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LABORATORY REPORT

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

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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_2) 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_2 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_2) 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.[1–3] CO_2 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_2 laser on the materials of various endotracheal tubes[4,5] and the development of techniques for protection of the endotracheal tube from damage[5,6] have improved the safety of CO_2 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.[7–10]

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.

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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	No visible damage	No visible damage	No visible damage	No visible damage
	Black printing	1* Black burn 1.0 mm	Black burn 1.5 mm	Black burn 1.5 mm	Black burn, deep crater
		2† Superficial melting	Black burn 0.5 mm	Black burn 1.0 mm	Black burn 2.0 mm, deep crater
		3‡ Black burn 2.0 mm	Black burn 2.0 mm	Black burn 2.0 mm	Deep black burn 2.6 mm
1.0 s	Clear	No visible damage	No visible damage	No visible damage	No visible damage
	Black printing	1 Black burn 1.0 mm	Deep black burn 1.0 mm	Deep black burn, crater 1.6 mm	Black burn, deep crater, 1.6 mm
		2 Black burn 0.5 mm	Perforation	Perforation, flame	—
		3 Black burn 1.5 mm pinpoint perforation	Perforation	—	—
2.0 s	Clear	No visible damage	No visible damage	No visible damage	No visible damage
Continuous	Clear	1 Superficial burn 8 s	Perforation 5 s	—	—
		2 No damage at 20 s	Melting 10 s	Crater 7 s	—
		3 —	Superficial burn 30 s	Superficial burn 30 s	—

* Rusch, Inc., 53 West 23rd St., New York, NY 10010.
† Sheridan Catheter Corp., Argyle, NY 12809.
‡ National Catheter Co., Mallinckrodt, Inc., 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_2 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 (⅜ 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	No visible damage	No visible damage	No visible damage	No visible damage
	Green printing	Black burn 2.0 mm	Black burn 2.0 mm	Black burn 2.5 mm	Black burn 3.0 mm
1.0 s	Clear	No visible damage	No visible damage	No visible damage	Pinpoint burn
	Green printing	Black burn 2.0 mm	Black burn 3.0 mm	Black burn 3.0 mm	Black burn 3.0 mm, deep crater
2.0 s	Clear	No visible damage	No visible damage	—	—
	Green printing	Black burn 3.0 mm	—	—	—
Continuous	Clear	No visible damage at 30 s	Charred black at 7 s	—	—

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

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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	Superficial burn	Flame	Flame
		6† Flame	Flame	Flame	Flame
	Black printing	5 Flame	Flame	Flame	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_2 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_2 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_2 laser. Considerable forward and back scatter into tissue, not visibly apparent to

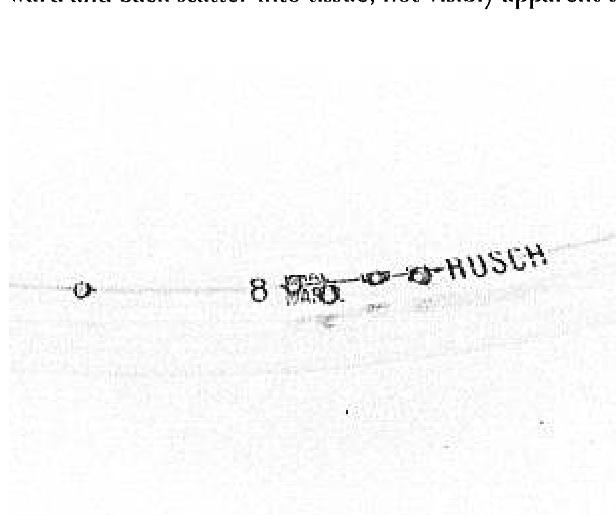

FIG. 1. Transparent polyvinylchloride tube demonstrates predilection for damage in area of black markings and lettering.

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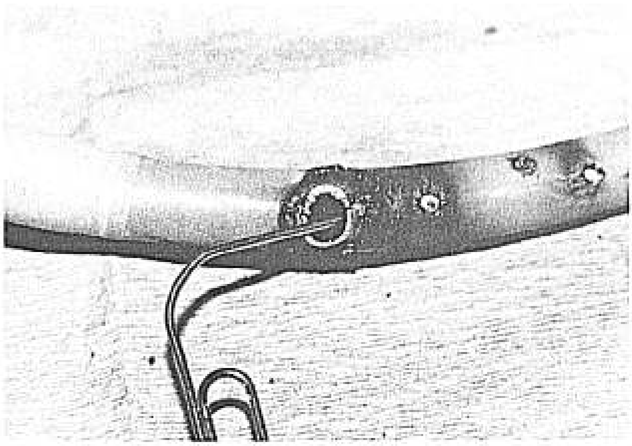

FIG. 2. Red rubber tube damaged by exposure to Nd-YAG laser in area where no lettering or markings were present.

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_2 laser.[5]

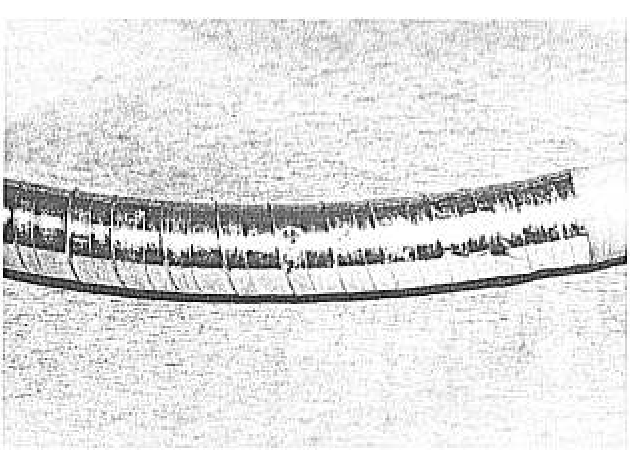

FIG. 3. Red rubber tube wrapped with protective aluminum foil perforated by Nd-YAG laser emission.

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[1–3] 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.[7–10] Dumon *et al.*[11] reported the results of a multicentric study in which 1,503 treatments were performed. These authors[11] and other investigators[12,13] 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.*[14] 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.*[14] 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[15,16] 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_2 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

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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.

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