We performed treatments with a Nd-YAG laser in 27 patients (19 men) with a mean age (± 1 SD) of 63 ± 15 years for incomplete obstruction of the tracheobronchial tree due to non-oat cell malignant neoplasm associated with cough, dyspnea, hemoptysis, or unresolved atelectasis or pneumonia. Sixteen patients had been previously treated with surgery, chemotherapy, or irradiation. Before surgery, their mean values were as follows: Karnofsky score, 41 ± 15 percent; British Medical Research Council dyspnea index, 3.7 ± 0.6; forced vital capacity (FVC), 64 ± 23 percent of predicted; and mean forced expiratory volume in one second (FEV1), 52 ± 19 percent of predicted. Immediate palliative relief was achieved in 23 patients and lasted one-half to six months after a single treatment. After surgery, the mean values were as follows: FVC, 77 ± 26 percent of predicted; FEV1, 74 ± 27 percent of predicted; Karnofsky score, 57 ± 15 percent (p < 0.05); and dyspnea index, 2.8 ± 0.7 (p < 0.05). Complications included one death, and two patients subsequently died of massive pulmonary hemorrhage within seven days of treatment. Rigid bronchoscopy was required in seven patients. We also performed laser treatments in 19 patients (eight men) with a mean age of 64 ± 10 years who had complete bronchial obstruction due to non-oat cell malignant neoplasm; all but one had received previous non-laser treatment. Before surgery the mean values were as follows: Karnofsky score, 30 ± 10 percent; dyspnea index, 3.7 ± 0.5; FVC, 46 ± 14 percent of predicted; and FEV1, 44 ± 19 percent of predicted. Immediate relief was achieved in six cases and lasted 0.25 to 1.5 months after a single treatment. After surgery the mean values were as follows: FVC, 59 ± 5 percent of predicted (p < 0.05); FEV1, 48 ± 13 percent of predicted; Karnofsky score, 34 ± 16 percent; and dyspnea index, 3.4 ± 0.5. Complications included two deaths, one associated with combustion of the outer sheath of the fiberoptic bronchoscope. Rigid bronchoscopy was required in five patients. Results suggest that laser therapy is most beneficial in patients with partial and not totally occluded airways ($\chi^2$, p < 0.05).

Society today is placing greater emphasis on the justification of monetary expenditures in our system for delivery of health care. There is increasing concern about the possible misallocation and overuse of current and new technologies. This takes on an added burden of moral dilemma when treating terminally ill patients. This communication addresses the issue of the clinical appropriateness of the neodymium:yttrium-aluminum-garnet (Nd-YAG) laser in the treatment of tracheobronchial obstruction due to malignant tumor. Currently, this remains an investigational procedure in the United States. Results indicate that treatment with the Nd-YAG laser may provide immediate and temporary palliative relief in 85 percent of the patients treated for incomplete malignant obstruction of large airways, as opposed to 32 percent limited improvement with complete malignant obliteration of the large airways.

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**Laser in Treatment of Lung Cancer**

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Material and Methods

The Nd-YAG laser (Medilas) generates a timed output of up to 80 to 100 W in the infrared wavelength, 1.064 nm, which is conducted by a flexible quartz monofilament. This filament may be passed either through the biopsy channel of a wide-channel fiberoptic bronchoscope (Olympus BF-1TR) or a rigid bronchoscope. Since the laser beam is invisible, a companion beam is simultaneously transmitted that projects a visible spot that allows for accurate aiming. A continuous flow of air is passed simultaneously through a coaxial Teflon sheath to keep the tip of the fiber cool and free of debris.

In practice, we use power of 40 to 60 W with an individual pulse time of 0.4 to 0.7 second in bursts every two seconds, with a target distance of 5 to 10 mm.

All procedures are performed in an operating room with an anesthesiologist present. Most procedures are performed on an outpatient basis or with a stay overnight. Patients are requested to refrain from eating or drinking for at least 12 hours prior to the procedure. Preoperative intramuscular medication consists of atropine (0.6 to 1 mg) and meperidine (50 mg). Topical anesthesia of the airway is achieved with 0.5 percent pontocaine; and for adequate intravenous sedation, diazepam, Fentanyl, and thiopental sodium may be required. Controlled mechanical ventilation and inhalational anesthetics infrequently were used. Enriched oxygen up to 100 percent has been required in selected patients, and arterial cannulas were required in selected patients to monitor arterial blood gas levels. In practice, we have used the flexible fiberoptic bronchoscope to deliver the laser beam in almost every patient, and when necessary, it easily passes through the rigid bronchoscope. Coagu-
lated and necrotic tumor, when not vaporized, is removed through the biopsy channel or through the rigid bronchoscope using aspirator and biopsy techniques.

Our indications to perform the laser treatment included the following: (1) obstructed airway with unresolved distal atelectasis, pneumonia, or abscess; (2) (associated) uncontrolled cough; (3) unrelenting dyspnea; and (4) recurrent hemoptysis in patients who were previously treated with other methods or who refused other forms of treatment. Detailed informed consent was obtained in each patient, consistent with guidelines from the manufacturer's specifications and the Food and Drug Administration, California Patient Bill of Rights, and local hospital institutional review committee. Immediate palliative improvement was determined by enlargement or recannulation of a previously obstructed airway with relief of dyspnea/cough, hemoptysis, or atelectasis/pneumonia. Isolated enlargement or recannulation of an airway without clinical, radiographic, or physiologic improvement was not judged to be a successful result. In all patients who exhibited atelectasis, it was present radiographically for less than one month.

Prior to laser therapy, we measured the patient's dyspnea index and modified it such that a dyspnea index of 1 is shortness of breath only upon stair climbing; 2 is inability to walk a mile on level land at normal pace; 3 is shortness of breath upon walking 100 yds on level land; and 4 is shortness of breath with slight exertion after dressing or talking. The Karnofsky score and pulmonary function (Collins) were measured, and results were compared to previously published standards.\(^{1,2}\)

**Results**

The patients were divided into two groups. One group consisted of 27 patients (19 men), with a mean age of 63 ± 15 years (± SD) who had incomplete malignant airway obstruction such that a partial airway lumen could be visualized. The other group consisted of 19 patients (eight men) with a mean age of 64 ± 10 years who had complete bronchial obstruction such that the distal airway lumen could not be visualized. Unrelenting cough or dyspnea was the major indication for laser treatment. In addition, recurrent hemoptysis was predominant in seven patients in the group with incomplete airway obstruction, whereas it was present in three patients in the group with complete airway obstruction.

Figure 1 describes the location of the malignant tumors in the two groups. We used the laser in patients who had lesions in the trachea, left main-stem bronchus, right main-stem bronchus, and in two instances including bronchus intermedius. When the tumor involved carina and both main-stem bronchi, we arbitrarily assigned it the bronchus which was predominantly involved.

Figure 2 describes the cell type and incidence of previous or concurrent therapy in both groups. At the time of laser therapy, most patients had already exhausted all other available therapeutic alternatives.

**Figure 2.** Incidence of cell type and previous or concurrent other therapy (Rx) including radiotherapy, pulmonary resection, or chemotherapy in patients with partially occluded airway and those with totally occluded airway (shaded area). S, Squamous cell carcinoma; A, adenocarcinoma; U, large cell undifferentiated carcinoma; and M, metastatic carcinoma.

**Figure 3.** Preoperative laser evaluation of patients with partial and totally occluded airways (shaded area) (mean ± SD). K, Karnofsky score expressed as percent; FVC, FEV\(_I\), and FEF25-75% are expressed as percent of predicted; and D, dyspnea index as described in text. Asterisk indicates significant difference (p<0.05) between two groups.
However, eight of the 11 patients with incomplete obstruction and in the one patient with complete obstruction, no previous conventional therapy was possible because these patients presented in acute respiratory distress associated with a tumor in a critical location.

Figure 3 describes the preoperative evaluation of both groups. All patients were markedly dyspneic with abnormal pulmonary function and Karnofsky scores. The group with incomplete airway obstruction had the following mean values: Karnofsky score, 41 ± 15 percent; dyspnea index, 3.7 ± 0.6; forced vital capacity (FVC), 64 ± 23 percent of predicted; forced expiratory volume in one second (FEV1), 52 ± 19 percent of predicted; and mean forced expiratory flow over the middle half of the FVC (FEF25-75%), 29 ± 15 percent. The group with complete airway obstruction had mean values as follows: Karnofsky score, 30 ± 10 percent; dyspnea index, 3.7 ± 0.5; FVC, 46 ± 14 percent of predicted; FEV1, 44 ± 13 percent of predicted; and FEF25-75%, 33 ± 12 percent of predicted. The Karnofsky score and FVC were significantly worse in the group with complete airway obstruction (p<0.05).

Following laser therapy, 23 of the 27 patients in the group with incomplete or partially occluding lesions had immediate palliative relief, whereas only six of 19 patients with completely obstructed airways had similar improvement. This difference was significant (χ²; p<0.05). Figure 4 describes the incidence of success by location following laser therapy. In the group with incomplete obstruction of the airway, after a single treatment, tracheal patency could be maintained 2.7 ± 1.3 months, in right main bronchus, 2.5 ± 1.3 months, and in left main bronchus, 1.5 ± 0.7 months before additional laser therapy was necessary. Furthermore, in three patients with incomplete main-stem lesions, the successful laser therapy allowed them to undergo subsequent irradiation therapy, Whereas initially they could not tolerate it and would have otherwise died. This is in contrast to the patients with complete airway obstruction whose improvement persisted in the right main bronchus only 0.6 ± 0.2 months, and left main bronchial patency could be maintained only 0.5 ± 0.2 months. Additionally, in two cases when the completely obstructed main-stem lesion was relieved, no pulmonary ventilation or reperfusion occurred. Rigid bronchoscopy was required in five patients in this group and in seven patients in the group with incomplete airway obstruction.

After the laser therapy in the group with incomplete airway obstruction, the mean values were as follows: Karnofsky score, 57 ± 18 percent; dyspnea index, 2.8 ± 0.7; FVC, 77 ± 26 percent of predicted; FEV1, 74 ± 27 percent of predicted; and FEF25-75%, 62 ± 24 percent of predicted. The improvement following laser therapy in the Karnofsky score, dyspnea index, and FEF25-75% was significant (p<0.05). The most dramatic clinical and functional improvement occurred in patients with tracheal lesions (Fig 5). In the group with complete airway obstruction, the mean values after laser therapy were as follows: Karnofsky score, 34 ± 16 percent; dyspnea index, 3.4 ± 0.5; FVC, 59 ± 8 percent of predicted; FEV1, 48 ± 13 percent of predicted; and FEF25-75%, 42 ± 16 percent of predicted. Only the FVC showed a significant improvement when compared to the value before laser therapy (p<0.05).

In the group with incomplete airway obstruction, there was one perioperative death in a patient who was undergoing a second laser therapy for recurrent tumor. This patient was very dyspneic, with gasping respirations, and adequate gas exchange could not be maintained. In two other patients, death was associated with massive hemorrhage, within two weeks of laser
therapy. Permission for autopsy was refused. Before surgery, the patients had proven extensive mediastinal metastases.

In the group with complete airway obstruction, there were two deaths. Both patients were bedridden with a dyspnea index of 4 and gasping respirations, Karnofsky scores of 15, FEV$_1$ of 1.5 L (58 percent of predicted) and 1.0 L (30 percent of predicted), and resting arterial oxygen tensions of 50 and 52 mm Hg associated with complete obstruction of the right main-steam bronchus with mediastinal spread in one case and with obstruction of the carina and left main-stem bronchus and mediastinal spread in the other case. In the latter case, following partial opening of the left main-stem bronchus, the partially inflamed left lung now revealed diffuse metastatic nodules. In this patient during the laser therapy, sparks from the burnt tissue ignited and destroyed the outer sheath of the fiberoptic bronchoscope. The bronchoscope was immediately removed, and no obvious tissue burns resulted. Both patients succumbed to a respiratory death with progressive hypoxemia within three days of laser therapy.

The surgical procedure and related hospital costs are estimated at $2,200 per laser treatment, with an additional professional component of $1,200. For comparison, the average hospital's daily charges are $1,000. The surgical procedure generally consumes two hours. Survival of the patients with incomplete obstruction was extended 4.9 ± 3.2 months (mean ± 1SD) and 2.0 ± 1.7 months for the patients with complete obstruction, and for patients with tracheal obstruction, 6.2 ± 3.3 months (p<.05).

**DISCUSSION**

The results of this study indicate that the Nd-YAG laser provide immediate palliative relief in 23 of 27 symptomatic patients with incomplete airway obstruction associated with life-threatening cough, dyspnea, or hemoptysis, whereas only limited success was obtained in 9 of 19 patients with complete airway obstruction. The present results confirm our initial experiences. The French investigators, Toty et al. and Dumon et al., developed the pioneering techniques that allowed laser bronchoscopy to clinically mature. Toty et al. reported a success rate of approximately 75 percent in 72 patients, and similar success was noted in 63 cases by Dumon et al.; however, these two teams of experienced investigators did not separate patients by extent of airway obstruction or provide physiologic or follow-up data. In an English study, Hetzel et al. reported temporary success in ten of 19 patients with partial airway obstruction, but only short-lived improvement in two of nine patients with complete airway obstruction. This, together with our initial and present results, suggests that patients with complete main-steam bronchial obstruction are, as a group, poorly responsive to laser therapy. They have more extensive tumor involvement, a higher dyspnea index, lower Karnofsky scores, and further impairment in pulmonary function. These patients remain at high risk and poorly tolerate rigid bronchoscopy, which is the recommended surgical procedure. Other than for control of hemoptysis, recannulation and subsequent re-expansion of lung due to a malignant, totally obstructed main-stem bronchus yield poor results. It is technically very difficult to clearly separate the obstructing tumor from the bronchial wall, which is often invaded with tumor, and this often precludes visual perception of the branching of distal airways. Furthermore, combined extrinsic tumor compression of the airway further complicates and reduces the effectiveness of laser therapy. In addition, recannulation and ventilation to a nonperfused lung would create the additional burden of physiologic dead space. Unfortunately, there is no way to predict those resultant ventilation-perfusion interrelationships.

The potential relationship between laser therapy and pulmonary hemorrhage must be stressed. While it may occur as a complication of laser therapy, it most likely results from tumor invasion into a major blood vessel. In a preliminary report, McDougall and Cortese noted two fatal hemorrhagic complications of laser therapy for bronchogenic carcinoma.

The complication of ignition of the fiberoptic bronchoscope has been reported and may be avoided if only rigid bronchoscopy is used; however, if the fiberoptic bronchoscope is used, careful attention at all times must address the location and cleanliness of the laser fiber tip. It is sometimes unavoidable to use a high concentration of inspired oxygen.

The French investigators favor the use of the rigid bronchoscope to deliver the laser fiber, as well as to provide better access to remove the involved tumor. Based on our own experiences, we would emphasize the importance of the position of the laser tip, since we believe that its poor location was probably most responsible for the ignition of the fiberoptic bronchoscope in our one case. The laser tip should extend at least 0.5 cm beyond the fiberoptic bronchoscope and should not be closer to the target tissue by a similar length. Subsequently, with more emphasis on proper location of the laser tip, we have had no similar ignition problems, despite using high concentrations of inspired oxygen whenever needed. The drawback of using the rigid bronchoscope is the need for deeper anesthesia, which may result in further respiratory embarrassment. Brutinel et al have documented the deterioration of gas exchange during laser therapy. While the fiberoptic bronchoscope may be adequate in many cases, the rigid bronchoscope is necessary and mandatory to remove large pieces of coagulated tumor.

CHEST / 86 / 5 / NOVEMBER, 1984    665
that are obstructing the trachea or main-stem bronchi. We favor the use of both fiberoptic and rigid bronchoscopes with intravenously administered sedatives and the patient still breathing on his own.

Finally, we must consider the issue of the clinical justification of this relatively expensive procedure. Once the technical challenges of the procedure are matured, laser bronchoscopy can be performed on a day-care basis, or with only an overnight hospitalization. It would appear to offer excellent palliative relief in patients with life-threatening dyspnea, cough, or hemoptysis, where there currently exists no other medical alternative. Optimal results will be achieved in patients who have partial malignant obstruction of the trachea or main-stem bronchi. We are currently the major referral center for the greater Los Angeles area, with a population of approximately 10 million. With increased education and awareness of physicians and patients, it could be anticipated there would be additional demands for laser therapy; however, based on our 14-month referral experience, this procedure, if limited primarily to partial obstruction of the trachea and main-stem bronchi, will never burden the physician manpower resources of additional referral centers in this area that would be anticipated. Furthermore, we believe that the biologic and monetary savings would far outweigh the prolonged cost of lengthy hospitalization of asphyxiating morbid patients in whom a reasonable therapeutic alternative (i.e., laser bronchoscopy) exists. While the financial resources of society are limited in health care delivery, we believe that this new technology is clinically justified and should be disseminated.

REFERENCES