

## Flammability of Endotracheal Tubes during Nd-YAG Laser Application in the Airway

Bennie Geffin, M.D.,\* Stanley M. Shapshay, M.D., F.A.C.S.,† Gary S. Bellack, M.D.,‡  
Kevin Hobin,§ Suzanne E. Setzer, B.S.¶

The effects of the neodymium-yttrium aluminum garnet (Nd-YAG) laser on several commonly used endotracheal tubes were examined. Six different types of tubes were tested for flammability. Three tubes were clear, transparent polyvinylchloride with black lettering on the surface. One was yellow-green silicone rubber with green lettering on the surface. One, which was opaque gray with no printing or marks on it, was designed specifically for use with the carbon dioxide (CO<sub>2</sub>) laser, and one was opaque red rubber with black letters printed on the surface. The latter was tested with and without a wrapping of reflective aluminum tape. On each tube a clear, unmarked area and an area with printing were tested. In each area the tube was impacted by the laser at three to five points. Pulsed and continuous patterns of laser impact were used. Power ranged from 20 to 50 W. The clear polyvinylchloride tubes were not damaged by a pulsed pattern of exposure in unmarked areas. Segments with black printing or marks were consistently damaged. Continuous laser exposure consistently damaged clear portions of the tube. In clear unmarked areas, silicone rubber tubes were damaged with the pulsed pattern when exposure reached 50 W for 1 s. Areas with green lettering were damaged at the lowest level of exposure. Continuous laser exposure at 30 W damaged clear portions of these tubes after 7 s. Opaque red rubber and opaque gray tubes were damaged at the lowest levels of exposure in both clear and marked areas with pulsed and continuous laser emission. A wrapping of reflective aluminum tape offered no protection. The study demonstrated that all the tubes tested are vulnerable to damage when exposed to the Nd-YAG laser. Transparent, unmarked polyvinylchloride is relatively resistant. Colored markings on clear tubes and colored opaque or semiopaque tubes absorb the light energy and are easily damaged. In contrast to CO<sub>2</sub> laser exposure the covering of red rubber tubes with reflective

aluminum tape offers no protection. (Key words: Anesthetic equipment: endotracheal tubes, flammability; laser, Nd-YAG. Complications: Airway burns; Explosions.)

THE CLINICAL USE of lasers in surgery began in 1973 with applications of the carbon dioxide (CO<sub>2</sub>) laser in otolaryngology. The precision with which this concentrated energy is focused permits the temperature of local tissue to increase greatly, and therefore the laser can incise or vaporize tissue with great accuracy, minimizing tissue trauma.

General anesthesia is usually employed for laser surgery involving the upper airway. This creates a potentially hazardous situation, and serious mishaps have been reported.<sup>1-3</sup> CO<sub>2</sub> lasers, in particular, have inadvertently damaged endotracheal tubes through which oxygen-rich mixtures of anesthetic gases were being delivered with resultant fires and explosions that have led to injuries and deaths. Evaluation of the incendiary effects of the CO<sub>2</sub> laser on the materials of various endotracheal tubes<sup>4,5</sup> and the development of techniques for protection of the endotracheal tube from damage<sup>5,6</sup> have improved the safety of CO<sub>2</sub> laser surgery in the upper airway during endotracheal anesthesia.

Recently, the neodymium-yttrium aluminum garnet (Nd-YAG) laser has become available for endoscopic application in the tracheobronchial tree. Its beam can be transmitted by flexible optic fibers. This permits successful endoscopic resection of previously untreatable recurrent or persistent malignant disease of the major airways. Commonly this is performed with the patient receiving general anesthesia.<sup>7-10</sup>

Although current experience suggests that clinical applications of the Nd-YAG laser will expand, its effects on endotracheal tubes previously have not been assessed. We examined the effects of the Nd-YAG laser on several commonly used endotracheal tubes. Our objectives were: 1) evaluation *in vitro* of the effect of the Nd-YAG laser on currently available endotracheal tubes and determination of the flammability of the tubes; 2) definition of safe limits of exposure for endotracheal tubes; and 3) identification of an endotracheal tube for clinical use that would not be damaged when inadvertently exposed during Nd-YAG laser treatments.

\* Department of Anesthesiology; Assistant Clinical Professor in Anesthesia, Harvard Medical School. Present address: Massachusetts Eye and Ear Infirmary, Boston.

† Department of Otolaryngology—Head and Neck Surgery and Eleanor Naylor Dana Laser Research Laboratory; Assistant Professor, Department of Otolaryngology, Boston University School of Medicine.

‡ Department of Otolaryngology—Head and Neck Surgery; Chief Resident, Boston University-Tufts University combined Otolaryngology Residency Training Program.

§ Department of Anesthesiology, Lahey Clinic Medical Center.

¶ Chief Laser Technician, Eleanor Naylor Dana Laser Research Laboratory.

Received from the Department of Anesthesiology, Department of Otolaryngology—Head and Neck Surgery, and the Eleanor Naylor Dana Laser Research Laboratory, Lahey Clinic Medical Center, Burlington, Massachusetts. Accepted for publication June 5, 1986.

Address reprint requests to Dr. Shapshay: Department of Otolaryngology—Head and Neck Surgery, Lahey Clinic Medical Center, 41 Mall Road, Burlington, Massachusetts 01805.

TABLE 1. Clear Polyvinylchloride Tubes

Exposure Time	Area of Tube Exposed	Power Setting			
		20 W	30 W	40 W	50 W
0.5 s	Clear Black printing	No visible damage 1* Black burn 1.0 mm 2† Superficial melting 3‡ Black burn 2.0 mm	No visible damage Black burn 1.5 mm Black burn 0.5 mm Black burn 2.0 mm	No visible damage Black burn 1.5 mm Black burn 1.0 mm Black burn 2.0 mm	No visible damage Black burn, deep crater Black burn 2.0 mm, deep crater Deep black burn 2.6 mm
1.0 s	Clear Black printing	No visible damage 1 Black burn 1.0 mm 2 Black burn 0.5 mm 3 Black burn 1.5 mm pinpoint perforation	No visible damage Deep black burn 1.0 mm Perforation Perforation	No visible damage Deep black burn, crater 1.6 mm Perforation, flame —	No visible damage Black burn, deep crater, 1.6 mm — —
2.0 s	Clear	No visible damage	No visible damage	No visible damage	No visible damage
Continuous	Clear	1 Superficial burn 8 s 2 No damage at 20 s 3 —	Perforation 5 s Melting 10 s Superficial burn 30 s	— Crater 7 s Superficial burn 30 s	— — —

\* Rusch, Inc., 53 West 23rd St., New York, NY 10010.

‡ National Catheter Co., Mallinckrodt, Inc., Argyle, NY 12809.

† Sheridan Catheter Corp., Argyle, NY 12809.

### Methods and Materials

Six different types of endotracheal tubes were tested. Three tubes were transparent polyvinylchloride with black lettering (Sheridan Catheter Corp., Argyle, NY; Rusch, Inc., New York, NY; and National Catheter Co., Mallinckrodt, Inc., Argyle, NY). One tube was yellow-green silicone rubber with green lettering on its surface (Surgitech®, Xomed, Inc., Jacksonville, FL). One tube, which was specifically designed for use with the CO<sub>2</sub> laser, was opaque gray without lettering (Xomed, Inc.). One tube was opaque red rubber with black lettering (Rusch, Inc.).

Two tubes of each type were studied. The laser beam was focused on two areas of each tube, *i.e.*, a clear, unmarked area and an area containing colored lettering. In the case of the opaque red rubber tube, additional testing

was carried out with the tube wrapped with reflective aluminum tape (3/8 in, product number 49-502, Radio Shack Corp., Fort Worth, TX).

The source of the laser beam was a 20- to 100-W continuous-wave Nd-YAG laser (Cilas Company, Paris, France). The delivery system consisted of a 2.4-mm-diameter flexible quartz catheter with Teflon® covering cooled by a continuous coaxial flow of nitrogen, which also diminished flammability. When operative, the fiber was kept at a constant 1 cm from the test site, creating a 2-mm laser spot size. The target area was made visible by a coaxial red helium neon pilot laser. The laser was activated with foot pedal control. Power varied from 20 to 50 W, and exposure ranged from 0.5 s to continuous.

In an attempt to simulate the clinical state, a constant flow of 50% oxygen was maintained through the endo-

TABLE 2. Silicone Rubber Tube\*

Exposure Time	Area of Tube Exposed	Power Setting			
		20 W	30 W	40 W	50 W
0.5 s	Clear Green printing	No visible damage Black burn 2.0 mm	No visible damage Black burn 2.0 mm	No visible damage Black burn 2.5 mm	No visible damage Black burn 3.0 mm
1.0 s	Clear Green printing	No visible damage Black burn 2.0 mm	No visible damage Black burn 3.0 mm	No visible damage Black burn 3.0 mm	Pinpoint burn Black burn 3.0 mm, deep crater
2.0 s	Clear Green printing	No visible damage Black burn 3.0 mm	No visible damage —	— —	— —
Continuous	Clear	No visible damage at 30 s	Charred black at 7 s	—	—

\* Surgitech®, Xomed Inc., 6743 Southpoint Drive North, Jacksonville, FL 32216.

TABLE 3. Opaque Tubes

Exposure Time	Area of Tube Exposed	Power Setting			
		20 W	30 W	40 W	50 W
0.5 s	Clear	5* Superficial burn 6† Flame	Superficial burn Flame Flame	Flame Flame Flame	Flame Flame Flame
	Black printing	5 Flame			
1.0 s	Clear	5 Flame 6 Flame			
2.0 s	Clear	Flame			

\* The laser beam was applied to one red rubber tube (Rusch, Inc., 53 West 23rd St., New York, NY 10010) after wrapping with foil. At the lowest level of exposure of 20 W for 0.5 s the foil was perforated,

and rubber was burned.

† Opaque gray tube, resistant to CO<sub>2</sub> laser (Xomed, Inc., 6743 Southpoint Drive, Jacksonville, FL 32216).

tracheal tube during the testing period. In each experiment the portion of the tube being tested was impacted at three to five points for 0.5 s, 1.0 s, and 2 s at power levels of 20 W, 30 W, 40 W, and 50 W. Testing was halted when severe damage was apparent. In the continuous mode a power level of 20 W was used initially. When no damage was noted after 20 s, the power was increased, and the process was repeated.

### Results

Our findings using clear polyvinylchloride tubes, silicone rubber tubes, and opaque red rubber and opaque gray tubes are summarized in tables 1, 2, and 3, respectively.

#### CLEAR POLYVINYLCHLORIDE TUBES

Pulsed emission with the Nd-YAG laser did not cause visible damage to unmarked portions of the clear polyvinylchloride tubing. In contrast, areas with black lettering on these same tubes were invariably damaged when exposed to identical patterns of laser emission. The extent and severity of this damage increased as exposure increased, progressing from superficial discoloration to crater formation and tube perforation with production of ash, smoke, molten plastic, and flame (fig. 1). The continuous mode of emission consistently resulted in damage to the clear portions of these tubes.

#### SILICONE RUBBER TUBE

The silicone rubber tube, which was opalescent yellow-green, was damaged in clear areas by the intermittent pattern of laser emission when power exceeded 40 W at 1-s exposure. Segments with green lettering were damaged at all levels of exposure. A continuous pattern of emission caused damage to clear portions of this tube at 30 W after 7 s.

#### OPAQUE RED RUBBER AND OPAQUE GRAY TUBES

The opaque red rubber tube and the opaque gray tube demonstrated visible thermal damage at the lowest levels of exposure when unmarked portions were exposed to either intermittent or continuous patterns of emission (fig. 2). When marked portions were exposed, damage was considerably more severe. Wrapping with silver reflective aluminum tape offered no protection (fig. 3).

### Discussion

The Nd-YAG laser operates in the invisible spectrum of light at a wavelength of 1,060 nm. It differs from the CO<sub>2</sub> laser, which is currently in more common use, not only in wavelength (10,600 nm) but also in its biologic effect on tissues. The Nd-YAG laser penetrates tissues more deeply (up to 5–7 mm, depending on power density and exposure as well as on color and density of soft tissue) and more diffusely than the CO<sub>2</sub> laser. Considerable forward and back scatter into tissue, not visibly apparent to

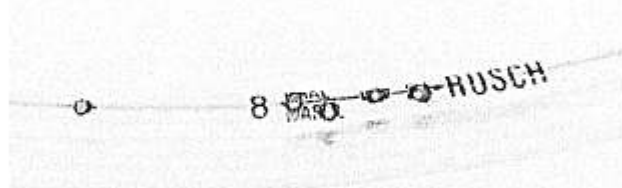


FIG. 1. Transparent polyvinylchloride tube demonstrates predilection for damage in area of black markings and lettering.

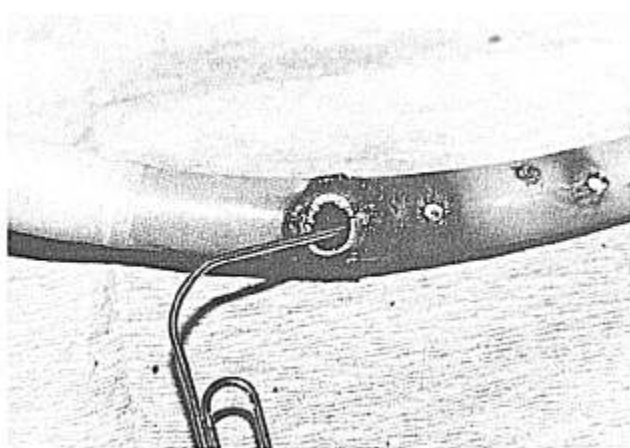


FIG. 2. Red rubber tube damaged by exposure to Nd-YAG laser in area where no lettering or markings were present.

the clinician, forms the basis for coagulation and hemostasis of tissue. An added advantage of the Nd-YAG laser is that it can be transmitted by fiberoptics, which makes it particularly amenable to surgical use in the airway.

Earlier *in vitro* studies (S. M. Shapshay, M.D., unpublished data) showed that dark colors, such as purple and black, absorb the wavelength of the Nd-YAG extremely well but that light colors permit greater penetration and less thermal concentration. Results of our study confirm these data and show that endotracheal tubes that have colored markings on their surface or in their substance or tubes made with colored materials absorb light from the Nd-YAG laser with resultant thermal damage.

Predictably, the extent of damage depended on the power and the duration of exposure. Mild damage manifested as external discoloration. More severe damage included crater formation, perforation, and disruption in the continuity of the endotracheal tube. Flaring and open

flame occurred in the most severe instances. The clear polyvinylchloride tubes were relatively resistant to damage from the Nd-YAG laser. This contrasts with their extreme flammability when exposed to the CO<sub>2</sub> laser.<sup>5</sup>

Damage to the endotracheal tube with perforation and disruption can lead to loss of control over the airway. The obvious major problems, however, relate to the possibility of flame and explosion. Severe injuries and deaths have been reported<sup>1-3</sup> in such circumstances.

Recent experience has shown that the Nd-YAG laser provides effective palliation in selected patients with neoplasms of the airway and in patients with fibrotic strictures that block the airway.<sup>7-10</sup> Dumon *et al.*<sup>11</sup> reported the results of a multicentric study in which 1,503 treatments were performed. These authors<sup>11</sup> and other investigators<sup>12,13</sup> have recommended the use of a rigid metal bronchoscope to maintain the airway in conjunction with spontaneous ventilation and intravenous anesthesia.

On the other hand, Warner *et al.*<sup>14</sup> reported a series of 22 patients with life-threatening inoperable obstruction of a major bronchus who underwent treatment with the Nd-YAG laser using endotracheal tubes and anesthesia with diazepam, fentanyl, and/or enflurane. Ventilation was controlled after paralysis with infusion of succinylcholine or a nondepolarizing relaxant. The type of endotracheal tube used was unspecified, but no untoward effects of the laser on the endotracheal tube were noted. Warner *et al.*<sup>14</sup> concluded that the risk of combustion to the endotracheal tube in these circumstances is low because the laser beam is delivered *via* the fiber, which is placed distal to the endotracheal tube. Fires have, however, been reported<sup>15,16</sup> when hot, carbonized fragments of resected tumor ignited the distal end of the endotracheal tube.

## Conclusion

This study demonstrates that all of the endotracheal tubes tested are vulnerable to thermal damage when exposed to the Nd-YAG laser. When the pattern and the technique of laser emission were similar to that used clinically, no thermal damage to the clear, unmarked segments of polyvinylchloride tubes was evident. The colored markings on the transparent polyvinylchloride tubes and the tubes that were colored, opaque, or semiopaque absorbed light energy and were damaged. Although reflective aluminum tape was effective in protecting tubes from exposure to the CO<sub>2</sub> laser, the tape offered no protection from the Nd-YAG laser. These findings suggest that when an endotracheal tube is required for management of the airway, a polyvinylchloride tube that is transparent and without markings is most appropriate. These tubes are not immune to thermal damage, however. Intraoperative soiling of the tubes with blood or tissue products may

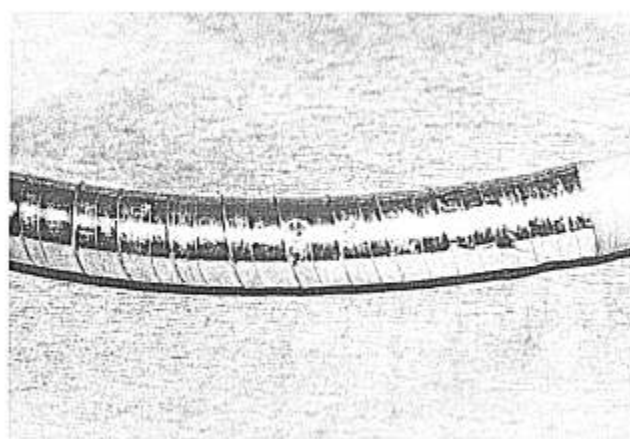


FIG. 3. Red rubber tube wrapped with protective aluminum foil perforated by Nd-YAG laser emission.

create colored marks that further increase their vulnerability. We therefore recommend that the use of endotracheal tubes be avoided when possible during application of the Nd-YAG laser in the tracheobronchial tree.

### References

1. Cozine K, Rosenbaum LM, Askanazi J, Rosenbaum SM: Laser-induced endotracheal tube fire. *ANESTHESIOLOGY* 55:583-585, 1981
2. Vourc'h G, Tannieres M, Freche G: Ignition of a tracheal tube during laryngeal laser surgery (letter). *Anaesthesia* 34:685, 1979
3. Snow JC, Norton ML, Suluja JS, Estanislao AF: Fire hazard during CO<sub>2</sub> laser microsurgery on the larynx and trachea. *Anesth Analg* 55:146-147, 1976
4. Treyve E, Yarrington CT Jr, Thompson GE: Incendiary characteristics of endotracheal tubes with the carbon dioxide laser: An experimental study. *Ann Otol Rhinol Laryngol* 90:328-330, 1981
5. Patel KF, Hicks JN: Prevention of fire hazards associated with use of carbon dioxide lasers. *Anesth Analg* 60:885-888, 1981
6. LeJeune FE Jr, Guice C, LeTard F, Marice H: Heat sink protection against laser endotracheal cuffs. *Ann Otol Rhinol Laryngol* 91:606-607, 1982
7. Toty L, Personne C, Colchen A, Vourc'h G: Bronchoscopic management of tracheal lesions using the neodymium yttrium aluminum garnet laser. *Thorax* 36:175-178, 1981
8. Dumon JF, Reboud E, Garbe L, Aucomte F, Meric B: Treatment of tracheobronchial lesions by laser photoresection. *Chest* 81: 278-284, 1982
9. McDougall JC, Cortese DA: Neodymium-YAG laser therapy of malignant airway obstruction: A preliminary report. *Mayo Clin Proc* 58:35-39, 1983
10. Shapshay SM, Dumon JF, Beamis JF Jr: Endoscopic treatment of tracheobronchial malignancy: Experience with Nd:YAG and CO<sub>2</sub> lasers in 506 operations. *Otolaryngol Head Neck Surg* 93:205-210, 1985
11. Dumon JF, Shapshay SM, Bourcereau J, Cavaliere S, Meric B, Garbi N, Beamis J: Principles for safety in application of Nd:YAG laser in bronchology. *Chest* 86:163-168, 1984
12. Shapshay SM: Bronchoscopic surgery using the Nd-YAG laser, Complications of Laser Surgery of the Head and Neck. Edited by Fried MP, Kelly JH, Strome M. Chicago, Year Book Medical Publishers (In press)
13. Vourc'h G, Tannieres ML, Toty L, Personne C: Anesthetic management of tracheal surgery using the neodymium-yttrium-aluminum-garnet laser. *Br J Anaesth* 52:993-997, 1980
14. Warner ME, Warner MA, Leonard PF: Anesthesia for neodymium-YAG (Nd-YAG) laser resection of major airway obstructing tumors. *ANESTHESIOLOGY* 60:230-232, 1984
15. Casey KR, Fairfax WR, Smith SJ, Dixon JA: Intratracheal fire ignited by the Nd-YAG laser during treatment of tracheal stenosis. *Chest* 84:295-298, 1983
16. Hirschman CA, Smith J: Indirect ignition of the endotracheal tube during carbon dioxide laser surgery. *Arch Otolaryngol* 106: 639-641, 1980