Anesthesiology
62:274–277, 1985

Helium Retards Endotracheal Tube Fires from Carbon Dioxide Lasers

Annette G. Pashayan, M.D., and Joachim S. Gravenstein, M.D.†*

Polyvinyl chloride (PVC) endotracheal tube segments were exposed to a 5.0-W CO_2 laser beam in the presence of different fractions of oxygen and either helium or nitrogen. Time from onset of exposure until ignition was recorded, and mean time to ignition (MTI) was calculated after 10 exposures with the same gas mixture. A second series was done with 40% oxygen in either nitrogen or helium and a laser intensity of 7.5, 10.0, or 12.5 W; a third with 40% oxygen, 60% helium, and 2% halothane and a 10.0-W laser beam; and a fourth with 40% oxygen and 60% helium and a 10.0-W laser beam directed at the radioopaque barium sulfate stripe on the tube. With 5.0-W and 20% oxygen in either nitrogen or helium, segments did not ignite. With concentrations of oxygen greater than 20% in nitrogen, segments ignited sooner than with comparable concentrations in helium: MTI_{He} = 55.6 s and MTI_{N_2} = 27.6 s in 40% oxygen ($P < 0.05$). Sixty per cent helium remained protective at laser intensities up to 10.0 W (MTI_{He} = 42.6 s *vs.* MTI_{N_2} = 14.3 s) ($P < 0.05$).

However, at 12.5 W, MTI_{He} = 11.5 s and MTI_{N_2} = 11.3 s. Two per cent halothane in 40% oxygen and 60% helium reduced MTI_{He} to 25.3 s compared with 42.3 s without halothane. With the laser directed at the barium stripe, MTI_{He} was 7.2 s and MTI_{N_2} 1.1 s. Adding helium in concentrations ≥ 60% to anesthetic gases delays laser-induced PVC endotracheal tube fires, if laser intensity is ≤10.0 W and laser bursts are ≤10 s. The barium sulfate stripe should be avoided when using this technique. **(Key words: Anesthetic techniques: endotracheal; inhalation. Anesthetics, gases: nitrous oxide. Complications: burns; intubation, endotracheal. Equipment: carbon dioxide lasers; tubes, endotracheal. Gases, nonanesthetic: helium, nitrogen, oxygen. Intubation, endotracheal: complications.)**

CARBON DIOXIDE LASERS, which are used in laryngeal and tracheal operations, can ignite plastic endotracheal tubes and, thus, cause laryngotracheal burns.[1–4] Both nitrous oxide and oxygen have been shown to support the combustion of endotracheal tubes exposed to laser energy.[4] We tested whether the inert gases, helium or nitrogen, when added to oxygen, could delay the ignition of polyvinyl chloride (PVC) endotracheal tube segments that were directly exposed to a laser beam. We also looked at the effect of laser intensity on endotracheal tube flammability and the effect of halothane in the gas mixture. Lastly, we measured the mean time to ignition (MTI) when the laser beam was aimed at the radioopaque barium stripe.

Methods

In a series of experiments, 2-cm PVC endotracheal tube segments (National Catheter Corporation Division, Mallinckrodt, Inc.) were tested with a dry gas flow of 5 $l \cdot min^{-1}$ provided by an anesthesia machine. The concentration of oxygen was confirmed by an oxygen analyzer in the inflow line. The gas was delivered through a steel catheter into the bottom of a 250-ml glass cylinder into the middle of which a segment of tube was suspended with a metal clamp. Both inside and outside of the tube segments were exposed to the gas. The laser beam passed through a hole drilled in the side of the cylinder and was directed at each endotracheal tube segment continuously for 60 s or until the tube ignited. Beam diameter measured 0.8 mm at the focal length; the segments were placed at the beam's focal length. A CO_2 laser (Systems 450 CO_2 Laser®, Coherant, Inc.) was used for all experiments. The intensity of the laser beam was confirmed by power meter analysis, and the beam diameter was measured at focal length both before and after the experiments. The time from onset of exposure until ignition was recorded and MTI calculated. If all segments in a series of 10 did not ignite by 60 s, the series was considered as not having ignited. If only some segments in a series of 10 did not ignite by 60 s, those that did not were considered as having ignited at 60 s and were analyzed as such.

In the first experiment, 10 endotracheal tube segments in each combination of oxygen and helium and oxygen and nitrogen were tested at 5.0 W (table 1). For a second series, at each laser intensity of 7.5, 10.0, and 12.5 W, 10 endotracheal tube segments in 40% oxygen and 60% helium were compared with 10 segments in 40% oxygen and 60% nitrogen, also tested at each laser intensity. In a third series, 10 endotracheal tube segments in 40% oxygen, 60% helium, and 2% halothane were tested at 10.0-W intensity.

* Assistant Professor of Anesthesiology and Neurosurgery.
† Graduate Research Professor of Anesthesiology.
Received from the Departments of Anesthesiology and Neurosurgery, University of Florida College of Medicine, Gainesville, Florida. Accepted for publication September 6, 1984. Presented in part at the annual meeting of the American Society of Anesthesiologists, Las Vegas, Nevada, October 1982.
Address reprint requests to Dr. Pashayan: Department of Anesthesiology, Box J-254, J. Hillis Miller Health Center, Gainesville, Florida 32610-0254.

TABLE 1. The Concentration of Each Gas in Test Combinations

Oxygen (%)	Helium (%)	Nitrogen (%)
20	80	—
30	70	—
40	60	—
50	50	—
20	—	80
30	—	70
40	—	60
50	—	50

In each of the preceding series, the laser beam was directed at an area of clear PVC, and the radioopaque blue barium sulfate stripe intentionally was avoided. In a final series of 10 segments in 40% oxygen and 60% helium and 10 segments in 40% oxygen and 60% nitrogen, a beam of 10.0-W intensity was aimed at the barium sulfate stripe. All data were reported ±1 SEM and underwent analysis of variance testing (repeated measures design on one factor) and Duncan's multiple range test whenever analysis of variance showed significance.

Results

The laser beam heated all tube segments enough to produce a hole at the site of exposure, even when they did not ignite. At 5.0 W, when the concentration of oxygen was 20% in either helium or nitrogen, tubes did not ignite for the duration of exposure, 60 s. With higher concentrations of oxygen, MTI_{N_2} was significantly shorter; MTI_{He} was not significantly shorter until the oxygen concentration reached 50% ($P < 0.05$) (table 2). MTI_{He} was significantly longer than MTI_{N_2} at 30% and 40% oxygen concentrations ($P < 0.05$) but not at 50% (table 2).

TABLE 2. The Effect of Inert Gases in Oxygen on Time to Ignition of Endotracheal Tube Segments Exposed to a 5-W Laser Beam

Concentration of Oxygen (%)	Time to Ignition (s): Helium Mean	Helium Range	Nitrogen Mean	Nitrogen Range
20	ND	ND	ND	ND
30	ND	ND	40.1 ± 3.0*,†	60–27
40	55.6 ± 3.2	60–30	27.6 ± 2.9*,†	37–6
50	45.3 ± 5.7*	60–3	9.0 ± 1.8*	16–1

Values are presented ±SEM. ND indicates no tubes in the series ignited by 60 s.
* $P < 0.05$ compared with different concentrations of oxygen within the same inert series.
† $P < 0.05$ compared with helium at the same oxygen concentration.

TABLE 3. The Effect of Laser Intensity on Time to Ignition of Endotracheal Tube Segments Exposed to 40% Oxygen in Helium or Nitrogen

Laser Intensity (W)	Time to Ignition (s): Helium Mean	Helium Range	Nitrogen Mean	Nitrogen Range
5.0	55.6 ± 3.2	60–30	27.6 ± 2.9†	37–6
7.5	42.3 ± 7.2	60–14	9.8 ± 2.8*,†	25–1
10.0	43.1 ± 5.4	60–21	14.3 ± 1.8*,†	22–3
12.5	11.5 ± 3.4*	29–2	11.3 ± 2.0*	22–2

Values are presented ±SEM.
* $P < 0.05$ compared with different laser intensities within the same inert gas series.
† $P < 0.05$ compared with helium at the same laser intensity.

MTI_{He} at 7.5 and 10.0 W was not significantly shorter than at 5.0 W, but it was shorter at 12.5 W ($P < 0.05$) (table 3). MTI_{N_2} was significantly shorter at 7.5, 10.0, and 12.5 W than at 5.0 W ($P < 0.05$) (table 3). MTI_{He} was significantly longer than MTI_{N_2} at 7.5 and 10.0 W but not at 12.5 W (table 3). At 10.0 W, the addition of 2% halothane to 40% oxygen and 60% helium significantly shortened MTI_{He} to 25.3 ± 1.9 s *vs.* 43.1 ± 5.4 s without halothane ($P < 0.01$). When a 10.0-W beam was directed at the barium sulfate stripe, both MTI_{He} and MTI_{N_2} were significantly shorter than when the beam was directed at clear PVC ($P < 0.001$) (table 4). MTI_{He} was significantly longer than MTI_{N_2}, even when the beam was directed at the barium stripe ($P < 0.001$) (table 4).

Discussion

The carbon dioxide laser is advantageous for microsurgery of laryngeal papillomas, polyps, nodules, and cysts by enabling an unobstructed, binocular view of a relatively bloodless operative field. In addition, laser

TABLE 4. The Effect of the Barium Sulfate Stripe on the Time to Ignition of Endotracheal Tube Segments Exposed to a 10-W Laser Beam in 40% Oxygen in Helium or Nitrogen

Site of Laser Exposure	Time to Ignition (s): Helium Mean	Helium Range	Nitrogen Mean	Nitrogen Range
Clear plastic	43.1 ± 5.4	60–21	14.3 ± 1.8*	22–3
Barium sulfate stripe	7.2 ± 0.6†	10–5	1.1 ± 0.1*,†	2–1

Values are presented ±SEM.
* $P < 0.001$ compared with helium at the same site.
† $P < 0.001$ compared with clear plastic.

TABLE 5. Physical Properties of Gases at 26°C

	Helium	Nitrogen
Thermal conductivity (cal [s·cm^2°C·cm^{-1}·10^{-6}]$^{-1}$)	360.36	62.40
Thermal capacity (cal·g^{-1}·°K^{-1})	1.24	0.249
Density (g·l^{-1})	0.179	1.25
Thermal diffusivity (cm^2·s^{-1})	1.621	0.199

Adapted from Weast RC, Astle MJ (eds): CRC Handbook of Chemistry and Physics, 60th edition. Boca Raton, CRC Press, 1980, p E2, with permission of the publisher.

beams produce minimal tissue edema. On contact with tissue, CO_2 laser energy is converted to thermal energy and, thus, destroys tissue.

In an oxidizing atmosphere (*e.g.*, oxygen or nitrous oxide), direct exposure of plastic endotracheal tubes to a laser beam can cause fires and subsequent burns of the larynx and trachea.[1-3] Even burning tissue near the endotracheal tube can ignite it indirectly.[4] Although the laser is aimed at tissue outside the endotracheal tube, uncuffed tubes or tubes with leaking cuffs may allow high concentrations of nitrous oxide and oxygen in the area of treatment. Plastic catheters used for anesthetic insufflation or gas scavenging[5] also may burn.

To prevent such fires, several techniques have been devised but each has disadvantages. Plastic tubes may be wrapped with heat-resistant tape, which, if improperly done, can kink the tube[6] or, if the tape becomes loose, can obstruct the airway.[7] Rough-edged tape can traumatize mucosa, or laser beams can reflect off the tape and burn normal tissue. Since neither the cuff nor the part of the tube distal to the cuff can be wrapped, it is still possible to ignite the tube by a laser aimed distal to the vocal cords. Wrapping the tube with water-soaked muslin is bulky,[6,8] and the cloth may dry and, thus, become ineffective during a lengthy procedure. A metal endotracheal tube devised for laser surgery[9] is rigid and, like tape, can reflect the laser.[10] These metal tubes have a large external diameter, which may obstruct the surgeon's view, and a small internal diameter, which increases airway resistance. Furthermore, metal tubes are not cuffed and so do not protect the airway from aspiration. Another alternative, a metal jet injector,[11,12] also may reflect the laser beam[10] or, if misplaced, may cause gastric distention or pneumothorax.[13] Also, the nonintubated patient is not protected from aspiration of secretions, vomitus, or surgical debris.

Preventing an oxidizing atmosphere in the anesthetic gas mixture is an alternative technique. Hirshman and Smith showed that laser energy ignites endotracheal tubes containing either 100% nitrous oxide or 100% oxygen.[4] We studied the effects of two inert gases; because neither helium nor nitrogen supports combustion, they were selected for study. Helium is inert, odorless, and tasteless and does not react chemically. The low density of helium produces little turbulence and, thus, improves gas flow, which may benefit patients with obstructive airway lesions. Nitrogen also is colorless, odorless, and largely inert and has the further advantage of being readily available in room air.

We demonstrated that helium, in a concentration of 60% or greater, retards PVC endotracheal tube ignition longer than nitrogen and therefore may protect patients from fire hazards when plastic is used during laryngotracheal laser surgery. The protective effect of helium may be due to its high thermal diffusivity. Thermal diffusivity is the quantity of heat passing through 1 cm^2 of cross-sectional area per unit of time and can be defined as the following:

$$\text{Thermal diffusivity} = \frac{\text{thermal conductivity}}{\text{density}} \times \text{thermal capacity}$$

The thermal capacity (or specific heat) of a substance is the quantity of heat necessary to produce a unit change in temperature in unit mass and thus is an index of the ability of the gas to prevent a rise in temperature. Thermal conductivity is the time rate of transfer of heat by conduction, through unit thickness, across unit area for unit difference of temperature. Density is the weight of a substance per unit volume. Helium has a high thermal diffusivity, much higher than that of nitrogen (table 5). Presumably, helium's high thermal diffusivity prevents a rise in temperature around the site of laser exposure and, thus, prevents endotracheal tubes from reaching their temperature of spontaneous ignition. An alternative explanation of helium's protective effect may be an increase in the spontaneous ignition temperature of plastic in the presence of helium.

It is important to note that in air (20% oxygen in 80% nitrogen) no endotracheal tubes ignited by 60 s, the longest test time. This may lead some anesthetists into a false sense of security. When using cuffed PVC endotracheal tubes and nitrous oxide–oxygen mixtures, one erroneously may assume that room air surrounds the mouth and areas of laser resection. Gases can diffuse through plastic and, thus, raise the concentration of oxygen or nitrous oxide in areas of laser exposure. Furthermore, if the endotracheal tube cuff is burst by the laser, oxygen and nitrous oxide will leak into the mouth; the laser also may melt a hole in the tube itself, and, again, allow a sudden rise in oxygen or nitrous oxide, which would support combustion of the tube. Therefore, our finding that endotracheal tubes do not burn in room air does not suggest that cuffed PVC tubes are safe to use when the anesthetic consists of oxygen and nitrous oxide.

We also found that the barium sulfate stripe ignites in significantly less time than clear PVC, probably because barium sulfate–impregnated PVC has a temperature of spontaneous ignition in oxygen that is 60° C lower than that of plain PVC.‡

Laryngotracheal laser surgery at our institution is performed with a beam of 8-W intensity, pulsed for 0.5-s duration. Our laboratory study demonstrated that a direct exposure of PVC tubes to a continuous laser beam of 10.0-W intensity delayed thermal ignition for a mean of 43 s when a dry gas flow containing at least 60% helium flowed through and around the tube at 5 $l \cdot min^{-1}$. When 2% halothane was added to the mixture, MTI, although shorter, was still 25 s. When laser intensity increased above 10.0 W, however, the advantage of 60% helium over 60% nitrogen was lost. Not enough helium can be added to a clinically useful concentration of nitrous oxide to prevent fires. We suggest that, if flammable endotracheal tubes or catheters are used, nitrous oxide should not be used before or during the laser resection. Air is safe as a carrier gas but cannot be enriched safely with oxygen. Helium, in a concentration of 60% or more, can be used until laser resection is complete. Since helium has no anesthetic properties, a potent inhalational agent may be added. The laser intensity must be limited to less than 10.0 W and to bursts of 10 s or less to ensure an adequate margin of safety. The laser beam should be stopped and repositioned at the first sign of smoke from the endotracheal tube. The energy delivered by CO_2 lasers in clinical use may not correspond to that indicated on the gauge of the laser, therefore, their output should be measured periodically to assure the accuracy of intensity gauges. If laser intensity higher than 10.0 W is necessary for the resection of a particular lesion, helium cannot be relied on to offer protection.

The radioopaque barium sulfate stripe should be avoided or the tube turned so that the stripe lies outside of the laser's range. However, it must be realized that reflected laser beams may reach a stripe that appears to be out of the direct line of sight, so it is preferable to use endotracheal tubes without such stripes.

The authors thank Nicholas Cassisi, D.D.S., M.D., Richard Schneider, Ph.D., John Cox, Ph.D., and Dinesh O. Shah, Ph.D., for their advice. They also thank Steven M. Barber, C.S.T., Greg Pugh, and Bill Winkle, B.M.E.T., for their technical assistance.

References

1. Snow JC, Norton ML, Saluja TS, Estanislao AF: Fire hazard during CO_2 laser microsurgery on the larynx and trachea. Anesth Analg 55:146–147, 1976
2. Burgess GE III, LeJeune FE: Endotracheal tube ignition during laser surgery of the larynx. Arch Otolaryngol 105:561–562, 1979
3. Vourc'h G, Tannieres ML, Freche G: Anaesthesia for microsurgery of the larynx using a carbon dioxide laser. Anaesthesia 34:53–57, 1979
4. Hirshman CA, Smith J: Indirect ignition of the endotracheal tube during carbon dioxide laser surgery. Arch Otolaryngol 106:639–641, 1980
5. Rita L, Seleny F, Holinger LD: Anesthetic management and gas scavenging for laser surgery of infant subglottic stenosis. ANESTHESIOLOGY 58:191–193, 1983
6. Patil V, Stehling LC, Zauder HL: A modified endotracheal tube for laser microsurgery (letter to the editor). ANESTHESIOLOGY 51:571, 1979
7. Kaeder CS, Hirshman CA: Acute airway obstruction: A complication of aluminum tape wrapping of tracheal tubes in laser surgery. Can Anaesth Soc J 26:138–139, 1979
8. Kalhan S, Regan AG: A further modification of endotracheal tubes for laser microsurgery (letter to the editor). ANESTHESIOLOGY 53:81, 1980
9. Norton ML, DeVos P: New endotracheal tube for laser surgery of the larynx. Ann Otolaryngol 87:554–557, 1978
10. Patel KF, Hicks JN: Prevention of fire hazards associated with use of carbon dioxide lasers. Anesth Analg 60:885–888, 1981
11. Urban GE Jr: Venturi insufflation oxygenation during nonintubated endolaryngeal microsurgery. Am Surg 42:48–51, 1976
12. Oulton JL, Donald DM: A ventilating laryngoscope. ANESTHESIOLOGY 35:540–542, 1971
13. Spoerel WE, Greenway RE: Technique of ventilation during endolaryngeal surgery under general anaesthesia. Can Anaesth Soc J 20:369–377, 1973

‡ Shah DO: Personal communication, 1984.