Thoracoscopic laser ablation of pulmonary bullae

Radiographic selection and treatment response

The purpose of this study was to develop objective preoperative selection methods for predicting outcome in patients undergoing thoracoscopic laser ablation of emphysematous pulmonary bullae. Initial radiographic presentation was correlated with physiologic function both before and after the operation in 24 patients entered into a prospective clinical protocol for evaluation of carbon dioxide laser treatment of emphysematous pulmonary bullae. Nineteen surviving patients underwent follow-up evaluation 1 to 3 months after the operation. Pulmonary function test results showed improvements in spirometry (forced vital capacity increased 0.82 ± 0.125 L, forced expiratory volume in 1 second increased 0.36 ± 0.07 L, and maximum voluntary ventilation increased 11.69 ± 2.6 L/m; $p < 0.002$); airway resistance decreased by 0.9 ± 0.35 cm of water/L per second, and specific conductance increased 0.019 ± 0.006 L/cm H₂O per second ($p < 0.02$). Lung volumes improved (residual volume decreased 1.25 ± 0.23 L, $p < 0.001$) without significant change in resting gas exchange. Quantitative radiographic grading of extent of preoperative pulmonary bullae correlated well with response to laser treatment in patients with preoperative and postoperative studies. Patients with large bullae accompanied by crowding of adjacent lung structures, upper lobe predominance, and minimal underlying emphysema had greatest improvement in pulmonary function results with laser bullae ablation ($p < 0.05$). However, some patients with multiple smaller bullae and diffuse emphysema also demonstrated objective improvement after operation. Quantitative radiographic analysis of the extent of bullous disease and the degree of associated emphysema can be used to determine short-term postoperative pulmonary response and may be useful in selecting future thoracoscopic laser bullae ablation candidates. Additional follow-up will be necessary to further improve selection criteria and help define the long-term role of thoracoscopic laser treatment of bullous emphysema. (J THORAC CARDIOVASC SURG 1994;107:883-90)

Matthew Brenner, MD, Raouf A. Kayaleh, MD, Eric N. Milne, MD, Louise Della Bella, RN, Kathryn Osann, PhD, Yona Tadir, MD, Michael W. Berns, PhD, and Archie F. Wilson, MD, PhD, Irvine, Calif.

From the Department of Medicine, the Pulmonary and Critical Care Division, and the Radiology Department at the University of California at Irvine Medical Center, Orange, Calif., and the Beckman Laser Institute and Medical Clinic, Irvine, Calif.

Supported by National Institutes of Health grant No. RR 01192, Department of Energy grant No. DOE/FE-03-91-ER 61227, and Department of Navy grant No. ONR-N00014-91-0134.

Address for reprints: Matthew Brenner, MD, Assistant Professor of Medicine, Pulmonary and Critical Care Medicine Division, University of California Irvine Medical Center, 101 City Drive South, Orange, CA 92668.

Received for publication June 1, 1993.

Accepted for publication July 27, 1993.

Copyright © 1994 by Mosby-Year Book, Inc.

00022-5223/94 \$3.00 + 0 12/1/50770

Surgical bullectomy is used to treat patients with rare massive isolated pulmonary bullae associated with compression or crowding of adjacent lung structures and minimal underlying emphysema.^{1, 2} Improvement in lung function after surgical bullectomy is thought, in most cases, to result from decompression of lung structures surrounding enlarged bullae.^{1, 3-5} More common cases of multiple ill-defined pulmonary bullae and diffuse emphysema respond poorly to treatment, and, generally, these patients are not considered candidates for surgical bullectomy.²⁻⁹

We recently reported a new technique of thoracoscopic carbon dioxide laser ablation of pulmonary bullae that appears to be effective treatment for some patients with multiple bullae and underlying emphysema.¹⁰ Selection

Fig. 1. Example of a preoperative CT scanning and chest radiography grading method for patients with bullous emphysema. *Left side:* upright chest radiograph from a patient with diffuse emphysema and poorly demarcated bullae. *Black lines* show the four quadrants in which the chest radiographs are graded: right upper, right lower, left upper, and left lower quadrants in the frontal view. *White dashed lines* represent the levels at which the three transverse CT scans are obtained. Chest radiographs were graded by quadrant as follows: right upper = 4, right lower = 2.8, left upper = 4, left lower = 2.7. *Right side:* upper lung, midlung, and lower lung CT scan sections from the same patient. Each CT scan section was graded separately for left and right hemithorax. CT scans were graded by quadrant as follows: right upper = 4, right middle = 4, right lower = 3.7, left upper = 4, left middle = 4, left lower = 2.5.

criteria must be defined for patients undergoing this procedure. This study analyzes radiographic and pulmonary functional characteristics of patients undergoing thorascopic laser bullae ablation to identify characteristics associated with optimal response. Preoperative chest radiography and computed axial tomography (CT) were quantitatively graded for extent of bullous changes and degree of emphysema in underlying lung tissue. Relationships between preoperative status and postoperative pulmonary response were analyzed.

This study demonstrates that short-term objective response to laser bullae ablation can be determined relatively accurately according to preoperative pulmonary radiographic status in patients.

Patients and methods

The protocol for this study was approved by the local Institutional Review Board. Informed consent was obtained from all patients before inclusion in the study.

Radiographic analysis. Chest radiographs and CT scans were interpreted by a chest radiologist (E. N. M.) blinded to

clinical information. CT scans and chest radiographs were graded for degree of emphysema and bullous changes with the use of previously published criteria.^{11, 12}

Chest radiographs. Chest radiographs were graded separately in four quadrants (right upper, right lower, left upper, left lower; Fig. 1) with the use of previously published criteria. The degree of tissue breakdown was graded on a scale of 0 to 4 as follows^{11, 12}:

Grade 0: normal. Vessels slightly sinuous in all lung areas. Normal flow distribution. Margins easy to see but not excessively sharp on lobar vessels. Lung background between vessels gray rather than black, with a faint pattern of poorly defined small vessels. Normal acute branching angles.

Grade 1: mild. Early loss of sinuosity of vessels and unusually well-defined vessel margins (seen down to segmental vessels). Background arteriolar pattern less evident, and lung parenchymal lucency increased, giving black rather than gray background. Normal lung volume.

Grade 2: moderate. Definite attenuation of pulmonary vessels. Marked increase in sharpness of vessel margins down to subsegmental vessels. Definite pruning with loss of vessel branches. Lucent black background with very little arteriolar pattern remaining. Increasing lung volumes,

occasional bullae. Heart size usually below normal. Diaphragm may lose curvature.

Grade 3: severe. Extremely attenuated, sharply defined, narrowed vessels with gross loss of background vascular making causing featureless black lung, bullae, and often complete loss of peripheral lung vessels. If destruction is principally in the upper lobes, as often occurs, diaphragm may not be flattened. Heart usually very small. Soft tissues cachectic. Narrow vascular pedicle.

Grade 4: gross. Almost complete replacement of normal vessels by black featureless lung. Bullae. Few remaining vessels in emphysematous areas are very slender and attenuated.

Quantitative grading of CT scans. Chest CT scans were graded at three levels in the thorax: midtrachea above the aortic arch, midlung, and above the diaphragm (Fig. 1). The degree of emphysematous lung changes in each lung field was graded separately on a scale of 0 to 4 at each level for left and right hemithoraces^{11,12}.

Grade N: normal. Vessels well defined down to lobular level, slightly sinuous; not as evident as on plain films. Many side branches with normal acute bifurcation angles. Between vessels, faint background pattern of small microvasculature. Almost homogeneous attenuation, increasing slightly from ventral to dorsal.

Grade 1: mild. A suggestion of early loss of side branches and some attenuation of larger vessels. Loss of attenuation gradient from ventral to dorsal surfaces.

Grade 2: moderate. Loss of sinuosity with some distortion of normal vessel pathways and loss of side branches. Irregular patchy increase in attenuation with one or more circumscribed lucencies per slice. Some branching angles increase. Increased retrosternal space often well shown.

Grade 3: severe. Very marked, often patchy localized areas of vessels curving around the lucent areas. Vessels distorted around bullae.

Grade 4: gross. Little or no normal attenuation areas remaining. Severe vascular pruning and distorted vessels around numerous bullae.

Demarcation of bullae walls was assessed as distinct or indistinct.

Pulmonary function testing. Complete pulmonary function testing was performed in surviving patients at the University of California at Irvine Medical Center pulmonary diagnostic laboratory before and 1 to 3 months after discharge from the hospital after laser bullous ablation operation. Standard pulmonary function testing included spirometric lung flows, forced expiratory volume in 1 second (FEV₁), forced vital capacity (FVC), peak inspiratory flow rate, peak expiratory flow rate, maximum voluntary ventilation, plethysmographic lung volumes, (residual volume, total lung capacity, and functional residual capacity), airway resistance, carbon monoxide diffusion in the lung (DLCO) (Sensormedics model No. 2450, Sensormedics Co., Anaheim, Calif.), and arterial blood gas measurements. Specific conductance was calculated.

Inclusion criteria. Inclusion criteria for the study are those previously described¹⁰: (1) respiratory symptoms sufficient to cause major impairment of activity and lifestyle and (2) radiographic or CT evidence of bullous lung disease with or without evidence of crowding of adjacent lung tissue.

Operative procedure. The operative procedure has been previously described.¹⁰

Laser equipment. The carbon dioxide laser was generated by an NIIR surgical system (model No. IR104; NIIC USA, Inc, Redwood City, Calif.). An Olympus carbon dioxide laser laparoscope (model No. A5308L; Olympus Corporation, Lake Success, N.Y.) was connected with an Olympus Medical Television System (model No. OTV-S2; Olympus) and a split-beam video camera (model No. AR-TF2; Olympus). Rigid Olympus telescopes (0, 30, and 45 degree with a 10 mm diameter) and conventional laparoscopy accessories with electrocautery attachments, such as grasping forceps, suction probe, and scissors, were used whenever necessary.

Laser application. The carbon dioxide laser beam was maximally defocused by adjusting the continuous variable focusing knob and firing in a continuous wave mode. When the defocused carbon dioxide laser beam was cast from a distance of 3 cm at a power setting of 20 watts, the power density on the target was approximately 250 watts/cm². Initially, the power level of the laser equipment was set at a low level (8 to 10 watts). The power level was then gradually increased by monitoring the tissue reaction through the thoracoscope.

The operation was performed while the patient was under general anesthesia with a double lumen endotracheal tube and contralateral lung ventilation. Defocused carbon dioxide laser energy was applied to bullous lesions through the thoracoscope in the pleural space. For cases of extensive or deep, thick-walled bullous lesions, partial excision was sometimes performed through the thoracoscope with the use of an endoscopic electrocautery spatula. Communicating airways were sealed with carbon dioxide laser or sutures.

Statistical methods. Means and standard errors are presented for pulmonary function tests, lung volume, and gas exchange measures both before and after the operation. Standard *t* tests for paired observations were used to determine whether changes in pulmonary function after the operation were significantly different from zero. Means and standard errors are given for grades assigned to CT scans and chest radiographs.

The relationship between CT scans or chest radiographs and changes in pulmonary function after the operation were examined with one-way analysis of variance. An *F* test was used to determine if change in pulmonary function differed between severity of abnormality of preoperative CT scan or chest radiograph. Adjustments were made for multiple comparisons with the Bonferroni method.

Results

Demographic data. Twenty-four patients are included in this study: 21 men and 3 women. Average age was 61.6 years in survivors and 68.7 in nonsurvivors. Average weight was 72 kg in survivors and 57 kg in nonsurvivors. Eight patients were from the local area, and 16 were referred from other regions.

Pulmonary function tests. Spirometry revealed significant increases in FEV₁ and FVC, without change in FEV₁/FVC ratio (Table I). Maximum voluntary ventilation also increased as did maximum inspiratory and expiratory flow rate for the total group.

In the subgroup of patients with massive pulmonary bullae and compression of underlying structures (*n* = 6), FEV₁ improved significantly more (change in FEV₁

Table I. Preoperative and postoperative pulmonary function in patients undergoing laser surgery

	Preoperative	Postoperative	Change after operation	% Change from baseline	p Value*
Survivors (n = 19)					
FEV ₁	0.815 ± 0.104	1.175 ± 0.143	0.362 ± 0.072	44.4	0.0001
FVC	2.137 ± 0.163	2.959 ± 0.141	0.822 ± 0.125	38.5	0.0001
MVV	32.889 ± 4.375	45.282 ± 5.197	11.687 ± 2.579	35.5	0.0002
DLCO	8.129 ± 1.140	8.269 ± 1.301	0.142 ± 0.923	1.7	0.79
Raw	3.554 ± 0.283	2.460 ± 0.195	-0.902 ± 0.354	-25.4	0.03
RV	6.444 ± 0.412	5.187 ± 0.399	-1.255 ± 0.232	-19.5	0.0001
SGaw	0.042 ± 0.005	0.061 ± 0.006	0.019 ± 0.006	45.2	0.06
Nonsurvivors (n = 5)					
FEV ₁	0.570 ± 0.093				0.26
FVC	1.742 ± 0.332				0.29
MVV	16.500 ± 1.500				0.24
DLCO	3.420 ± 1.171				0.05
Raw	2.650 ± 0.800				0.63
SGaw	0.065 ± 0.015				0.10
RV	5.960 ± 0.373				0.49

Values are mean ± standard error of the mean. MVV, Maximum voluntary ventilation; Raw, airway resistance; RV, residual volume; SGaw, specific conductance.

*Compared with preoperative values.

†Compared with survivors.

0.6 ± 0.3 L) after the procedure than in patients without evidence of compression (change in FEV₁ 0.2 ± 0.2 L, $p < 0.05$).

Lung volumes. Preoperative and postoperative body plethysmography showed a consistent pattern of smaller lung volumes. Decreases were seen in residual volume (-1.25 ± 0.23 L, $p < 0.001$), functional residual capacity (-0.95 L, $p < 0.05$), and total lung capacity (-0.62 L, $p < 0.05$).

Gas exchange. Single-breath Meade-Jones DLCO did not change after the procedure for the overall group of patients. Patients with upper lobe disease had greater improvement in DLCO than patients with mixed and lower lobe disease: +3.2 ml/mm Hg per minute increase for upper lobe disease versus +0.18 ml/mm Hg per minute for lower disease and -3.3 ml/mm Hg per minute for mixed lobe disease ($p < 0.05$, one-way analysis of variance). Resting arterial oxygen tension, oxygen saturation, and alveolar-arterial gradients did not change after the operation in the overall group of patients.

Resistance. Airway resistance decreased, and, coupled with the decrease in lung volumes, specific conductance increased significantly (Table I).

Relationship between preoperative radiologic presentation and response to treatment. Relationships between change in pulmonary function (preoperative to postoperative change in FEV₁, FVC, and maximum voluntary ventilation) and degree of emphysema on both CT

scans and chest radiographs were examined by one-way analysis of variance in patients with baseline and postoperative data.

Patients with greater severity of disease in upper chest radiographs (grade ≥ 3.5) experienced greater improvement in FEV₁ compared with those with less severe involvement (grade < 3.5, $p < 0.05$, Table II). The change in maximum voluntary ventilation was also closely associated with upper chest radiography score ($p < 0.008$). DLCO did not change.

In contrast, patients with more severe disease in the lower lung fields had poorer response to treatment. Patients with lower chest radiographs graded 3.5 or higher experienced less improvement in both FEV₁ and FVC (Table II). Advanced degrees of bullous changes in the lower lung region also correlated with reduced MVV response post operatively ($p = 0.0003$ left lower lobe, Table I).

The relationship between change in pulmonary function and CT scan was also examined for CT scans of right and left upper, middle, and lower sections. When patients were grouped by CT grade into those with less severe emphysema (CT grade < 3.5) and those with more severe emphysema (CT grade ≥ 3.5), no significant differences were found between groups in mean change in FEV₁ or FVC. Although results show that there was a greater improvement in FEV₁ and FVC after the operation when upper and middle CT scan regions indicated more severe

Table II. Relationship between initial chest radiography and pulmonary function response to laser surgery

Quadrant (n = 19)	Change after operation		p Value
	Radiography score <3.5	Radiography score ≥3.5	
Right upper			
FEV ₁	0.252 ± 0.073	0.550 ± 0.125	0.04
FVC	0.696 ± 0.153	1.039 ± 0.204	0.20
MVV	6.113 ± 1.783	22.830 ± 4.070	0.001
DLCO	-0.446 ± 0.492	1.317 ± 2.684	0.55
Right lower			
FEV ₁	0.485 ± 0.092	0.151 ± 0.061	0.01
FVC	0.931 ± 0.139	0.636 ± 0.240	0.27
MVV	16.124 ± 3.446	4.714 ± 2.020	0.03
DLCO	0.823 ± 1.434	-0.929 ± 0.712	0.37
Left upper			
FEV ₁	0.266 ± 0.074	0.630 ± 0.890	0.02
FVC	0.701 ± 0.138	1.160 ± 0.236	0.11
MVV	8.240 ± 2.478	23.750 ± 3.750	0.01
DLCO	-0.718 ± 0.920	3.150 ± 2.236	0.08
Left lower			
FEV ₁	0.446 ± 0.090	0.219 ± 0.105	0.13
FVC	0.926 ± 0.174	0.644 ± 0.155	0.29
MVV	17.727 ± 2.945	2.194 ± 1.072	0.001
DLCO	0.482 ± 1.468	-0.393 ± 0.697	0.66

Values are mean ± standard error of the mean. MVV, Maximum voluntary ventilation.

involvement, F tests did not show statistical significance after adjustment for multiple comparisons.

Survival. Nineteen patients survived and underwent follow-up evaluation 1 to 3 months after carbon dioxide laser ablation of pulmonary bullae in this series. Three patients died during the perioperative period. Two patients died at 3 and 4 months without postoperative pulmonary function tests. The causes of perioperative death were myocardial infarction, pneumonia, and postoperative hypoxemic respiratory failure of unclear origin (possibly a result of alveolar hemorrhage or edema). One patient died at 3 months after the operation of chronic respiratory failure and recurrent pulmonary infections. Another patient died at 4 months of contralateral pneumonia. One patient died 15 months after the operation of acute embolic stroke. He had been doing very well with regard to respiratory condition before the stroke.

Patients who survived the procedure had higher mean preoperative DLCO than did nonsurvivors (8.12 ± 4.8 , ml/mm Hg per minute versus 3.4 ± 2.6 ml/mm Hg per minute, $n = 5$; $p < 0.05$). Surviving patients had less severe emphysema on the nonoperative side as seen with chest radiography (emphysema score for the nonoperative side 3.87 ± 1.7 , $n = 19$, in survivors compared with 5.75 ± 1.2 , $n = 5$, in nonsurvivors; $p < 0.05$). Five additional patients underwent operation with this protocol and survived but did not have complete follow-up data ($n = 30$

entered in the protocol at our institution). Patients with incomplete follow-up information did not differ statistically in any baseline pulmonary function values or radiographic gradings compared with those with complete follow-up data reported here.

Morbidity. Air leak was the single major cause of morbidity. All patients had some degree of air leak lasting from 1 day to 37 days. Three patients were discharged from the hospital with Heimlich valves in place that were removed in the outpatient clinic. Median hospital stay was 16 days. Median intensive care unit stay was 6.5 days. With experience, the duration of hospitalization decreased to a median of 10 days in the last 10 patients entered in the study.

Discussion

Surgical bullectomy is effective in the treatment of patients with compressive bullous lung disease.^{3,4,13} Optimal surgical bullectomy candidates have bullae occupying at least 50% of the hemithorax with evidence of compression of underlying lung parenchyma.^{1,3-5} The concept of compression of surrounding tissues has been the subject of debate.^{3,5,14-17} Reexpansion of adjacent lung after removal of bullae results in increased functional lung tissue^{1,3} and is accompanied by increased gas transfer capabilities (DLCO) in surgical bullectomy reports.¹⁹ However, crowding, rather than true compression of adjacent lung, may more accurately describe re-

Fig. 2. Preoperative CT scan and chest radiographs show large bilateral, well-demarcated pulmonary bullae with crowding of surrounding lung structures. *Left side:* upright chest radiograph from a patient with large bilateral bullae crowding surrounding lung. Chest radiographs were graded by quadrant as follows: right upper = 4, right lower = 2.5, left upper = 4, left lower = 2.0. *Right side:* upper lung, midlung, and lower lung CT sections from the same patient. The CT scans were graded by quadrant as follows: right upper = 3.8, right middle = 3.8, right lower = 2.5, left upper = 3.8, left middle = 3.8, left lower = 3.2.

quisite physiology for response to surgical bullectomy.^{3, 17, 18}

In contrast to many surgical bullectomy reports, patients who underwent carbon dioxide laser ablation of emphysematous bullae demonstrate improvements in pulmonary function in the absence of crowded lung tissue. Resting spirometry (FEV₁ and FVC) and specific conductance improved significantly after laser ablation procedure, and lung volumes decreased. Despite the improvements in spirometry, lung volumes, and airway resistance, resting gas exchange measures were not improved by the procedure in the overall group of patients. These findings suggest that mechanisms other than decompression of lung tissue were predominantly responsible for pulmonary improvement in patients who undergo laser treatment with multiple bullae and severe emphysema. One potential mechanism of spirometric improvement in patients may be mechanical advantages occurring from decreased size of the thoracic cavity leading to more optimal respiratory muscle positioning with consequent increased ventilatory capacity.

Another potential mechanism for benefit in patients who undergo laser treatment is possible increased airway

support. This hypothesis is partially supported by improved airway resistance and specific conductance. Increased airway support can result from removal of space-occupying bullous lesions and reduction of surrounding airway compression as previously reported in surgical bullectomy patients.^{1, 2, 6, 15, 18} Because preoperative parenchymal crowding was not seen in most of the patients who underwent laser treatment, reduction in airway resistance could instead have resulted from reduction in overall lung volume and increased radial traction on remaining lung tissue. Similar mechanisms were postulated in the early 1950s and led to unsuccessful surgical removal of lung tissue segments as potential treatment for emphysema.^{13, 20, 21} In those instances, deterioration in overall lung function was frequently seen. Improved localization of dysfunctional lung areas with CT scanning and more directed intervention with laser approaches could explain improved short-term outcomes seen in patients who undergo laser treatment.

Ideal candidates for surgical bullectomy have a rare combination of isolated giant bullous lesions without underlying emphysema.^{3, 22} More commonly, bullae form in association with severe diffuse emphysema. In

surgical series, diffusely emphysematous patients have poor acute and long-term outcomes.²⁻⁹ Most patients treated with laser bullae ablation in our series have had moderate-to-severe emphysema. Nonetheless, in short-term postoperative follow-up, improvement has been seen in almost all patients. More extensive underlying emphysema is associated with less objective response. In essence, severity of bullous changes must be weighed against degree of emphysema in selecting individual patients for laser bullectomy.

Numerous studies have documented effectiveness of CT scanning in assessing severity of pulmonary bullous emphysema.^{6, 23-26} The degree of emphysema is frequently difficult to interpret with pulmonary function testing in patients with multiple bullae because of variable effects of bullae on air trapping, air flow, lung volumes, dead space ventilation, gas transfer, and inconsistent degrees of ventilation of the bullae themselves.^{3, 6, 19, 27} Thus, quantitative examination of the appearance of lung parenchyma by chest radiograph and CT scan appears to provide additional information for assessing degree of emphysematous destruction in underlying lung.²⁴ Our studies show a closer correlation between outcome and chest radiographic analysis than between outcome and CT scanning. This may have resulted from our grading of only three sections on each CT scan. Quantitative grading of more than three CT scan sections would probably improve the correlation with outcome but would be impractical as a general approach.

Location of pulmonary bullae is also a factor in determining response to treatment and can be quantitatively assessed with radiographic imaging.²⁴ In patients undergoing thoroscopic laser bullae ablation, upper lobe bullae are associated with more favorable response; similar to results from standard bullectomy series.

Some bullae are discreet and well demarcated, whereas others appear as a continuum of lung destruction. In later cases, degree of emphysema is generally more severe, and response to standard surgical bullectomy is poorer.³ However, despite smaller objective incremental improvements, patients with severe underlying emphysema may have substantial symptomatic relief and improvement in performance status after bullectomy.^{3-5, 10, 16, 28-30}

A major concern in surgical bullectomy series of severely emphysematous patients is rapid deterioration in respiratory status after the operation because of continued progression of underlying emphysema, recurrent bullae, or stress relaxation of surrounding tissue.^{2, 3, 5, 13, 18, 21} Only relatively short-term follow-up is available in patients who have undergone thoroscopic laser bullectomy.

Of additional concern is the high mortality seen in patients in this series. The extreme severity of underlying emphysema in a number of patients and inexperience during development of a new technique may contribute to the mortality reported here. Mortality was more difficult to predict than potential degrees of improvement in surviving patients according to initial radiographic results in this series. In a recent abstract by Wakabayashi and associates,³¹ a lower mortality of 4% in 128 patients treated for bullous emphysema with the use of contact tip neodymium:yttrium-aluminum-garnet lasers was reported. The lower mortality may be more reflective of expected mortality as experience with this technique is gained.

In conclusion, we have found that objective preoperative radiographic assessment correlates well with response to laser ablation of emphysematous bullae. Improvement appears to result from mechanical advantages and decreased airway resistance. Outside the scope of research settings or for physicians who do not have extensive experience with this procedure, it would appear prudent to restrict indications at present to patients who clearly benefit (i.e., those with large bullous lesions and minimal underlying emphysema). Larger numbers of patients and follow-up of longer terms will be needed to further define selection criteria and determine the eventual role of laser treatment in patients with emphysematous bullous lung disease.

We thank Dr. Akio Wakabayashi for the performance of the thoroscopic procedures and for his help, advice, and comments in the preparation of this manuscript. Pulmonary function results of the initial 12 patients have been reported in *The Lancet* 1991;337:881-3.

REFERENCES

1. Connolly JE, Wilson AF. The current status of surgery for bullous emphysema. *J THORAC CARDIOVASC SURG* 1989;97:351-61.
2. Nakahara K, Nakaoka K, Ohno K, et al. Functional indications for bullectomy of giant bulla. *Ann Thorac Surg* 1983;35:480-7.
3. Gaensler EA, Jederlinic PJ, Fitzgerald MX. Patient work-up for bullectomy. *J Thorac Imaging* 1986;1:75-93.
4. Laros CD, Gelissen HJ, Bergstein PG, et al. Bullectomy for giant bullae in emphysema. *J THORAC CARDIOVASC SURG* 1986;91:63-70.
5. Fitzgerald MX, Keelan PJ, Cugell DW, Gaensler EA. Long-term results of surgery for bullous emphysema. *J THORAC CARDIOVASC SURG* 1974;68:566-87.
6. Morgan MD, Denison DM, Strickland B. Value of computed tomography for selecting patients with bullous lung disease for surgery. *Thorax* 1986;41:855-62.
7. Gunstensen J, McCormack RJ. The surgical management of bullous emphysema. *J THORAC CARDIOVASC SURG* 1973;65:920-5.

8. Billig DM. Surgery for bullous emphysema [Editorial]. *Chest* 1976;70:572-3.
9. Ogilvie C, Caterall M. Patterns of disturbed lung function in patients with emphysematous bullae. *Thorax* 1959;14:216-24.
10. Wakabayashi A, Brenner M, Kayaleh RA, et al. Thoracoscopic carbon dioxide laser treatment of bullous emphysema. *Lancet* 1991;337:881-3.
11. Milne ENC, Pistolesi M. Detecting and quantifying chronic bronchitis and emphysema. In: *Reading the chest film: a physiologic approach*. St. Louis: CV Mosby, 1992:267-310.
12. Milne ENC, Bandler M, Li C. The early diagnosis of COPD: the value of the plain film versus computed tomography. *ARRS Categorical Course on Chest Radiology* 1989;143-7.
13. Head JM, Head LR, Hudson TR, Head JR. The surgical treatment of emphysematous blebs and localized vesicular and bullous emphysema: analysis of 50 cases. *J THORAC CARDIOVASC SURG* 1960;40:443.
14. Pierce JA, Growdon JH. Physical properties of the lungs in giant cysts. *N Engl J Med* 1962;267:169.
15. Potgieter PD, Benatar SR, Hewitson RP, et al. Surgical treatment of bullous lung disease. *Thorax* 1981;36:885-90.
16. Benfield JR, Cree EM, Pellett Jr RB, Mendenhall JT, Hickey RC. Current approach to the surgical management of emphysema. *Arch Surg* 1966;93:59.
17. Ting E. Mechanical properties of pulmonary cysts and bullae. *Am Rev Respir Dis* 1963;87:538.
18. Rogers RM, DuBois AB, Blakemore WS. Effect of removal of bullae on airway conductance and conductance volume ratios. *J Clin Invest* 1968;47:2569-79.
19. Pride NB, Barter CE, Hugh-Jones P. The ventilation of bullae and the effect of their removal on thoracic gas volumes and tests of overall pulmonary function. *Am Rev Respir Dis* 1973;107:83-98.
20. Brantigan OE, Mueller E, Kress MD. A surgical approach to bullous emphysema. *Am Rev Respir Dis* 1959;79:194-206.
21. Knudson RJ, Gaensler EA. Surgery for emphysema. *Ann Thorac Surg* 1965;21:332-62.
22. Laurenzi GA, Turing GM, Fishman AP. Bullous disease of the lung. *Am J Med* 1962;32:361-78.
23. Bourgouin P, Cousineau G, Lemire P, Herbert G. Computed tomography used to exclude pneumothorax in bullous lung disease. *J Can Assoc Radiol* 1985;36:341-2.
24. Morgan MD, Strickland B. Computed tomography in the assessment of bullous lung disease. *Br J Dis Chest* 1984;78:10-25.
25. Fiore D, Biondetti PR, Sartori F, Calabro F. The role of computed tomography in the evaluation of bullous lung disease. *J Comput Assist Tomogr* 1982;6:105-8.
26. Carr DH, Pride NB. Computed tomography in pre-operative assessment of bullous emphysema. *Clin Radiol* 1984;35:43-5.
27. Baldwin E, Harden AA, Greene DG, Cournand A, Richards DW. Pulmonary insufficiency. IV. A study of 16 cases of large air cysts or bullae. *Med* 1950;29:35.
28. Boushy SF, Billig DM, Kohen R. Changes in pulmonary function after bullectomy. *Am J Med* 1969;47:916-23.
29. Foreman S, Weill H, Duke R, George R, Ziskind M. Bullous disease of the lung. Physiologic improvement after surgery. *Ann Intern Med* 1968;69:757-67.
30. Fain WR, Conn JH, Campbell GD, Chavez CM, Gee HL, Hardy JD. Excision of giant pulmonary emphysematous cysts: report of 20 cases without deaths. *Surgery* 1967;62:552-91.
31. Wakabayashi A, Peters H, Singh N, et al. Thoracoscopic treatment of bullous emphysema using sapphire contact tip neodymium yttrium aluminum garnet laser (contact YAG): preliminary report. Presented at the Seventy-third Annual Meeting of The American Association for Thoracic Surgery; April 25-28, 1993; Chicago, Ill.