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# Reduction Pneumonoplasty for Emphysema

## Early Results

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### Objective

The authors determined the role of Nd:YAG laser reduction pneumonoplasty for selected patients with diffuse emphysema.

### Summary Background Data

The study is based on the concepts introduced 30 years ago by Brantigan regarding the value of lung reduction surgery in patients with emphysema. The authors used minimally invasive techniques with the hopes of providing appropriate clinical results with the least surgical morbidity.

### Methods

Fifty-five patients with advanced symptomatic emphysema were treated with unilateral Nd:YAG laser reduction pneumonoplasty to achieve lung volume reduction.

### Results

Patients experienced significant improvement in exercise capacity and relief of breathlessness. This correlated with improvement in objective measures of pulmonary function and with reduction in lung volume by radiographic and spirometric measures. Significant associated hospital morbidity and a 5.5% mortality were associated.

### Conclusions

These encouraging results with treatment of only one lung will be built on with both sequential lung and simultaneous, bilateral lung treatment protocols.

The thoracic surgery community is experiencing a surge of interest in and enthusiasm for surgical treatment of patients with diffuse, bullous emphysema. For clarity, we define and distinguish among some terms used in this field. Emphysema is a subset of chronic obstructive pulmonary disease defined as "distention of the air spaces distal to the terminal bronchiole with destruction of alveolar septa." [1] Bullous emphysema is present when there are "confluent air spaces with diameters in excess of one cm. Gradual increases in size of such air spaces (or bullae) result from traction applied by regions with better elastic recoil properties and such regions lose vol-

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ume as the bullae become enlarged."[1] Thus, although we are not considering patients with so-called giant bullae, essentially every patient with emphysema has some degree of bullous formation. Therefore, ablation or resection of diseased peripheral lung in patients with emphysema includes treatment of bullous areas, although the bullae or air spaces may not be distinct in appearance but, rather, incorporated within the generalized disease tissue.

Brantigan focused on the possibility of surgical intervention for patients with diffuse bullous emphysema.[2-6] His basis for excising "localized emphysematous areas" involved three theoretical benefits. First, he hypothesized that reduction of these nonfunctioning and space-occupying areas would result in expansion and improved function of the more normal and previously compressed areas of the lung. Second, he postulated that his operation would restore a more nearly normal, negative intrathoracic pressure, which would result in increased pull and traction on bronchi, thereby promoting their patency. Third, he believed that lung volume reduction might result in elevation of the diaphragm and a less expanded thoracic cage, which in tandem would permit more efficacious motion of the chest wall and diaphragm. His clinical experience with emphysema patients proved that his operation, which included unilateral thoracotomy and resection of the most diseased portions of the lung, benefitted the majority of patients when assessed on clinical grounds. However, this undertaking was associated with a daunting perioperative mortality in excess of 15%.

This concept introduced by Brantigan essentially lay dormant for several decades until recently, when it has been recognized and resuscitated. Wakabayashi et al. reported their experience with a thoracoscopic carbon dioxide laser contraction of peripherally diseased areas.[7,8] Particularly encouraging is the report from the Washington University Thoracic Surgery Group, who demonstrated that in 20 carefully selected patients with diffuse, bullous emphysema, an approach involving a median sternotomy and buttressed, stapled resection of what Brantigan called "localized emphysematous areas" resulted in betterment of subjective, symptomatic breathlessness and objective measurements of pulmonary function.[9]

Our group at the University of Nevada has likewise become interested in the challenge of surgical treatment for patients with emphysema. Knowing the theoretical benefits of minimally invasive surgery, we have approached these patients in a flexible fashion. Patients with giant bullae receive a sternotomy or thoracotomy with standard open resection techniques. Patients with diffuse bullous emphysema without the appearance of any so-called "true bullae" have been approached using

**Table 1. TEN-POINT BORG DYSPNEA CATEGORY SCALE**

| | |
|---|---|
| 0 | Nothing at all |
| 0.5 | Very, very slight (just noticeable) |
| 1 | Very slight |
| 2 | Slight |
| 3 | Moderate |
| 4 | Somewhat severe |
| 5 | Severe |
| 6 | |
| 7 | Very severe |
| 8 | |
| 9 | Very, very severe (almost maximal) |
| 10 | Maximal |

either video-assisted thoracic surgery and neodymium: yttrium aluminum garnet (YAG) laser contraction of these peripheral lung areas or median sternotomy and bilateral resection of diseased tissue. Finally, patients with both diffuse bullous emphysema and modest-sized true bullae have been treated by video-assisted thoracic surgery technique with a combination of laser ablation of the diffusely diseased areas and staple resection of the true bullae. The purpose of this report was to focus on the use of the video-assisted thoracic surgery approach and a YAG laser technique of ablation of the most diseased regions of the lung in patients with diffuse bullous emphysema. We have termed this lung reshaping operation a reduction pneumonoplasty.

## METHODS

### Patients

Fifty-five consecutive patients with the clinical diagnosis of emphysema were treated at the University Medical Center of Southern Nevada for breathlessness and dyspnea on exertion, which severely impaired their quality of life despite intensive medical therapy. The following procedures were performed: sternotomy or thoracotomy for resection of giant bullae in three patients, sternotomy and bilateral resection of diffuse bullous emphysema in six patients, and simultaneous laser contraction and thoracoscopic staple resection in five patients. An additional 26 patients were evaluated but not accepted for treatment because of severe bronchitis, significant carbon dioxide retention (>50 torr), congestive heart failure or cor pulmonale, and/or end-stage chronic obstructive pulmonary disease. This latter judgment included patients who were so limited by their breathlessness that they were unable to ambulate and had $FEV_1$ below 0.35 L despite vigorous rehabilitation efforts.

The study population consisted of 18 women and 37

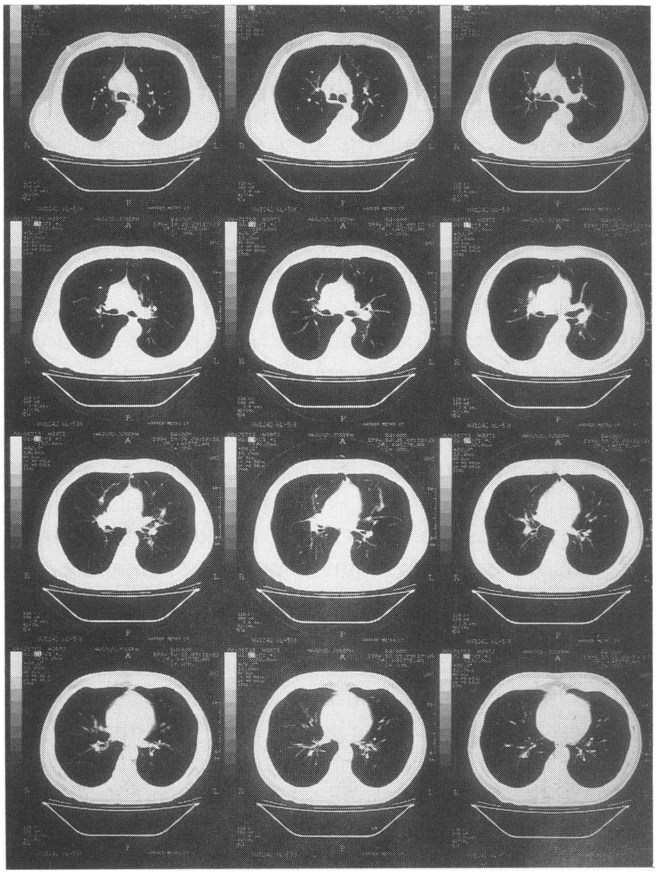

**Figure 1.** This chest computed axial tomography scan shows multiple areas of poorly perfused lung, consistent with advanced, diffuse bullous emphysema. No true bullae are present.

men with both a mean and median age of 66 years. All patients had a history of smoking, but all had ceased this activity, most for several years.

All patients were using nebulizer bronchodilator treatment delivery systems. In addition, 34 (62%) of these patients were taking oral prednisone at the time of surgery, and 40 (73%) were using home oxygen either continuously (13 patients) or intermittently (27 patients). All patients had significant limitation of their activities because of shortness of breath. This limitation was evaluated with two dyspnea indexes, which are defined in Table 1 and Table 2. The Borg category scale uses a subjective perspective to assess the extent of activity necessary to cause dyspnea. It is used to evaluate the intensity of respiratory sensations in dyspnea and has been validated both in healthy subjects and in patients with emphysema. The higher the score, the worse the breathlessness. The Modified Medical Research Council scale is used to correlate breathlessness with varying levels of daily activities. This dyspnea rating scale is considered a more objective assessment, because it correlates breathlessness with specific, clearly defined activities. The higher the score, the less intense is the activity required to produce dyspnea. In addition to the clinical assessment, patients were evaluated with measurement of room-air arterial blood gases and standard pulmonary function tests.

Radiologic assessment included posterior–anterior and lateral chest x-rays and thoracic computed axial tomography scans. All patients had the typical chest x-ray manifestations of emphysema, including a flattened diaphragm, generally increased lung size, and, particularly, an increased posterior–anterior diameter. The posterior–anterior and lateral chest x-rays were used to estimate total lung volume. The areas of the right and left lungs, exclusive of the mediastinum and heart, were combined with the area on the lateral projection according to the method described by Harris et al.[10] The total area in centimeters squared was converted to total lung volume in liters using a regression equation.[10]

Those selected for reduction pneumonoplasty had computed axial tomography scan results like the one demonstrated in Figure 1: vascular markings do not extend to the lung periphery, and there are large spaces between vascular markings. These "black holes," which are predominantly located peripherally, apically, and along the visceral pleural sides of the fissures, represent Brantigan's localized emphysematous areas in which the bullous component of the disease is found.

Preoperative pulmonary rehabilitation was not routinely required of each patient. When patients did complete a 6-week pulmonary rehabilitation program, postrehabilitation arterial blood gases and pulmonary function tests were used as the preoperative values for comparison with postoperative results.

Values are expressed as mean ± standard error of the mean. Statistical analysis was performed using the Student's t test and chi square comparison, as appropriate. Probability values of less than 0.05 were considered to be statistically significant.

## Surgical Procedure

The first eight patients in this study were admitted for operation the day of surgery, as required by the insurance companies. However, during this time, two patients had to have their operations canceled when they arrived anxious and breathless and not in stable enough condition to proceed. After this experience, all patients were admitted the night before surgery for evaluation of their fitness for the operation. Intravenous fluids were administered, because many of the patients were thought to be chronically dehydrated. Intravenous bronchodilators were used for most patients to treat or prevent bronchospasm and to increase the contractility of the respiratory muscles. Intravenous steroids were administered the morning of surgery to patients who had been taking oral steroid com-

Table 2. MODIFIED MEDICAL RESEARCH COUNCIL DYSPNEA SCALE

| Grade | |
|---|---|
| 0 | Not troubled with breathlessness except with strenuous exercise |
| 1 | Troubled by shortness of breath when hurrying on the level or walking up a slight hill |
| 2 | Walks slower than people of the same age on the level because of breathlessness or has to stop for breath when walking at own pace on the level |
| 3 | Stops for breath after walking about 100 yards or after a few minutes on the level |
| 4 | Too breathless to leave the house or breathless when dressing or undressing |

pounds and to reduce the inflammatory response to the laser and the talc powder.

In the operating room, general anesthesia was administered, and a double-lumen endotracheal tube was placed in the left main-stem bronchus. Patients were then positioned in the left decubitus position, and thoracoscopic access was gained into the right chest, which was chosen to allow for treatment of the largest lung. Initial port placement was in the posterior axillary line in the seventh or eighth intercostal space. After blunt dissection through the intercostal muscles and pleura, a fingertip was inserted to ensure that the lung had collapsed sufficiently to allow safe port placement. A Hopkins zero-degree right angle operating telescope (Karl Storz Endoscopy, Culver City, CA) was connected to a Stryker camera and video system (Stryker Endoscopy, San Jose, CA) and inserted into the chest. When minor adhesions were encountered, they were sharply divided using electrocautery endoscissors. More significant adhesion formation was considered a contraindication to the laser pneumonoplasty procedure, because of the barrier to laser access to the lung surface created by blood and the thickened visceral pleura. The two patients in whom this scenario was encountered instead received a lung-shaving approach through a median sternotomy during the same anesthetic exposure.

A Laser Sonics G56 YAG laser fiber (Heraeus Laser Sonics, Inc., Milpitas, CA) was introduced through the operating lumen of the telescope and used to apply radiation to the lung surface. A free beam rather than contact technique was used consistently. One surgeon preferred a setting of 40 W and a 0.5-second pulse interval. The other surgeon preferred a lower energy setting of 10 to 15 W and used the YAG laser in a continuous wave mode. All surfaces of the lung were treated. Other entry sites and port placements were used as necessary to either approach the lung with the laser from a different direction or to insert manipulating instruments to maneuver the lung. By the end of the series, most patients needed only two entry sites. When the more diseased areas collapsed because of air resorption, the anesthesiologist was asked to temporarily reinflate the lung, thus allowing identification of the area of demarcation from the more normal lung parenchyma.

With experience, we learned the best distance to position the laser from the lung surface to maximally contract the most diseased areas without creating a full-thickness visceral pleural defect. More pigmented areas of the lung absorb more energy, so for treatment of these areas, the laser was farther away than for the less pigmented lung surfaces.

After completion of the procedure, talcum powder (J.T. Baker Chemical Co., Phillipsburg, NJ) was instilled through the chest trocars in most patients. Patients younger than 55 years who might be potential candidates for lung transplantation did not receive the talcum powder, which was used to promote a postoperative pleurodesis for rapid sealing of lung defects and resolution of air leaks. One or two chest tubes were placed, and the patient was awakened. When possible, the patients were extubated in the operating room. Otherwise, they were taken to the recovery room, where they were evaluated for extubation. In later patients, epidural catheters were placed preoperatively for postoperative analgesic administration.

As describe: , only one lung was treated. Although it was tempting to treat both lungs simultaneously, we were concerned about one-lung anesthesia where the ventilated lung had just received the laser pneumonoplasty procedure. Consequently, we elected the more conservative route of treating only one lung initially.

We described this operation to patients as new and without an established track record. We emphasized that although other experiences suggested there would be a clinical benefit, follow-up was limited, and risks for both morbidity and mortality, while not established, were likely to be significant in this relatively high-risk population.

Table 3. SYMPTOM ANALYSIS

| | BORG | MMRC |
|---|---|---|
| Before operation (N = 55) | 7.6 ± 0.3 | 3.6 ± 0.1 |
| After operation | | |
| 3 mo (n = 32) | 6.2 ± 0.4* | 2.9 ± 0.2† |
| 6 mo (n = 17) | 5.7 ± 0.5* | 2.8 ± 0.2† |

* $p < 0.01$ vs. Before Operation.
† $p < 0.05$ vs. Before Operation.

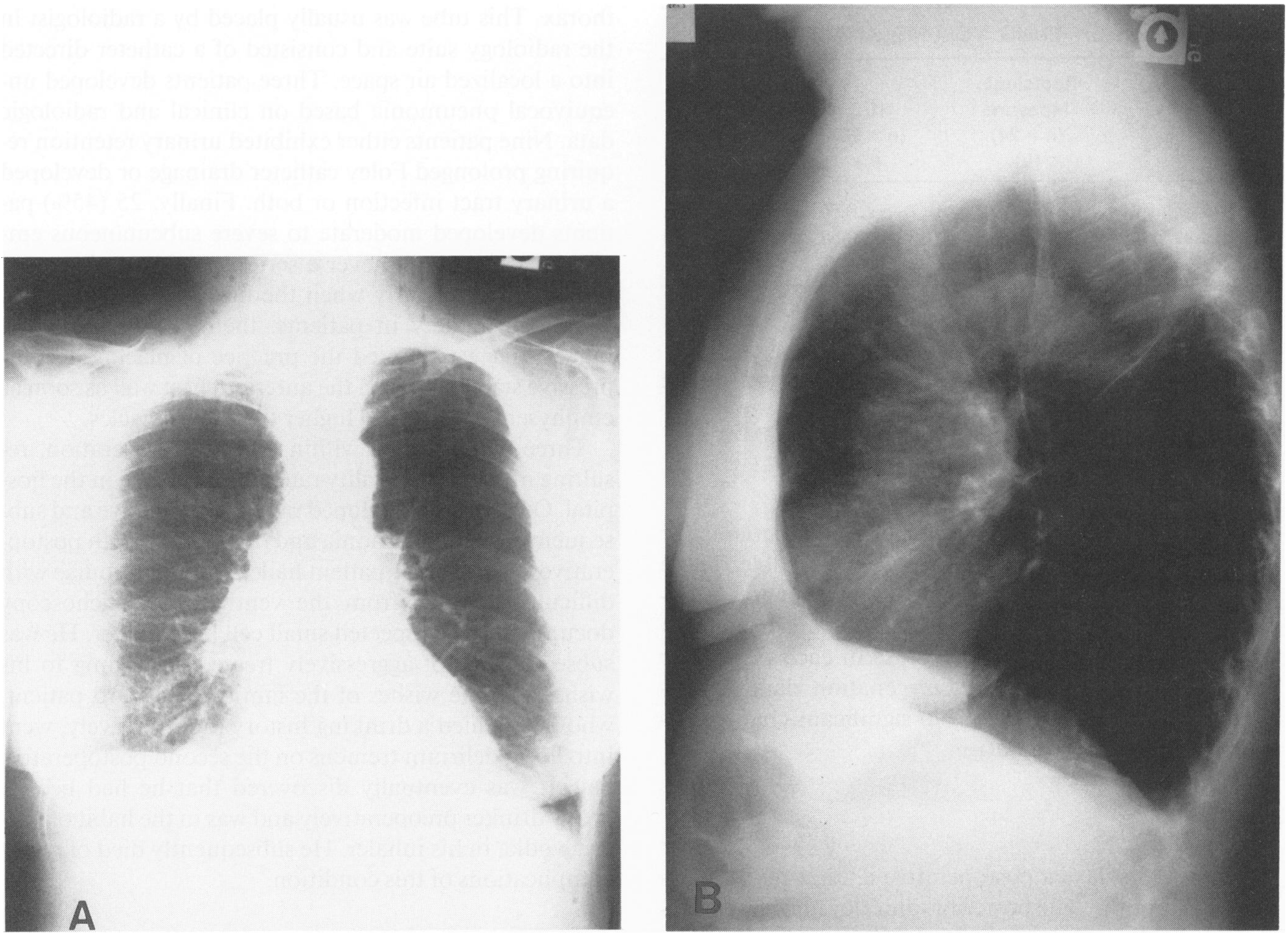


**Figure 2.** (A) This representative posterior–anterior chest x-ray was obtained 3 months after right-side reduction pneumonoplasty. It shows a right hemithorax that is considerably smaller than the left hemithorax. (B) The lateral film shows that the left hemidiaphragm remains flat, while the elevated right hemidiaphragm is now dome shaped.

## RESULTS

### Clinical

Table 3 displays the overall symptomatic response with comparison of Borg and Modified Medical Research Council dyspnea index scores for the 32 patients who were available for 3-month evaluations and the 17 who were available for 6-month evaluations, remembering that lower scores reflect better values (Table 1). Patients exhibited significant improvement in their symptom status at 3 months

**Table 4. PULMONARY FUNCTION ANALYSIS**

| | $FEV_1$ (n = 28) (L) | FVC (n = 28) (L) | DLCO (n = 10) (mL/min/mmHg) | $P_{O_2}$ (n = 22) (mmHg) |
|---|---|---|---|---|
| Before operation | 0.74 ± 0.07 | 1.82 ± 0.13 | 10.3 ± 2.3 | 59.3 ± 1.7 |
| After operation | 0.85 ± 0.06 | 2.21 ± 0.15 | 13.7 ± 2.4 | 63.3 ± 2.3 |
| % Change | 18.1 ± 5.5 | 29.6 ± 7.9 | 42.3 ± 18.6 | 11.3 ± 1.1 |
| p value | 0.009 | 0.003 | 0.005 | 0.036 |

Table 5. LUNG VOLUME ANALYSIS

| | Radiologic Measure (n = 24) (L) | TLC (n = 20) (L) | RV (n = 20) (L) |
|---|---|---|---|
| Before operation | 6.48 ± 0.72 | 7.15 ± 0.80 | 4.55 ± 0.51 |
| After operation | 6.02 ± 0.58 | 6.14 ± 0.68 | 4.07 ± 0.49 |
| p value | <0.001 | 0.009 | 0.037 |

by both measures. In addition, there was a trend toward continued improvement at 6 months.

## Pulmonary Function Analysis

Table 3 provides spirometry data in the patients for whom 3-month follow-up studies were available. These data are expressed in both absolute values and in percentage change, where the percentage changes for each patient were averaged. The increase in each parameter was statistically significant. Oxygenation data are expressed using room-air $Po_2$. No significant changes occurred in $Pco_2$, pH, or $Sao_2$.

## Radiologic

Figure 2 displays a postoperative chest x-ray in a patient at 3 months. The posterior-anterior film shows dramatic reduction of the right lung size compared with the left, and the lateral film shows that the right hemidiaphragm is now dome shaped, particularly in comparison to the flat left hemidiaphragm. Table 5 provides lung volume measurement using radiologic analysis; spirometric volume values are also shown. Significant reduction in total lung volume was achieved with unilateral reduction pneumonoplasty.

## Hospital Experience

The mean hospital stay was 12.9 ± 1.4 days (median, 10.5 days). Twenty-five of the 55 patients were never admitted to the intensive care unit. For the 55 patients, the average stay in the intensive care unit was 1.7 ± 0.5 days. The mean time for ventilator support was 1.9 ± 0.9 days, with a range of 0 days in the 41 patients who were extubated in the immediate perioperative period to a maximum of 37 days. Seven patients were discharged to an intermediate care facility, two of whom were receiving ventilatory support, for intensive rehabilitation. All have subsequently returned to their home.

Regarding perioperative morbidity, 11 patients required placement of a new chest tube for late pneumothorax. This tube was usually placed by a radiologist in the radiology suite and consisted of a catheter directed into a localized air space. Three patients developed unequivocal pneumonia based on clinical and radiologic data. Nine patients either exhibited urinary retention requiring prolonged Foley catheter drainage or developed a urinary tract infection or both. Finally, 25 (45%) patients developed moderate to severe subcutaneous emphysema. Although never a serious problem, this complication, particularly when the face was involved, created such anxiety in patients, their families, and the nurses that we adopted the practice of placing decompressive stab wounds in the anterior chest wall as soon as emphysema progressed higher than the clavicles.

Three patients died within 30 days of operation, resulting in a 5.5% mortality rate. All three died in the hospital. One patient developed rapidly progressive and subsequently fatal pneumonia and died on the sixth postoperative day. Another patient had an indolent course with difficulty weaning from the ventilator. Bronchoscopy documented unsuspected small cell lung cancer. He was subsequently not aggressively treated, according to his wishes and the wishes of the family. The third patient, who had denied a drinking history preoperatively, went into florid delirium tremens on the second postoperative day. It was eventually discovered that he had been a heavy drinker preoperatively and was in the habit of putting vodka in his inhaler. He subsequently died of septic complications of this condition.

## DISCUSSION

Emphysema is a subset of chronic obstructive pulmonary disease, with chronic bronchitis being the other, characterized by, "distention of the air spaces distal to the terminal bronchiole with destruction of alveolar septa." [1] The destruction of parenchyma, almost always by cigarette smoke, is the initial event, with inflation and distension of these weakened areas by inhaled air following. As predicted by the law of Laplace, progressive distension is inevitable, and eventually there are "confluent air spaces—or bullae." [1]

The history of surgery to resect large, dominant or giant bullae is documented.[11,12] Both re-expansion of previously compressed lung and functional improvement are predictable. Although these patients frequently have some element of emphysema, the dominant pathophysiologic feature is the giant bullous. This is a source of some confusion, because of the terminology "bullous emphysema." Essentially, all emphysema is bullous in the strict definitional sense, that is, air spaces in excess of 1 cm. The differentiation of importance is between diffuse emphysema and a process dominated by the presence of a few giant bullae.

Brantigan married the successful history of surgery to excise giant bullae with his prescient understanding of emphysema to develop an operation for the treatment of diffuse bullous emphysema. His procedure, a unilateral thoracotomy and resection of localized emphysematous areas, produced an unacceptably high mortality, which exceeded 15%. Nonetheless, his experiences have benefitted later researchers, as can be seen in the reports by Wakabayashi et al.[7] and Cooper et al.[9]

Wakabayashi et al. used a carbon dioxide laser to ablate peripheral bullous/localized emphysematous areas via the video-assisted thoracic surgery approach in patients with advanced emphysema. Treating one side and one lung at a time, they documented symptomatic improvement, which correlated with enhancement of various objective measures of pulmonary function. However, this was accomplished with considerable morbidity and a mortality rate of 10%.[7]

Cooper et al. returned to the open approach espoused by Brantigan, but used a median sternotomy, which allowed bilateral lung access. Peripheral disease areas were resected using stapling devices and bovine pericardial strips to bolster and minimize postoperative air leaks through the staple line. Three-month follow-up of 20 patients documented symptomatic and objective improvement. Significant anatomic and physiologic reduction in lung volume occurred, consistent with the goals and principles espoused by Brantigan. Further, this was accomplished with modest morbidity and no perioperative deaths in this small series.[9]

As the surgical community works toward an understanding of the role of surgery for emphysema, we must understand some technical and technologic distinctions. When the word "laser" is used, there must be an understanding of the laser specifics. For example, the carbon dioxide laser is a cutting laser with the beam emitted from the laser head rather than a fiber and achieves minimal tissue penetration. A potassium titanyl phosphate laser reacts with pigmented tissue and achieves modest tissue penetration. The free beam YAG laser is in the infrared spectrum, reacts nonspecifically with all tissue, and can penetrate tissue to a depth of 10 mm. Finally, the argon beam coagulator is really a noncontact electrocautery and not a laser. In addition to these free beam mode characteristics, lasers can be attached to a sapphire crystal tip and used in a contact mode with the tip used in contact with tissue. In this mode, the crystal tip heats and controls the laser energy. If it is allowed to adhere to the lungs, tears and air leaks can result.

In conclusion, our group was persuaded by the results of Brantigan, Wakabayashi, and Cooper and their colleagues that there was a legitimate role for surgical treatment of patients with diffuse, bullous emphysema. Our experience documents that significant objective and subjective improvement can be accomplished by unilateral YAG laser reduction pneumonoplasty in patients with diffuse bullous emphysema. Our group will continue to define the role of our approach by documenting the results of sequential treatment of each lung and exploring the possibility of simultaneous bilateral reduction pneumonoplasty.

## Acknowledgements

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## Discussion

DR. JOEL D. COOPER (St. Louis, Missouri): Throughout this century, which is nearing its close, many procedures for the relief of dyspnea have been enthusiastically promoted only to be subsequently discarded when subject to rigorous scientific scrutiny. These include costochrondrectomy, glomectomy, phrenic nerve crush, radical pulmonary denervation, and others. All appeared in their time to produce subjective improvement in some patients, but the results were inconsistent, short-lived, and not associated with measurable functionally significant improvement.

Dr. Little has presented the results achieved by his group with