the institution of this study there has been

interest in performing volume reduction using stapled techniques. Cooper and coworkers¹⁹ reported on 20 patients undergoing sternotomy and bilateral volume reduction. Improvements in pulmonary function and reduction in residual volume were greater than were achieved in our study even when taking into consideration bilateral versus unilateral procedures. Cooper's group demonstrated a mean improvement in FEV₁ of 82% in this study. Even recently reported results using a unilateral thoracoscopic approach with stapled resection by Keenan and colleagues²³ achieved better improvement in FEV₁ than our results with a mean improvement of 27%. This information suggests to us that volume reduction may be more effectively achieved using stapled techniques.

Conclusion

Laser bullectomy demonstrated some benefit with statistically significant improvement in pulmonary function tests, reduced lung volumes, better diaphragmatic mobility, reduced air trapping, reduced oxygen requirements, and improved exercise ability. Although statistical significance was reached, we would consider this improvement to be modest and suggest that pulmonary rehabilitation in addition to this procedure are responsible.

The mechanisms for improvement would appear to be related to improved function of the diaphragm resulting from its more optimal position owing to volume reduction, improved elastic recoil, and reduced airway resistance and air trapping.

The morbidity and mortality for this procedure are significant and hence careful selection criteria should exist. Given our data we suggest that patients with limited exercise ability, carbon dioxide tension retention, and severely reduced DLCO are at too great a risk to be routinely offered this procedure. Comparative data would suggest that the stapled techniques are superior to the contact-tip Nd:YAG laser lung reduction.

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Discussion

Dr. Paul F. Waters (*Los Angeles, Calif.*). We owe the authors a great debt in providing some hard data on a procedure that many of us have suspected for quite some time is not particularly successful in the treatment of these patients. At our center we have done the volume reduction procedure as popularized by Dr. Cooper and his group, which I think is probably one of the fastest growing procedures in this country. I believe that in a group of patients who are carefully selected, as Cooper and associates propose, the results can be duplicated. The St. Louis group has published some data suggesting the doubling of the FEV₁ in the first 6 months after the procedure. The group of patients who present themselves for some kind of emphysema operation are typically very ill, very desperate patients who will accept almost any procedure that you offer them. We as physicians and surgeons who are doing these procedures owe them at least the honesty to tell them what procedure is likely to give them a good result. This paper demonstrates that contact laser bullectomy does not produce good results in these desperately ill patients. The price that is paid for those bad results is a mortality rate close to 10% plus some very serious complications, as Dr. Hazelrigg has honestly reported.

I have a couple of questions, Dr. Hazelrigg. One of them concerns pulmonary rehabilitation. In the patients who have undergone lung transplantation, whom we see regularly and subject to pulmonary rehabilitation, we often see a significant improvement in exercise ability, particularly the 6-minute walk test, and some of the pulmonary function tests. It has been suggested by some groups that perhaps the results of this kind of operation, including the open volume reduction operation, are attributable to pulmonary rehabilitation. Dr. Cooper's group has shown that additional benefit is provided by the operation over and above the benefits of rehabilitation. Were your patients offered pulmonary rehabilitation and were the results good? Do you have that information?

Dr. Hazelrigg. We believe strongly that pulmonary rehabilitation is an important component. Unfortunately, it was not a rigid and rigorous part of our preoperative evaluation in this group. Patients were not required to be in a pulmonary rehabilitation program. Some of that was just logistical, in that more than 75% of the patients in our study came from outside a 150-mile radius of our center. This made it difficult although not impossible to rigorously have them all in pulmonary rehabilitation programs. Approximately a third of the patients were reportedly in pulmonary rehabilitation programs, although the majority of those were programs we are not familiar with in the sense that we had any hands-on experience with these programs. Many people, including Dr. Cooper, have shown improvements in the same range of what we saw with this technique simply by the institution of a formal rigorous pulmonary rehabilitation program. We believe rehabilitation is important, and I am certain it played some role in the improvement that we saw in this group of

patients. At present our belief is that patients who are at higher risk because of low walk distances or because of lower DLCOs should be enrolled preoperatively in pulmonary rehabilitation programs. This is not as necessary for those who are in better condition initially.

Dr. Waters. Dr. Hazelrigg, the volume reduction results have suggested that the results are ongoing; in other words, at 3 months compared with 6 months there is continued improvement up to the 6-month mark, where it seems to level off. I know that the follow-up in this group of patients has been 3 months, but there must be some patients in whom it is longer. Have you noticed any improvement beyond the 3-month mark?

Dr. Hazelrigg. There has been a wide spectrum, but overall I would say that whatever improvement has been gained by 3 months has remained stable, although there are a few exceptions to that. We have also noticed some deterioration after 1 year, but we do not have enough patients yet for me to make a strong comment on that.

Dr. Waters. You stopped accruing patients. Does anybody in this group of surgeons still perform the procedure? If so, what are the indications for laser bullectomy using this technique?

Dr. Hazelrigg. I do not believe any of the surgeons that participated in this study are using the laser actively, certainly not as the primary modality. Some may be using it in addition to stapled volume resection for some areas. We have actually moved on to using a unilateral approach endoscopically with the stapling device to compare directly to this group.

Dr. John Eugene (*Torrance, Calif.*). Laser bullectomy began at The University of California, Irvine, with Dr. Wakabayashi. There was a lull in the project from 1991 to about 1993, and then we began again by performing laser reduction pneumonoplasty as a modification of his original operation. This operation is performed using free-beam KTB or Nd:YAG laser radiation for the plication or for the contracture of diffuse emphysema. It is coupled with resection of areas of discrete emphysema and resection of frank bullous disease. Using this approach, we have operated on more than 200 lungs. The improvement in FEV₁ approaches 40% for unilateral operations and 80% for bilateral operations. Prior work from our laboratory has shown that the use of the contact-tip or artificial sapphire crystal probe on the tip of a laser fiber causes pulling and tearing and actual injury to tissue. Probes transmit mostly heat, whereas free-beam laser radiation transmits pure laser light to accomplish the reduction. I do not know why you chose to use the contact technique, but I am certain that if you were to change to the free-beam technique your results would be much better. Dr. Little and his group recently reported on a substantial improvement by using free-beam laser radiation alone without any associated resection on their group of 55 patients presented at the American Surgical Association.

Dr. Hazelrigg. I congratulate you on your results. I really cannot comment because we used the contact mode. We selected that type because when we started this study back in late 1993 that was the most prevalent and most touted method. In fact, I think it was the method that Dr. Wakabayashi himself was using at that time, so that we were attempting to study the group with what we thought

at that time was the best method. Since accruing this information we have had others tell us the same thing, that the free beam is better. I have no data on which to base an opinion. Again, I congratulate you on your results. You may well be right.

Dr. Walter B. Cannon (*Palo Alto, Calif.*). In this time of managed care, are managed care organizations and other insurance companies willing to pay for this procedure, which is something that they may consider experimental surgery? Second, do you do anything with the pleura, such as putting talcum powder or anything else on the pleura to make the lungs stick, to improve some of the air leak problems in the postoperative period?

Dr. Hazelrigg. At least thus far the vast majority of payers have paid for this procedure.

We started out not doing much in the way of pleural procedures. We had some patients who returned with pneumothorax 1 to 3 weeks after the procedure, and after that we started to use pleural procedures, such that almost 80% of this group of patients had some sort of a pleural procedure. The only ones on whom we would not perform a pleural abrasion were those that we thought were young enough and potentially candidates for lung transplantation at a later date. Some had talc instilled. The majority had pleural scarification or abrasion.

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