
Special Purpose Endotracheal Tubes

J Michael Jaeger MD PhD and Charles G Durbin Jr MD

Introduction

Tracheal Tube Cuffs

Techniques for Lung Separation

Double-Lumen Endotracheal Tubes

Endobronchial Cuffs

Bronchial Blockers

Endotracheal Tubes Designed for Laser Surgery

Endotracheal Tubes with Additional Ports

Special Tubes and Devices to Aid with Intubation

Head and Neck Surgery

Summary

[Respir Care 1999;44(6):661–683] *Key words: endotracheal tube, endotracheal tube cuff, lung separation, artificial airway, bronchial blocker.*

Introduction

Unique artificial airways and airway devices have been developed to solve a variety of diverse clinical problems. Since the early 1960s when plastics replaced rubber in the manufacture of endotracheal tubes (ETs), thousands of individual airways have been designed and produced. Unbridled imagination and a creative spirit have led to the invention of a variety of devices, many of which have the potential for patient harm. The problem of tissue toxicity of the materials used and the need to connect to other respiratory devices and anesthesia devices necessitated some common standards to which all devices must conform. These concerns of compatibility among the various designs have been minimized by development and adoption of consensus standards within the American Society for Testing and Materials (ASTM) (Internet address: <http://www.astm.org>) and the American National Standards Institute (ANSI).

The original ASTM technical subcommittee dealing with anesthesia and airway equipment was designated the Z-79 Committee. This has now been replaced with the F-29

Committee, or Anesthesia and Respiratory Equipment Committee, which has numerous subcommittees dealing with various kinds of anesthesia and respiratory care devices. Most of the subdivisions are listed in Appendix 1. Conformity to the standards developed by the ASTM is voluntary, but most American and international manufacturers endorse and promulgate these standards. The American National Standards Institute (ANSI) (Internet address: <http://web.ansi.org>) and the International Standards Organization (ISO) (Internet address: <http://www.iso.ch>) disseminate technical standards for respiratory care devices (among other things), and there is a significant amount of cross-over between these organizations. Devices that conform to these standards are permitted to have ISO, ANSI, ASTM or F-29 imprinted on them, reassuring the user that they have passed a required series of evaluations, will meet a set of requirements, and can be connected to other devices with standard fittings. Current individual standards are available, for a fee, from these organizations. Collections of these standards may also be obtained by joining the organization for a yearly fee. Documents can be ordered online and downloaded or faxed from the Internet.

Many aspects of ETs are specified by standards: labeling conventions; inside diameter and outside diameter; distance markers from the tip; material toxicity testing method; implant testing; packaging requirements; angle and direction of the tip bevel; size and shape of the Murphy eye; presence and density of radiopaque marker; radius of tube curvature; reactivity of composition material; and char-

J Michael Jaeger MD PhD and Charles G Durbin Jr MD are affiliated with the Department of Anesthesiology, University of Virginia, Charlottesville, Virginia.

Correspondence: J Michael Jaeger MD PhD, Department of Anesthesiology, University of Virginia, Box 10010, Charlottesville VA 22906-0010. E-mail: jmj4w@virginia.edu.

acteristics of the pilot balloon system are all determined by standard. Standard sized slip fittings are required and specified. Conventional ETs must have the inside and outside diameter imprinted on the tube, and the cross section must be circular, with a uniform wall thickness to resist kinking. A bevel facing left must be present at the tip, its angle should be between 30 and 45 degrees from the longitudinal axis. If present, the Murphy eye must be at least 80% of cross sectional area of the tube, and located opposite the bevel of the tip. Tubes without a Murphy eye are called Magill-type tubes and can have a higher risk of tube occlusion if the tip impinges against the tracheal or bronchial wall. However, secretions may be more likely to build up in a tube with a Murphy eye. The tips of Murphy-type and Magill-type tubes are shown in Figure 1. The Murphy eye should not weaken the tube, and the tip and the eye should have no sharp points or surfaces. Tubes should have a natural curve to facilitate entry into the larynx. The angle of curvature is specified in the standards as between 12 and 16 degrees. The distance from the tube tip must be indicated in centimeters. A radiopaque stripe or a tip marker must be present, to aid in locating the tube on a radiograph. A typical, standard Murphy cuffed ET is shown in Figure 2, illustrating some of these required standard elements. Some of these required standards are relevant to the special purpose ETs discussed below, but many are not. Most special purpose ETs are produced by a single manufacturer with unique features protected by patent.

The most important standards to which most special purpose ETs conform are the common connection to the breathing circuit and the material standards. Tracheal tubes must have a standard 15 mm slip fitting to connect to a breathing circuit (ISO standard 5361-1, ISO standard 5366-1); the tightness of this fitting is also specified. If equipped with a cuff, the pilot balloon must accept a standard luer syringe (ANSI standard MD70.1). The material the tube is made from must be nonreactive when implanted in the skin of an animal or nontoxic to tissue-cultured cells. There are currently no additional requirements for material content of airway devices. Surgical lasers are used on and around the airway, and fire safety standards for the materials used in ETs used with lasers have recently been developed (ISO standard 14408:1998). Concerns regarding latex allergy have led to changes in ET materials; currently, most are made of polyvinyl chloride (PVC) or silicone, and contain no latex. Specific components, such as the pilot balloon, may contain latex, and specific manufacturers should be contacted about their individual devices if latex allergy is a concern.

Other components of the standards described above cannot easily be applied to special purpose ETs. This has led to a large variety of tube designs to solve the same clinical problem. Herein, several clinical problems, and some of the devices developed to solve them, are described. This

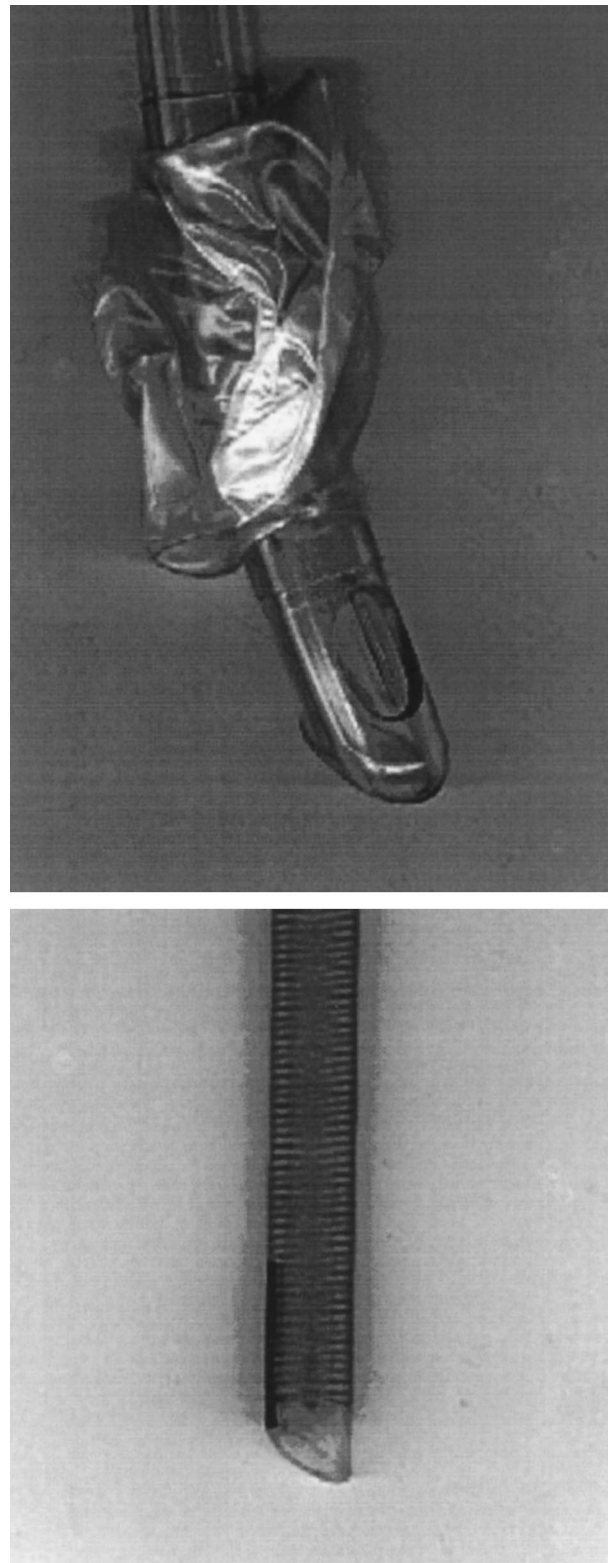


Fig. 1. A: The tip of a Murphy endotracheal tube, showing the characteristic eye. B: The tip of a Magill-type tube, without an eye.

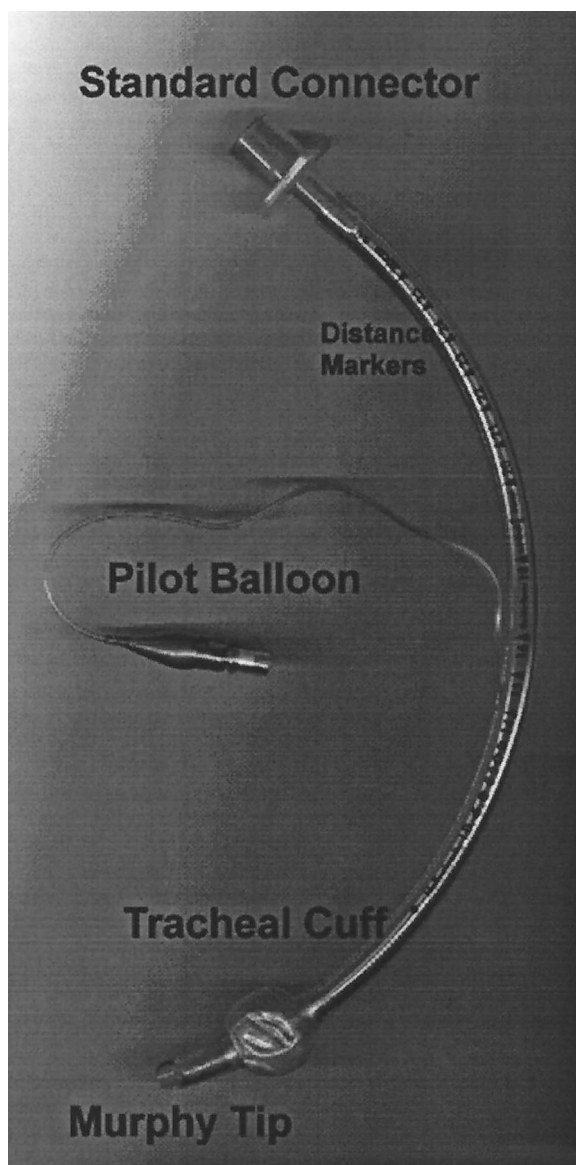


Fig. 2. A standard, cuffed Murphy-type endotracheal tube, with specified standard components labeled.

review also considers tracheal tube cuffs, lung separation, hazards of laser surgery, tubes with additional tracheal ports, tubes to facilitate airway management and intubation, and special requirements for head and neck surgery.

Tracheal Tube Cuffs

Many ETs have a cuff system that creates a seal between the ET and the trachea, preventing aspiration from the pharynx into the lungs, and allowing positive pressure ventilation to be applied through the tube. The cuff also stabilizes the tip of the tube in the center of the trachea, minimizing the likelihood of impingement on the tracheal

Cuff Pressure (mm Hg)

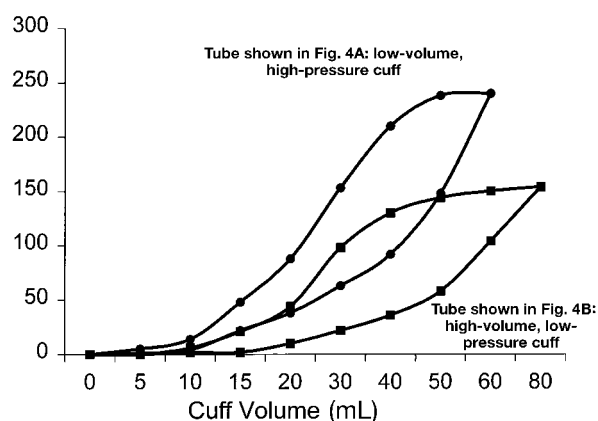


Fig. 3. The pressure-volume relationship of high-compliance and low-compliance endotracheal tube cuffs. The hysteresis effect of inflation and deflation is related to the plastic material used. Actual tracheal pressures vary with volume, time, and temperature.

wall. Tracheal injury from the ET or cuff is a concern in patients who require long-term intubation. One of the most serious complications is erosion by the tube through the trachea and into the esophagus (tracheoesophageal fistula) or into the innominate artery or other vessels. This is a rare but usually fatal complication. Less severe but more common is the development of tracheal narrowing at the cuff site following extubation. Besides the physical trauma of the tube rubbing against the trachea, tracheal wall pressures from the cuff may impede blood flow to the tracheal mucosa. Capillary pressure is a function of arterial blood pressure and is normally in the range of 25–35 mm Hg. Lateral wall cuff pressure higher than 25–35 mm Hg can cause mucosal ischemia, leading to sloughing and tracheal denudation.¹ During hypotension, ischemia can result at even lower tracheal wall pressures.² This initial mucosal ischemic injury may progress to cartilage loss with tracheomalacia or tracheal stenosis occurring during the healing process. Frequent measurement and adjustment of cuff pressures to below 30 cm H₂O, and using the “just seal” technique of cuff inflation are recommended to minimize cuff-induced ischemia. Cuff material, shape, and compliance are important factors in this problem.

The rubber cuffs used before 1960 were low-compliance and needed very high pressures to achieve a tracheal seal. The low compliance, tissue toxicity, and rigidity of the tubes often caused tracheal damage. PVC ETs and cuffs replaced rubber, and the incidence of tracheal (and laryngeal) damage declined. Some of these plastic cuffs are low-compliance, with a small profile. These cuffs permit easier intubation and produce a high-pressure tracheal seal to prevent aspiration and permit high-pressure mechanical ventilation. Low-compliance cuffs increase pressure on the trachea and increase the risk of ischemic in-

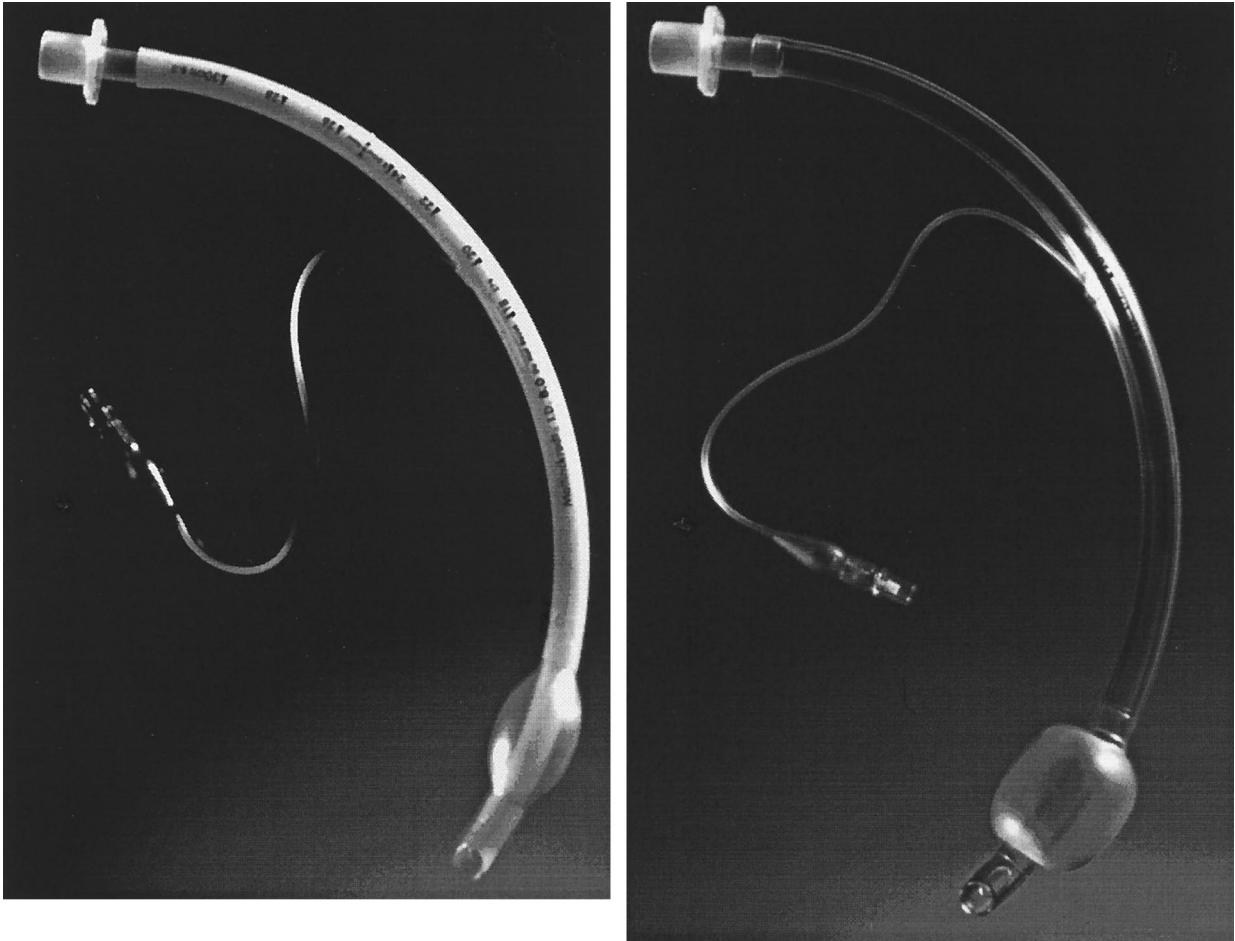


Fig. 4. A: Endotracheal tube with low-volume, high-pressure cuff. B: Endotracheal tube with high-volume, low-pressure cuff.

jury. The tracheal cuff pressure curves shown in Figure 3 were generated using a low-volume, high-pressure cuff ET similar to the one shown in Figure 4A, and a high-volume low-pressure cuff, as shown in Figure 4B. The data in Figure 3 were obtained by step-wise inflation of the cuff and immediate measurement of the cuff pressure. Once the cuff was fully (over) inflated, the deflation pressure curve was recorded. These pressures were measured at the pilot balloon connector, at room temperature (23°C), not in the trachea.

The technique of inflating the cuff only enough to “just seal” was developed to help minimize the tracheal risk. Manometers to monitor and adjust the cuff pressure to 25 cm H₂O became the standard of care in patients with prolonged intubation. The impact on the development of tracheal injury from careful pressure management has not been established in controlled studies. Larger, high-compliance cuffs were developed to spread the cuff contact point over a larger area so as to minimize the pressure at any one point. ETs with larger cuffs are more difficult to insert through the larynx, since they are bulkier and are less effective at preventing aspiration around the cuff.³

The use of high-pressure, low-compliance cuffs during surgery is associated with development of extremely high cuff pressures because of the diffusion of nitrous oxide into the cuff.⁴ The magnitude of this problem is related to the concentration of nitrous oxide used and the duration of the anesthetic. The true tracheal pressure is not easy to estimate when these cuffs are used, since most of the cuff pressure is dissipated in expanding the cuff itself. However, the cuff contact points in the trachea are small in area and often exceed mucosal perfusion pressure. Most of the concerns about aspiration risk and cuff pressures relate to long-term intubation. Special cuffs and tube designs have been developed to reduce the risk of aspiration while also maintaining a cuff seal.

High-volume, high-compliance, floppy cuffs form a seal by contacting and conforming over a large area of the tracheal wall. Cuff pressure in these tubes reflects the lateral wall tracheal pressure.⁵ A high-volume, high-compliance cuff is shown in Figure 4B, and its compliance curve is shown in Figure 3. The potential ischemic area is larger than with low-compliance cuffs. A very large cuff will have folds that can allow aspiration around the cuff.⁶

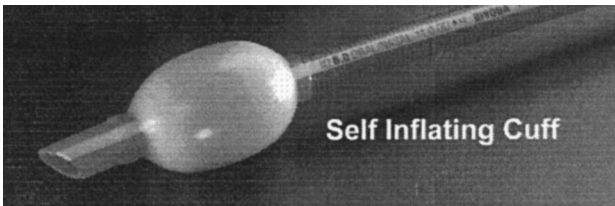


Fig. 5. Bivona Fome-Cuf. The cuff must be aspirated flat for insertion and then opened to air in order to self-inflate. (Photo courtesy of Bivona Medical Technologies.)

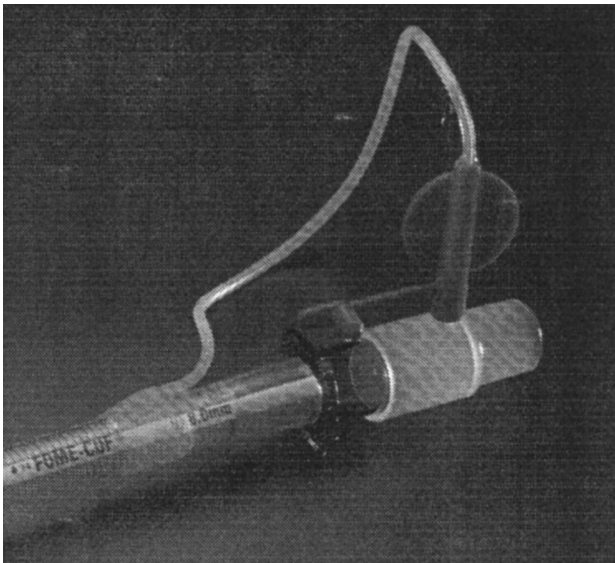


Fig. 6. With the Bivona Fome-Cuf endotracheal tube, airway pressure from the mechanical ventilator is delivered to the foam cuff, increasing cuff pressure and maintaining a seal during inhalation. (Photo courtesy of Bivona Medical Technologies.)

It appears that there is a reduction of tracheal cuff complications with large-volume, high-compliance cuffs. However, there is no guarantee that cuff pressure will remain low, and, even when properly used, these cuffs do not totally eliminate tracheal injury.

Another solution for prevention of high tracheal wall pressures is using self-inflating foam material to fill the cuff. A foam-filled cuff must be actively deflated prior to insertion, then allowed to passively fill by opening the cuff pilot tube to air. This type of cuff, the Fome-Cuf (Bivona Medical Technologies, Gary, Indiana), is shown in Figure 5. The seal formed by the foam-filled cuff is low-pressure and spread over a large surface area of the trachea. In order to provide positive pressure ventilation without a ventilation leak, the cuff pressure can be raised to airway pressure by connecting the pilot lumen to the airway. With the setup illustrated in Figure 6, during inspiration the cuff pressure is increased to ventilation pressure, reducing the leak. There is no check valve in the pilot tube, and if high cuff pressures are constantly needed, a stopcock or clamp

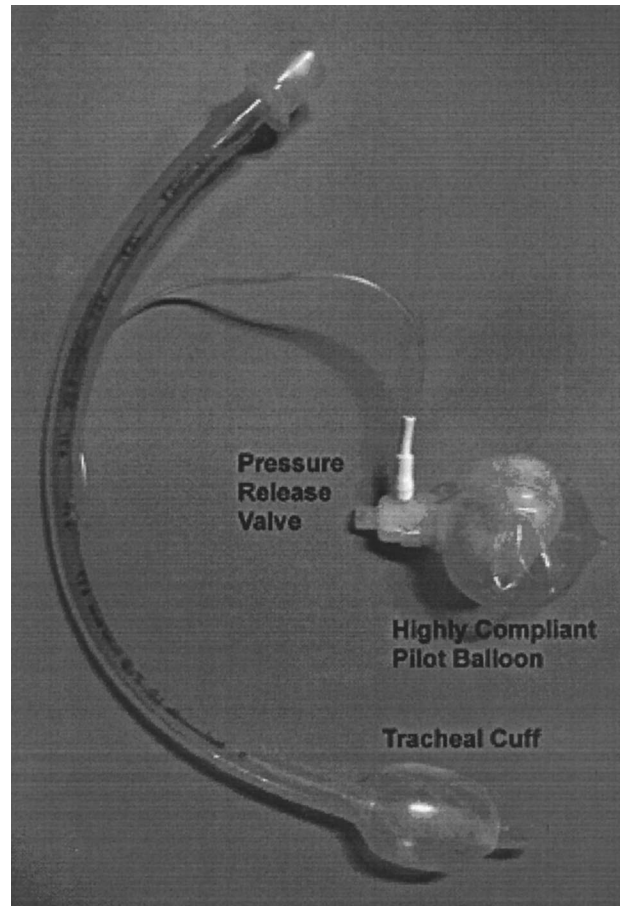


Fig. 7. Lantz cuff pressure-regulating system.

can be added, though this overcomes the low-pressure seal advantage of this cuff design.

Figure 7 shows an automatic tracheal cuff pressure-regulating system (the Lantz system), which connects a high-compliance external cuff to the tracheal seal cuff. When pressures in the tracheal cuff exceed 30 mm Hg, air is slowly bled into the pilot balloon. On initial rapid inflation, the tracheal cuff is inflated to a high pressure. During successive positive pressure breaths, air redistributes from the tracheal cuff to the pilot balloon, reducing tracheal cuff pressure to 25–33 mm Hg. Since gas flow is one-way, a cuff leak often develops, and cuff reinflation is needed to achieve a seal. If very high pressures are needed, the pilot balloon can be overinflated to seal in the protective outer sheath, and the system becomes a high-volume unregulated system.⁷

Techniques for Lung Separation

Complicated surgery of structures within the thorax (eg, lungs, esophagus, sympathetic nervous system ganglion, thoracic vertebrae, thoracic lymphatic system, and the tho-

racic portions of the great blood vessels), is facilitated by the technique of one-lung ventilation. One-lung ventilation is a process that requires a specialized ET or a combination of a standard single ET and an airway-blocking device to physically isolate ventilation to the right or left lung. Generally, one lung is isolated and collapsed while the other lung is ventilated. This approach produces excellent visualization of the thoracic structures and markedly reduces movement within the exposed hemithorax. During partial or total pneumonectomy, deflation of the resected lung allows careful, deliberate dissection and control of vessels and bronchi prior to clamping the specimen. During vascular procedures such as thoracic aneurysmectomy, deflation of the lung protects it from severe bleeding and contusion that can occur because of systemic anticoagulation. At the conclusion of surgery, the collapsed lung is re-expanded and two-lung ventilation is re-established.

In addition to surgical indications, there are a number of special conditions that can occur and can benefit from lung isolation. One classical indication for lung isolation is massive hemoptysis, which can occur from a ruptured pulmonary artery, arteriovenous malformation, endobronchial carcinoma, or pulmonary embolus. Necrotizing pneumonia or lung abscess might also require lung isolation. In these situations, isolation of the uninvolved lung can help prevent contamination from the involved lung by infected secretions or blood that would otherwise spread infection to and worsen ventilation and perfusion mismatching in the uninvolved lung. This preservation of the normal lung becomes essential if gas exchange is severely compromised in the diseased lung.

Lung separation can be used to apply different forms of mechanical ventilation in patients with bronchopleural fistulas, pulmonary parenchymal lacerations, or those with lungs of markedly different compliance or airway resistance, such as following single lung transplantation. Any combination of mechanical ventilation techniques can be used to ventilate or "rest" either lung independently. Lung separation is also used to perform bronchoalveolar lavage, either to wash out blood or infected secretions from the affected lung, or to sequentially remove the thick, tenacious secretions from each lung of patients with pulmonary alveolar proteinosis.

The earliest approach to lung isolation was developed in the 1930s, and utilized "bronchial blockers" fashioned from bundles of gauze or balloon-tipped catheters placed in the bronchus through a rigid bronchoscope. Variations of these devices are still used today in special situations, and will be discussed below.

Double-Lumen Endotracheal Tubes

The double-lumen endotracheal tube (DLET) is the most common device used to allow separate ventilation of the

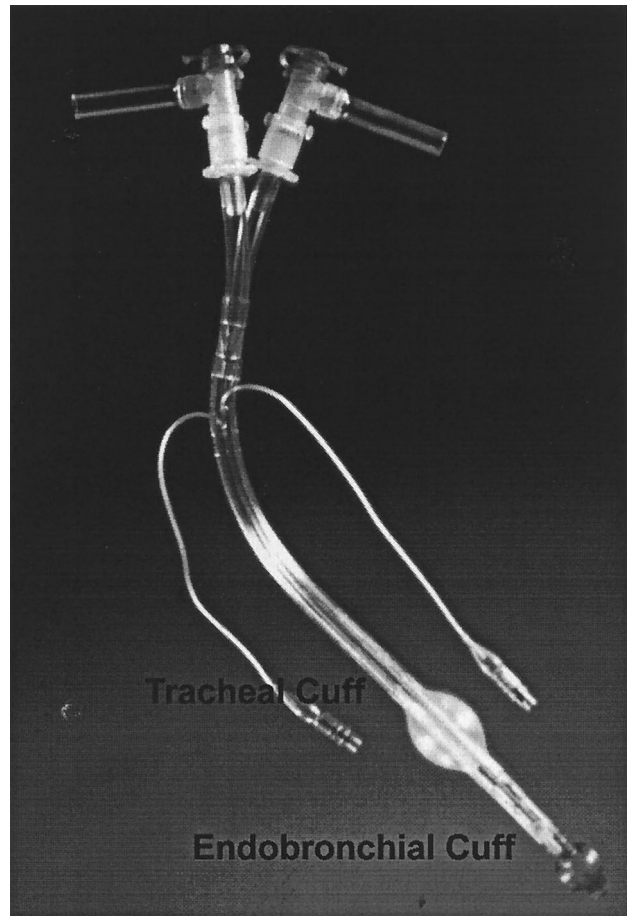


Fig. 8. Double-lumen endotracheal tube. (Photograph courtesy of Mallinckrodt Inc.)

lungs. One such tube is shown in Figure 8. It is simply two long, cuffed ETs fused together so as to permit one lumen and cuff to reside in a pulmonary bronchus and the other to remain more proximal in the trachea. With each lumen independently connected to a ventilator or both lumens united via a bridge connector (Cobb adapter, Fig. 9) attached to a single ventilator, gas flow into each lung can be controlled. As an example of its application, consider the patient with a right lung mass undergoing surgical resection. The patient is placed under general anesthesia and the trachea is intubated with a left-sided DLET. The DLET is inserted to a depth that places the endobronchial tube with its small cuff within the left main bronchus. The tracheal lumen opens more proximally on the shaft of the DLET, above the carina. Proximal to the tracheal lumen opening, a larger cuff completely envelops the device such that, when inflated, it forms an air-tight seal within the trachea, like a standard ET. With the small endobronchial cuff inflated, the left lung becomes isolated from the right lung. The only way for air to flow into the right lung is via the tracheal portion of the DLET, and the only way for air to flow into the left lung is via the endobronchial portion of



Fig. 9. A Cobb connector (adapter) is used to connect both lumens of a double-lumen endotracheal tube to one ventilator.

the DLET. The endobronchial cuff effectively seals off the left main bronchus from the trachea. To collapse the right lung and provide a motionless operative field for the surgeon, the lumen of the tracheal portion of the DLET bridge connector is occluded with a hose clamp, and the air within the right lung is allowed to egress when the thorax is entered. With the right side of the DLET clamped, air from the mechanical ventilator on the anesthesia machine is directed solely to the left endobronchial side of the DLET. This establishes one-lung ventilation, which, as long as acceptable gas exchange continues, can be used for prolonged periods of time. At the conclusion of the surgery, the remainder of the right lung is gently reinflated by reattaching the tracheal side of the DLET and releasing the clamp, thus reestablishing bilateral air flow to the lungs.

There are several versions of the DLET on the market. The most popular is the Robertshaw-like design (no carinal hook), which is constructed of the same nonreactive materials as previously described for the single-lumen ET. DLETs are available in a variety of sizes: 28 Fr, 35 Fr, 37 Fr, 39 Fr, and 41 Fr, are about 42 cm long, and are produced by a variety of different manufacturers. The choice of size depends on the patient's anatomy and is crucial. If the DLET is too large, it will not fit into the main bronchus and is difficult to pass through the glottis. If the DLET is too small, it will require a high cuff pressure to obtain a seal, resulting in inappropriately high pressure against the bronchial mucosa. Also, the smaller the DLET, the higher the resistance to air flow. For example, the air flow resis-

tance of the endobronchial side of a 39 Fr DLET is equivalent to a 7.0 mm inside diameter single-lumen ET, while a 35 Fr DLET is equivalent to a 6.0 inside diameter ET. Of note, the lumens of a DLET are not perfectly round (as they are in a single-lumen ET). The tracheal lumen is D-shaped, with the flat portion of the lumen abutting the shared wall with the endobronchial lumen. This imposes significant limitations on the passage of suction catheters and fiberoptic bronchoscopes (FOBs). Some versions of the DLET are constructed of red rubber with latex cuffs, to allow re-sterilization for multiple use. These are less commonly used because of problems of uneven cuff inflation after multiple uses, tissue toxicity, stiffness, and the uniformly higher cuff pressures required for adequate seal.⁸ Bronchial mucosal damage is more common with the use of red rubber DLETs.⁹ These rubber DLETs contain latex, and, of course, should not be used in patients with latex allergy.

The Carlens DLET (a variation of the Robertshaw style) incorporates a special carinal hook midway between the endobronchial cuff and the lumen of the tracheal side. The hook is designed to straddle the carina and prevent a left-sided DLET from being inserted too far, as well as to provide stabilization of the distal portion of the DLET. A right-sided version, the White DLET, was also developed. However, neither of these types (Fig. 10) are currently popular because the carinal hook (1) increases the difficulty of passing the device through the glottis, (2) can cause malpositioning in the bronchus, (3) can cause trauma to the airway during insertion, and (4) has been known to separate from the body of the DLET in situ. They are, however, easier to position correctly and are less likely to become displaced during use.

All disposable and reusable DLETs are marked (in centimeters) along their length to aid in correct placement. As a first approximation, for both males and females 170 cm tall, the average depth of insertion is 29 cm at the teeth.¹⁰ For each 10 cm increase or decrease in height, the placement depth will be increased or decreased approximately 1 cm. To aid in visualization on roentgenograms, the DLET has one radiopaque ring marker around the endobronchial lumen lip, another one proximal to the cuff, and a radiopaque line running the length of the tube.

Endobronchial Cuffs

Both the small-volume, blue (by convention) endobronchial cuff, and the larger, clear tracheal cuff are inflated by their corresponding color-coded inflation valves, which are incorporated into the walls of the DLET in the same way as in single-lumen ETs. The endobronchial cuff design differs between right-sided and left-sided DLET, and between manufacturers. Most left-sided DLET endobronchial cuffs are similar and consist of a spheroid or ellip-

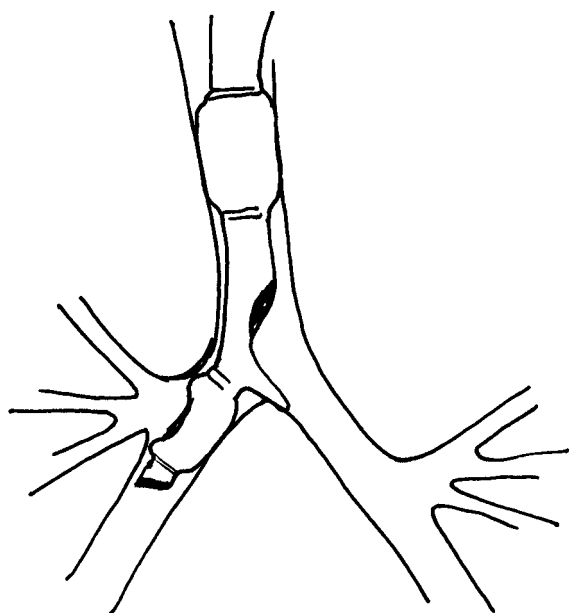


Fig. 10 A: White double-lumen endotracheal tube, with carinal hook in position.

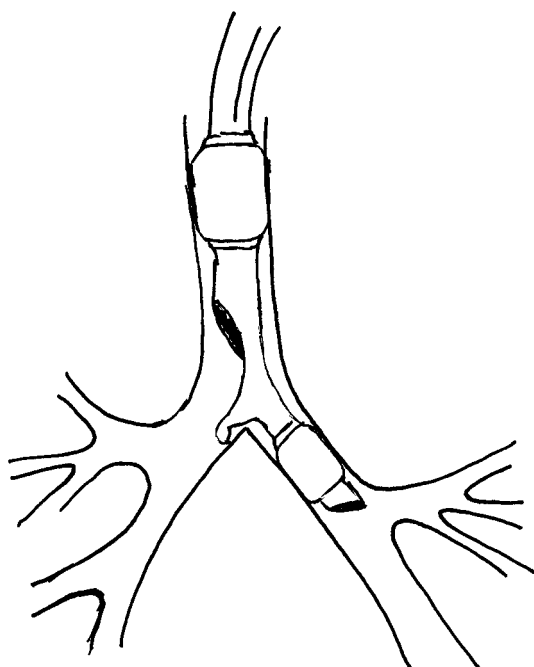


Fig. 10 B: Carlen double-lumen endotracheal tube, with carinal hook in position.

tical cuff approximately 1 cm proximal to the end of the tube. Right-sided DLET designs have incorporated several approaches to accommodate the short right main bronchus (length averages 14 mm in adult females and 18 mm in adult males), and the orifice of the right upper lobe bronchus. Two of these design approaches are shown in Figure 11. The right BronchoCath (Mallinckrodt Inc, Pleasanton,

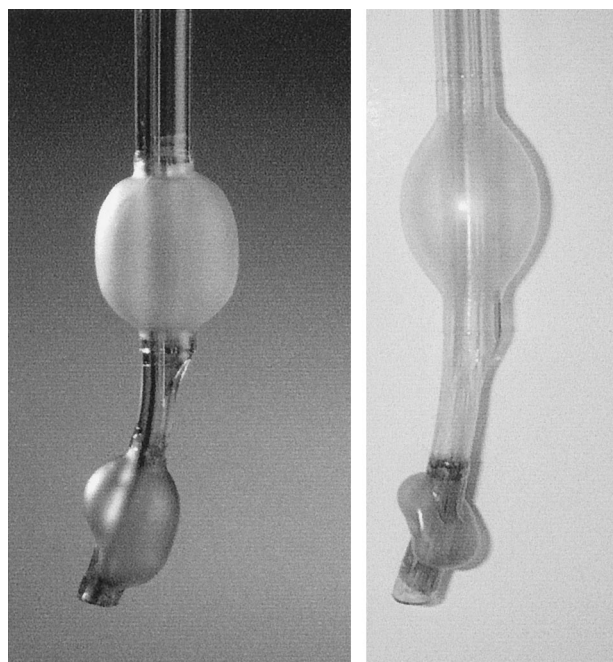


Fig. 11. Two types of right-sided double-lumen endotracheal tubes, showing different cuff designs to accommodate the take off of the right upper lobe bronchus.

California) utilizes an elongated, S-shaped endobronchial cuff attached at an acute angle to allow the addition of a large Murphy eye to oppose the orifice of the right upper lobe bronchus. The right-sided Sher-i-Bronch (Kendall Healthcare, Mansfield, Massachusetts) incorporates two small, round endobronchial cuffs that straddle a through-and-through slit-like opening in the distal wall of the endobronchial tube. Rusch Inc (Duluth, Georgia) manufactures a tube similar to Mallinckrodt's, except that instead of an elongated, angled "wedding band" type cuff, it uses a "signet ring" shaped cuff that becomes extremely narrow on the side opposite the orifice of the right upper lobe bronchus, to accommodate a Murphy eye. The Robertshaw design has a hole through the lateral aspect of the cuff. The crucial feature of all cuff designs is to allow sealing and isolation of the right or left bronchus without occluding any of the upper lobe bronchi. In actual use, the right upper lobe is often partially or completely occluded and poorly ventilated. Most authors suggest using only left sided DLETs unless left mainstem intubation is contraindicated.

Most DLETs come disassembled in multiple sterile packages and must be constructed and tested prior to use. First, the components are removed from their packages and placed on a clean surface (the large package containing the endobronchial tube works best). The Cobb adapter is assembled with care taken to keep individual tube adapters in register to ease the final assembly after intubation. The endobronchial and tracheal cuff assemblies are tested for

leaks and symmetry after inflation. The DLET is inserted with the cuffs deflated. The stylet, a stiff wire that runs the length of the endobronchial side of the DLET, can be lubricated lightly with a nonpetroleum-based lubricant to allow easy removal. The tip of the DLET can be bent or straightened as deemed necessary by the individual performing intubation.

All DLETs are relatively stiff and are bulky compared to their single lumen counterparts. Therefore, their introduction through the glottis is considerably more difficult, and great care must be taken to avoid harming the patient or damaging the DLET during intubation. A typical DLET intubation would be performed as follows. With the patient's head and neck in the "sniffing" position, the patient breathes 100% oxygen for several minutes. A sedative-hypnotic drug is given to induce a state of deep anesthesia, and narcotics or intravenous lidocaine can be added to suppress laryngeal reflexes. A muscle relaxant is administered to facilitate laryngoscopy. Laryngoscopy is performed when all medications have reached their peak effect. The natural curvature of the endobronchial tip facilitates placement in the right or left main bronchus as the DLET is advanced. It interferes with glottic passage and necessitates a series of rotational movements. With the glottic opening in view, the tip of the endobronchial tube is inserted between the open vocal cords, with the preformed curvature directed anteriorly. As the endobronchial cuff passes through the vocal cords, the DLET is rotated approximately 90–100 degrees to align the curved tip with the orientation of the appropriate main bronchus. At this point, some intubators would remove the stylet to allow the tip more flexibility and presumably decrease the risk of damage to the trachea and bronchus. Note, however, that a recent controlled trial found no significant increase in the incidence of tracheal damage by leaving the stylet in until the DLET was in final position.¹¹ The DLET with the stylet in place is carefully advanced until resistance is felt, indicating that it is seated in the bronchus. The tracheal cuff is inflated to form a seal, and the Cobb adapter is inserted into the proximal lumens. As the lungs are inflated, the chest is assessed (visually, by auscultation, and by measurement of exhaled carbon dioxide) to confirm endotracheal placement.

The final step is the fine adjustment of the DLET to enable isolation of the lungs without unintentional obstruction of the airways. The endobronchial cuff is inflated and the chest is carefully auscultated bilaterally while the tracheal and endobronchial lumens are sequentially occluded with a hose clamp. When the DLET is correctly placed, a distinct separation of breath sounds should be readily identifiable with clamping and unclamping of each lumen. Nonetheless, one study found that when strict criteria were applied, FOB examination indicated that between 38% and 83% of DLETs are malpositioned when

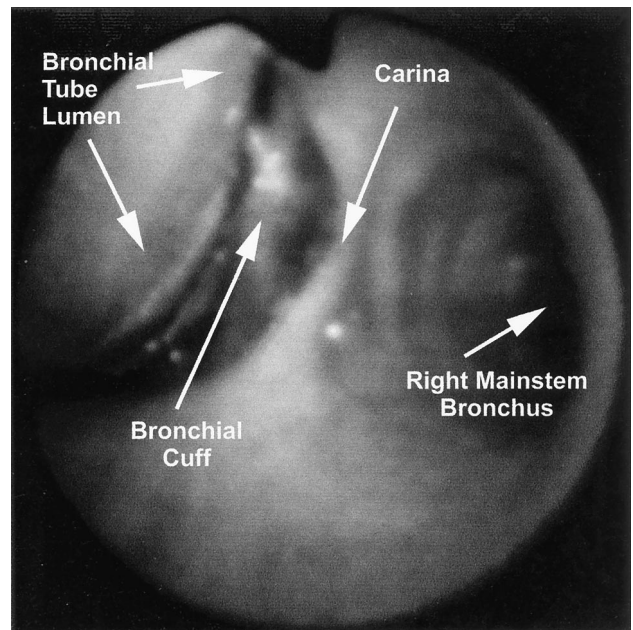


Fig. 12. Note that the bronchial balloon is protruding slightly at the carina.

placed by auscultatory means alone.¹² Final determination of correct DLET placement *must* be made via FOB, so a FOB must be readily accessible. Because movement of the DLET is possible whenever movement of the patient occurs, bronchoscopy should be repeated after any patient position change. Correct DLET placement is confirmed when the blue bronchial cuff is seen protruding slightly at the carina, as shown in Figure 12.

Bronchial Blockers

Although DLETs are the most common devices used to separate the lungs, other devices and approaches can be more efficient in certain circumstances. One such device is the single-use Inoue Univent tube (Fuji Systems Corporation, Tokyo, Japan) shown in Figure 13. It consists of a large, single-lumen silicone rubber ET with an extra channel fused to its entire length.¹³ This channel contains a long, thin, cuffed hollow rod that can be advanced into the right or left main bronchus, then inflated to block the airway (Fig. 14). The bronchial blocker can be connected to suction (to evacuate air, blood, or secretions from the occluded lung), connected to a high-frequency jet ventilator, or it can be capped. It is more difficult to blindly place the bronchial blocker in the correct bronchus, especially the left bronchus, than it is to place a standard DLET. Therefore, a FOB is essential. The Univent tube is constructed with the bronchial blocker on the right side and tends to favor entry into the right bronchus when the blocker is advanced. A left-sided placement is accomplished by rotating the Univent tube about 180 degrees while advanc-

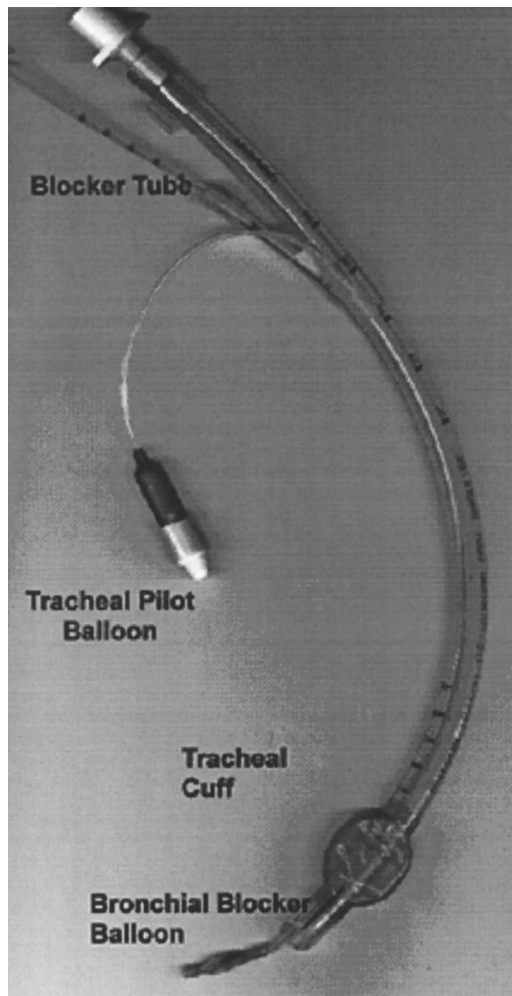


Fig. 13. The Univent tube has a self-contained bronchial blocker that can be advanced into either bronchus.

ing the blocker. The blocker can also be guided with the tip of the FOB. It is recommended that the blocker be inserted well into the bronchus and not inflated until the patient is placed in the optimal surgical position. Once the patient is in final position, the endobronchial blocker cuff can be pulled back out of the bronchus to its optimum position and inflated under direct vision. It can be positioned with the cuff barely visible at the carina. However, the blocker has a tendency to slip out of the bronchus easily, so it is recommended that the blocker be inserted deeper into the bronchus, such that when the cuff is inflated it partially occludes the lumen of the right or left upper lobe bronchus. This is less of a problem than with a DLET, since ventilation of the lung with the blocker is not an issue. This will assist in maintaining position during surgical manipulation of the lung. Of course this will also prevent air or secretions from leaving the upper lobe. During lung surgery, suspension of mechanical ventilation just before the pleural space is entered, and inflation of the

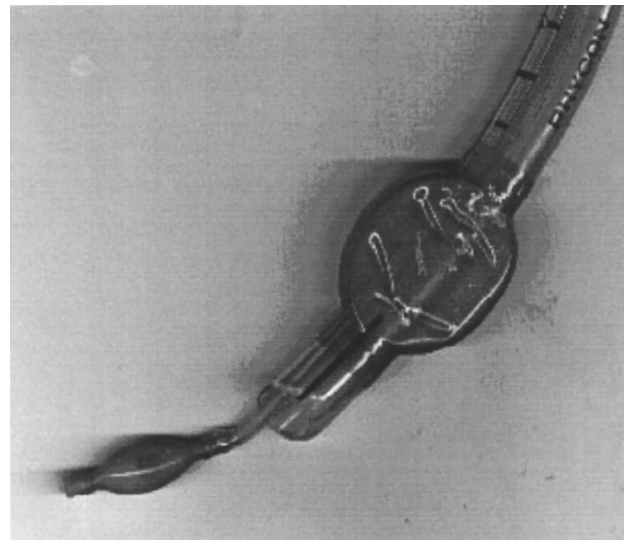


Fig. 14. Close up of the bronchial blocker exiting the Univent tube.

bronchial blocker results in the desired lung collapse. The Univent tube comes in sizes ranging from 3.5 mm to 9.0 mm inside diameter, with corresponding outside diameters ranging from 8.0 to 14.0 mm. Its greatest advantage over a DLET is that it is easier to insert into a difficult airway. Once lung separation is no longer required, the blocker can be retracted into the channel and the ET used in the standard fashion without reintubation.

Latex Foley catheters and Fogarty embolectomy catheters have also been used as bronchial blockers, in conjunction with a standard cuffed ET or tracheostomy appliance. These catheters were not designed for use as endobronchial blockers and therefore must be used very cautiously for this purpose. The Fogarty balloon catheter is probably the easiest to use, and is readily available in most hospitals. Their wide range of balloon sizes (diameter when fully deflated, 3.9 Fr, 4.7 Fr, 5.7 Fr, 14 Fr, and 22 Fr) allows the use of Fogarty catheters as endobronchial blockers in both pediatric and adult lungs.^{14,15} These catheters come with a wire stylet that allows the tip to be pre-formed to facilitate insertion into the bronchus. Once in place, the stylet is removed in order to inflate the balloon with an air-filled syringe. A sliding lock on the syringe Luer-Lok (Becton Dickinson and Company, Franklin Lakes, New Jersey) secures the inflated balloon. The main disadvantage of using these substitute endobronchial blockers is that the balloons are high pressure and low-volume, and therefore exert relatively high pressure on the bronchial mucosa, which can lead to necrosis and stenosis. We recommend that their duration of use be limited to no more than 2 hours. In addition, the balloons are fairly short, often grossly asymmetrical, and easily slip out of the bronchus. Fogarty catheters are extremely long (40–80 cm) and stiff. Because of the risk of perforating a small bron-

chus, these catheters should never be inserted very far into the trachea without direct visualization. Finally, the only way to evacuate air or secretions from the occluded lung is to deflate the balloon. Despite these drawbacks, these catheters have proven useful in difficult airways and special circumstances. One approach to placing these catheters is to intubate the trachea with a standard ET and then pass a Fogarty catheter through the port of a FOB ET adapter and into the trachea. Alternatively, the trachea can be intubated first with the thin Fogarty catheter and then a standard ET is placed next to the catheter. A FOB inserted through the ET is used to visualize the target bronchus and guide the catheter into position. Once the blocker is no longer needed, it can be withdrawn past the ET without losing control of the airway.

Fiberoptic bronchoscopy allows for unequivocal determination of correct DLET or bronchial blocker placement, fine adjustments to the depth of insertion and position of the endobronchial cuff, examination of the airways for damage during insertion, and selective bronchial toilet. The size of the FOB is critical. It is easy to damage the scope if a large sized FOB is forced or, more frequently, if the scope becomes lodged in the tube during attempted withdrawal. In general, a pediatric FOB (outside diameter 3.6–4.2 mm) fits down all sizes of DLET, while a FOB of intermediate size (4.9 mm) only fits through a 39 Fr or 41 Fr DLET. The FOB should be properly prepared before insertion into the DLET. Applying a thin layer of water-based sterile lubricant to the length of the FOB lessens the chance of its plastic coating adhering to the walls of the DLET. Warming the FOB in body-temperature water prior to insertion, and application of a commercial lens-anti-fog preparation, will greatly enhance visualization. The lubricated FOB is gently inserted through a bronchoscopy sleeve at the top of the ET elbow adapter (usually included with the disposable DLET) on the tracheal side of the DLET. It should be gently advanced while observing progress through the eyepiece. This approach allows easy navigation through the junction of endobronchial and tracheal tubes and, more importantly, negotiation of the tip past any mucous or blood adhering to the walls of the DLET. Once the FOB exits the lumen of the DLET, the carina is identified and the presence of the endobronchial portion of the DLET in the appropriate bronchus is established. In most situations, the DLET should be advanced or retracted until just a “lip” of the blue endobronchial cuff is visible at the carina when the cuff is inflated adequately (see Fig. 12). This should place the cuff at a short distance within the bronchus, which will not obstruct either the left upper lobe bronchus (in the case of a left-sided DLET) or the right upper lobe bronchus (in the case of a right-sided DLET). However, the margin of error is much smaller in the case of a right-sided DLET because the right main bronchus is so short.¹⁶ Therefore, FOB examination of the

endobronchial lumen is recommended, with particular attention to viewing the orifice of the right upper lobe bronchus through the Murphy eye of the right-sided DLET. This is more difficult than it may appear at first. It can be useful to carefully direct the tip of the FOB toward the Murphy eye with the intent of searching for the dark shadow of the orifice to the right upper lobe bronchus. Sometimes the orifice can be readily seen through the clear blue wall of the tube or, if not, then after slow rotation of the DLET while looking through the Murphy eye. Since, in the majority of cases, the orifice lies between the 12 o'clock and 3 o'clock positions, initial rotation counterclockwise is used. Ultimately, it is only important that the cuff does not occlude the right upper lobe bronchus. It is not necessary to juxtapose the Murphy eye with the orifice.

The final step is to secure the DLET or Univent tube (using twill tape or adhesive tape) to prevent accidental dislodgment. It is essential to realize that any attempt to secure and stabilize these rather large devices only prevents extubation—it does *not* assure the maintenance of the correct relationship between the endobronchial tube or bronchial blocker with its cuff and either the upper lobe bronchi or the carina. This is because the tube is only stabilized at the mouth. The distal end is free to move in or out as the airways are moved by shifts in the mediastinum or hilum of the lung. Surgical manipulation is an obvious potential cause of malpositioning, but changes from supine to lateral decubitus are just as common causes, whether for the purpose of surgery or for performing respiratory physiotherapy. Movement of the DLET or bronchial blocker by only millimeters can drastically change the ability to ventilate the patient.

When switching from two-lung ventilation to one-lung ventilation using a DLET or a bronchial blocker, several important aspects should be remembered. First, the long narrow lumens of the DLET impose a large resistance to air flow, so a considerable drop in airway pressure occurs across the DLET during both inspiration and expiration, whether the patient is breathing spontaneously or mechanically ventilated. Since most measurements of airway pressure are made proximal to the ET, a very large peak pressure will be achieved during the delivery of an otherwise reasonable tidal volume (V_T). The plateau or static airway pressure measured during the inspiratory pause should more accurately reflect the distal airway pressures. Second, the V_T of a mechanically-delivered breath should be adjusted downward to avoid hyperinflation of the alveoli when providing one-lung ventilation. During surgery a V_T of 8–10 mL/kg ideal body weight is recommended, rather than the usual 10–15 mL/kg. Minute ventilation can be maintained by increasing the rate slightly. However, higher rates tend to cause auto-positive end-expiratory pressure because of the flow limitation imposed by the DLET, so it is necessary to limit the respiratory rate and adjust the inspiratory-

expiratory ratio setting of the mechanical ventilator accordingly.¹⁷

One of the most feared and lethal pulmonary problems is massive hemoptysis. Very few medical conditions require as prompt a response and intervention to maximize the chance of a good outcome. Pooling of blood in the airways and the resulting asphyxiation (as opposed to absolute blood loss), is the immediate threat to life, so rapid isolation and containment of the bleeding lung offers the only hope of survival.¹⁸ Fortunately, most cases of massive hemoptysis, defined as greater than 100 mL/24 hours, require less haste to address.^{19,20} There are a wide variety of causes of massive hemoptysis, but most frequently it is due to infection. Therefore the caregiver must use caution and appropriate measures to protect against contamination of the environment as well as of the unaffected lung.

In general, massive hemoptysis is approached with an initial examination of the bronchial tree. A chest roentgenogram can provide useful information if a sufficient amount of blood has accumulated to be visible and if it is restricted to a particular lobe. At the very least, the chest roentgenogram may identify the side of the lung that is bleeding. Flexible bronchoscopy can be performed rapidly, with minimal patient preparation, to identify the source of bleeding, which is essential to guide further management and, possibly, surgery. If bleeding is brisk, it will virtually be impossible to visualize the bronchial tree with a FOB. Bronchoscopic suction is limited and cannot remove large clots. In most circumstances this requires massive pulmonary toilet and examination with a rigid bronchoscope under general anesthesia. Clearly this is not an ideal situation, but it is potentially life-saving. If bronchoscopy fails to determine the location, and the patient's condition allows, selective pulmonary and bronchial arteriography can be performed.

In all cases of brisk hemoptysis, the bleeding lung or lobe should be isolated from the uninvolved lung. This is usually achieved by intubation with a DLET, especially in circumstances of brisk bleeding. With both cuffs inflated, the lungs are isolated and each side can be intermittently lavaged to remove blood and to protect from further contamination. If circumstances allow, a small Fogarty catheter can be inserted into the bleeding secondary bronchus to occlude the appropriate portion of the lung. From a technical standpoint, this is much more difficult and time consuming, and nearly impossible if the upper lobe is involved.

In a dire emergency, if death is imminent, we recommend one of the following approaches. If a left-sided double-lumen endobronchial tube is available, intubate and insert it until the tube is wedged into the bronchus. With both cuffs inflated, the lungs will be isolated and can be ventilated independently while lavage and suction can be used to determine which side is bleeding. Then, positive

end-expiratory pressure can be applied to the bleeding side to assist in slowing the bleeding and directing blood flow to the uninvolved lung. Once bleeding has slowed sufficiently, flexible bronchoscopy can commence. The other approach is to attempt a blind intubation of the right main bronchus with a standard ET. This will work temporarily, but is only effective if the left lung is the source of bleeding. Intubation of a main bronchus is the only choice in pediatric cases of massive hemoptysis, since DLETs for children are not available. Intubation of either the right or left main bronchus with a single-lumen ET can be achieved by maintaining the styletted ET in the "hockey stick" configuration and rotating the tube in the manner described for insertion of the DLET into the same bronchus. Although this is still a blind approach, the pediatric bronchi diverge at fairly equal angles from the trachea (in contrast to the adult lung, where the right mainstem branches at a less acute angle from the carina than the left). Once the airway has been secured, ventilation with 100% oxygen and positive end-expiratory pressure should be initiated, and frequent lavage and suctioning to remove blood clots from the lung should be attempted.

Endotracheal Tubes Designed for Laser Surgery

With the advent of laser surgery of the upper airway, the risk of ET fires has led to development of specialized, ignition-resistant endotracheal devices. There are a variety of different lasers in use, and laser-resistant ETs may function differently with different laser systems.^{21,22} The risks with tubes and laser therapy are: (1) direct ignition of the tube itself; (2) reflection of the laser from the tube surface, causing accidental tissue damage; and (3) cuff failure from laser perforation. ETs designed to be suitable for laser surgery are stiffer, bulkier, less stable when inserted, and more likely to cause direct airway tissue damage.

The Norton tube (Fig. 15), is a reusable, stainless steel, flexible tube which is unaffected by any laser. It has no cuff, and a tracheal seal must be established by packing around the tube with damp surgical sponges or by attaching a latex cuff. Note that this latex cuff is *not* laser-resistant; it can be ignited, and it can be dislodged from the tube and enter the distal airway. With this tube it is *possible* to ventilate without using sponge packing or a cuff, but doing so requires accepting a large ventilation leak and compensating for the leak by increasing gas flows. Also, a low fraction of inspired oxygen must be used, so as to prevent increasing the fire hazard during tissue vaporization. This type of tube is bulky, stiff, and can easily damage airway structures if not placed and secured carefully. It is usually necessary to use a stylette to maintain shape for intubating. The shiny surface reflects laser bursts, which can cause accidental burns to surrounding tissues.

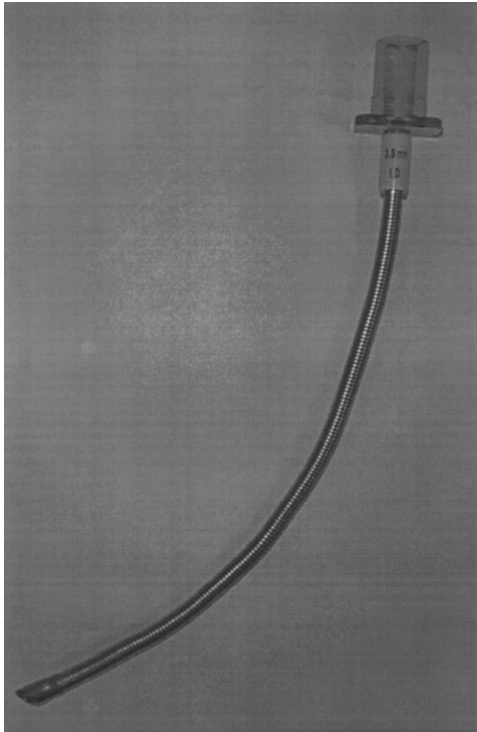


Fig. 15. The stainless steel Norton endotracheal tube protects against several hazards of laser surgery.

Reflective foil wrappings can be applied to any conventional tube to increase laser resistance. Problems with this approach include laser reflection damage, exposed areas that can ignite, an unprotected cuff, and airway damage from the sharp edges of the wrappings.²³ Foils may unwrap during use, thus interfering with the surgery and making tube removal difficult.²⁴

Tubes of various laser-resistant materials have been developed. None are completely safe from damage from direct laser hits, but they do not burst into flame.²⁵ The Laser-Shield II (Xomed-Trease Inc, Jacksonville, Florida) (Fig. 16), is a silicone tube with an inner aluminum wrap and an outer Teflon coating. It has been used with potassium-titanyl-phosphate (KTP) lasers, neodymium-yttrium-aluminum-garnet (Nd-YAG) lasers, and CO₂ lasers. The cuff is not laser resistant, and contains a blue marker to identify perforation. To prevent fire, the cuff should be inflated with water or saline solution. The tube distal to the cuff is also unprotected. The Laser Flex tube (Mallinckrodt Inc, Pleasanton, California) (Fig. 17) is a stainless steel tube with a matte finish. It can be used uncuffed or with two cuffs attached in series (as with other laser tube cuffs), these should be inflated with water or saline solution). The Laser Flex tube is designed for use with the CO₂ laser and the KTP laser, but not with the Nd-YAG laser. The Sheridan red rubber, copper-wrapped Laser Trach tube (Kendall Healthcare, Mansfield, Massachusetts) (Fig. 18)



Fig. 16. The Laser Shield II endotracheal tube is metal-wrapped and covered with laser-resistant material. (Photograph courtesy of Xomed-Trease Inc.)

is also for use with the CO₂ laser and KTP laser. It comes with pledgets that are to be soaked and packed around the cuff to protect the cuff. The Lasertubus (Rüsch Inc, Duluth, Georgia) (Fig. 19) is made of white rubber and has a cuff-within-a-cuff design. Its surface is covered with a sponge material that can be soaked in water to reduce ignition potential. Reflection is not a problem with this tube, which can be used with the argon laser, the Nd-YAG laser, and the CO₂ laser. The Bivona Fome-Cuf laser tube (Bivona Medical Technologies, Gary, Indiana) was designed to solve the perforated-cuff-deflation-problem. It consists of an aluminum wrapped silicone tube with a Bivona foam-filled self-inflating cuff. Even when penetrated by the laser, the cuff maintains a seal. The tube, however, is poorly resistant to all lasers, and fires can occur. If the cuff is penetrated, it can no longer be deflated for removal. From the variety of different designs available, it is apparent that no one design is ideal for all lasers and all procedures. Continuing innovation is likely in this area of tube manufacturing.

Endotracheal Tubes with Additional Ports

Several issues have arisen to advance the development of tubes with additional ports. One of these is the recognition that many drugs can be quickly administered by way of the lungs in situations where intravenous access has not yet been established. During medical emergencies,

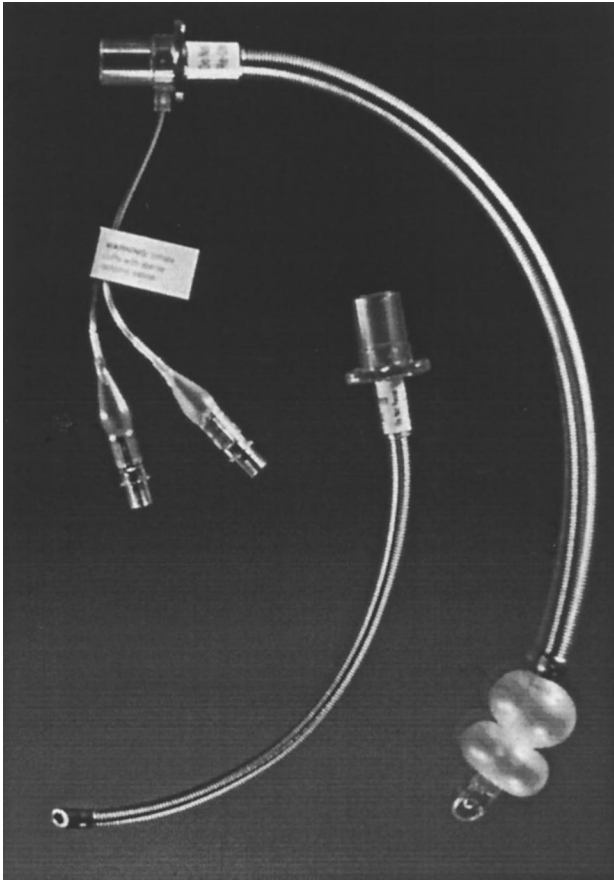


Fig. 17. The Laser Flex endotracheal tube comes with a double-cuff or no cuff. (Photograph courtesy of Mallinckrodt Inc.)

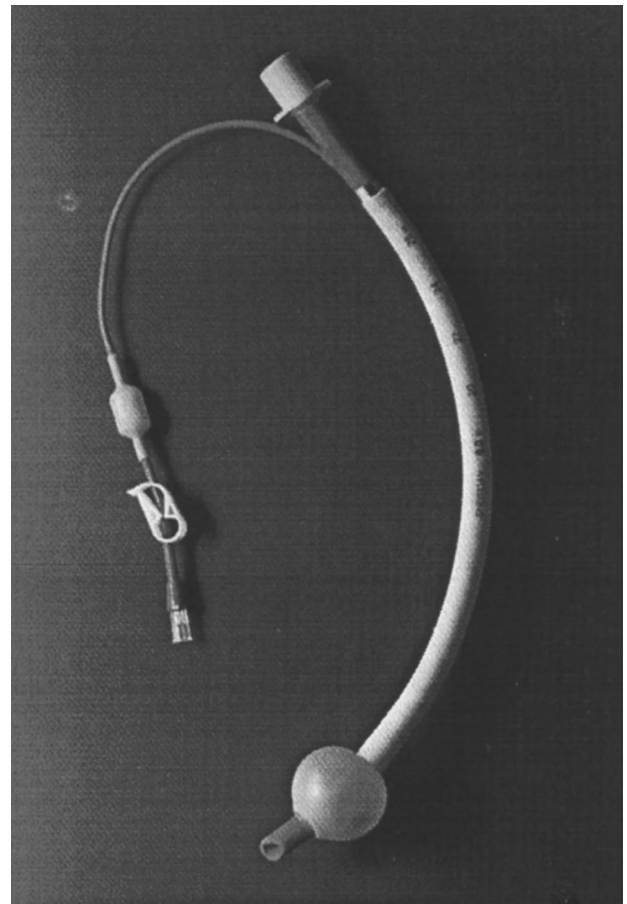


Fig. 18. The Laser Trach endotracheal tube has a copper foil wrapping and a fabric covering.

intravenous access may not be quickly obtainable, and an ET is often in place before intravenous access is established, so drug administration via the lung is an important option in certain emergency situations. Special ETs with medication ports embedded in the tube wall are now available, and these tubes allow drugs to be given without interrupting mechanical ventilation. The medication port may include a one-way valve or, if not, must be capped to prevent loss of gas during positive pressure ventilation.

The American Heart Association has moved intubation up on the priority list in treating cardiac arrest. During treatment of ventricular fibrillation, after defibrillation (which should be attempted up to 3 times without interruption even for airway management), the next priority is intubation to allow drug administration (epinephrine) and ventilation to treat acidosis. Current recommendations suggest that 2–2.5 times the intravenous dose should be administered through the ET, in at least 10 mL volume. However, experimental data suggest that this dose should probably be increased to 5–10 times the usual dose, at least for epinephrine.²⁶ Emergency drugs that can be administered to the lung through the ET include: epinephrine, norepinephrine, lidocaine, atropine, diazepam, and nalox-

one. Figure 20 shows an ET that features a medication lumen.

Tracheal gas insufflation can be performed through a distal tracheal lumen. Decreased anatomical dead space and increased arterial oxygenation can result when several liters of oxygen are insufflated through an additional lumen. The effectiveness of this technique in acute respiratory distress syndrome and asthma may be related to the proximity of gas flow to the carina.^{27,28} Separate catheters advanced deeper into the airway may be more effective, but special ETs with an additional port may allow similar benefit with less risk.²⁹ The contribution of this collateral gas to increased peak airway pressure (and V_T) should be taken into account when considering using this technique of ventilatory support.^{30–33}

Distal airway pressures can be measured through an additional lumen. Figure 21 shows tubes designed for optimization of mechanical ventilation and reduction of the work of breathing by measuring airway pressures at the tracheal end of the airway. Triggering of demand systems and improvement of patient-ventilator synchrony can be enhanced by distal airway pressure measurements. The

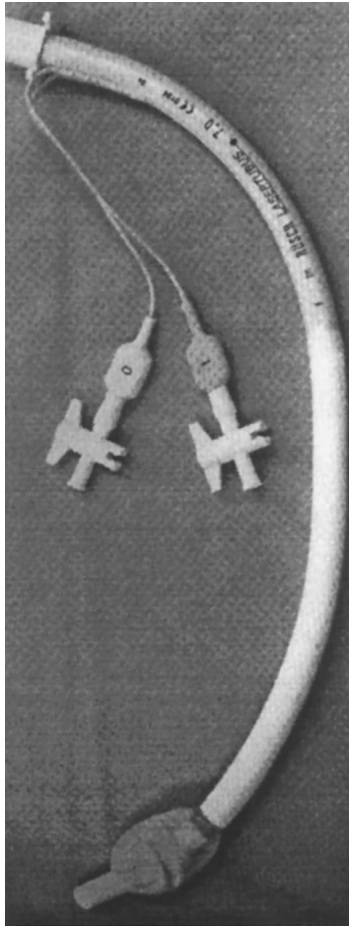


Fig. 19. The Lasertubus endotracheal tube is constructed of white latex rubber. (Photography courtesy of Rüschi Inc.)

early detection of a partially obstructed airway can be facilitated by recognition of a difference in proximal and distal pressures. Because of these benefits, distal and proximal airway pressure monitoring should be considered in all patients receiving mechanical ventilation, but especially in those who are very tenuous or difficult to wean.

The Hi-Lo Jet (Mallinckrodt Inc, Pleasanton, California) tube (Fig. 22) was designed to provide high-frequency jet ventilation through an additional port embedded in the wall of the ET. The tube is more rigid than conventional tubes, so as to preserve a straight path for the jet gas flow. The bias flow and positive end-expiratory pressure can be added with a circuit attached to the ET connector. When using high frequencies, adequate gas entrainment from the bias flow circuit is necessary to produce adequate ventilation. The bias circuit is also the conduit for exhalation, and adequate exhalation time during the jet cycle is required.

Intubated and ventilated patients are at high risk for developing pulmonary infections. The incidence of noso-

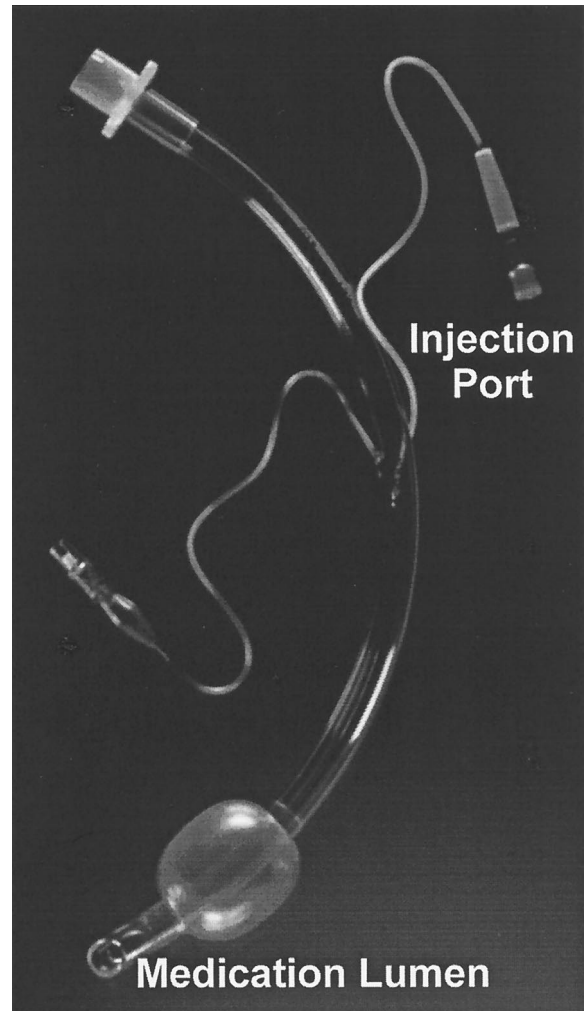


Fig. 20. The medication lumen embedded in the endotracheal tube wall allows tracheal drug administration without interrupting ventilation. (Photograph courtesy of Mallinckrodt Inc.)

comial ventilator-associated pneumonia is reported to be between 10% and 60%, and is associated with increased mortality.^{34,35} Lung infection can result from aspiration of bacteria-laden oropharyngeal secretions around the ET cuff. The route of oral colonization is believed to be from the stomach. Preventive strategies include reducing gastric colonization by maintaining an acid environment, and selective decontamination with nonabsorbable antibiotics.^{36,37} Reducing the aspirated bacterial load can also be accomplished by oral and subglottic secretion removal.³⁸ A recent modification of the ET shown in Figure 23 allows continuous aspiration of subglottic secretions. Preliminary results with this tube suggest a decrease in the frequency and a delay in the onset of ventilator-associated pneumonia.³⁹

Topical anesthesia of the airway may improve patient tolerance of intubation. In fragile patients, spraying the

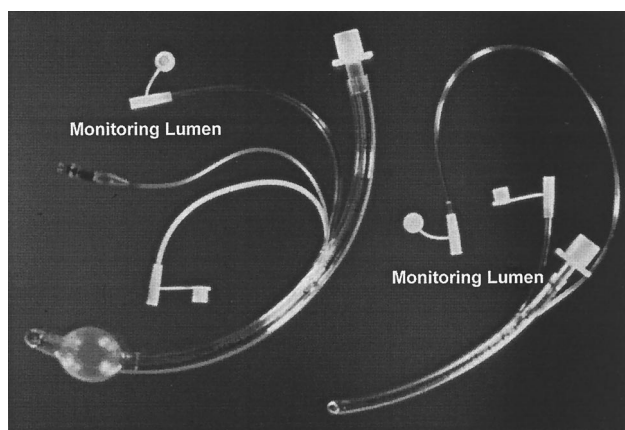


Fig. 21. Endotracheal tubes with extra lumens for distal airway pressure measurement. (Photograph courtesy of Mallinckrodt Inc.)

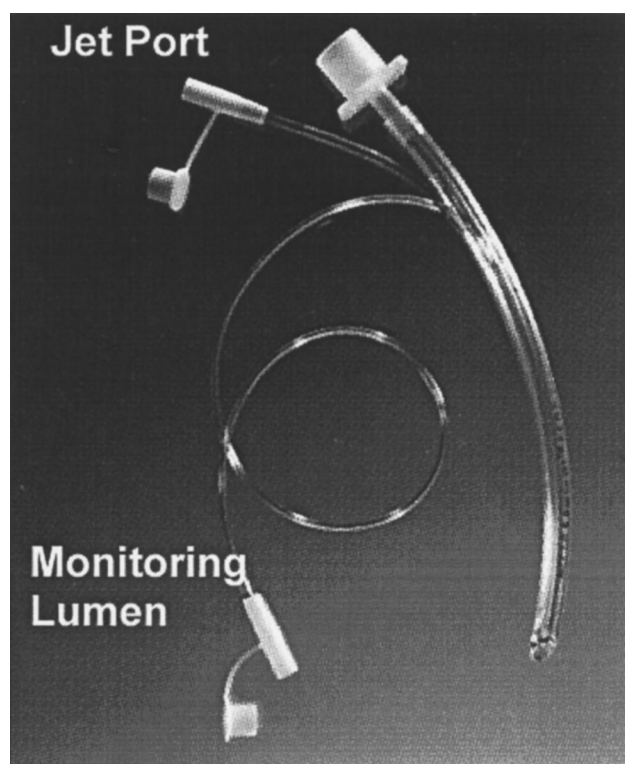


Fig. 22. The additional port on this endotracheal tube allows jet ventilation. (Photograph courtesy of Mallinckrodt Inc.)

vocal cords and larynx with a local anesthetic prior to intubation decreases the expected rise in blood pressure and reduces the incidence of cardiac stress. This rise in blood pressure during ET placement is also a concern in patients with altered intracranial compliance (head injury, hemorrhage, or tumors) and measures (including deep anesthesia and topical anesthesia) are often needed to prevent brain herniation during intubation. Tracheal suction and movement of the tube during nursing maneuvers may

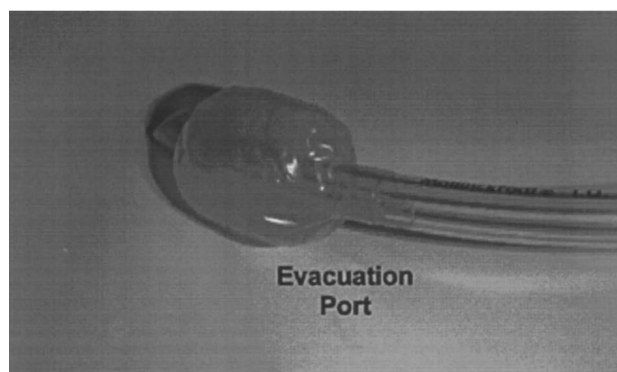
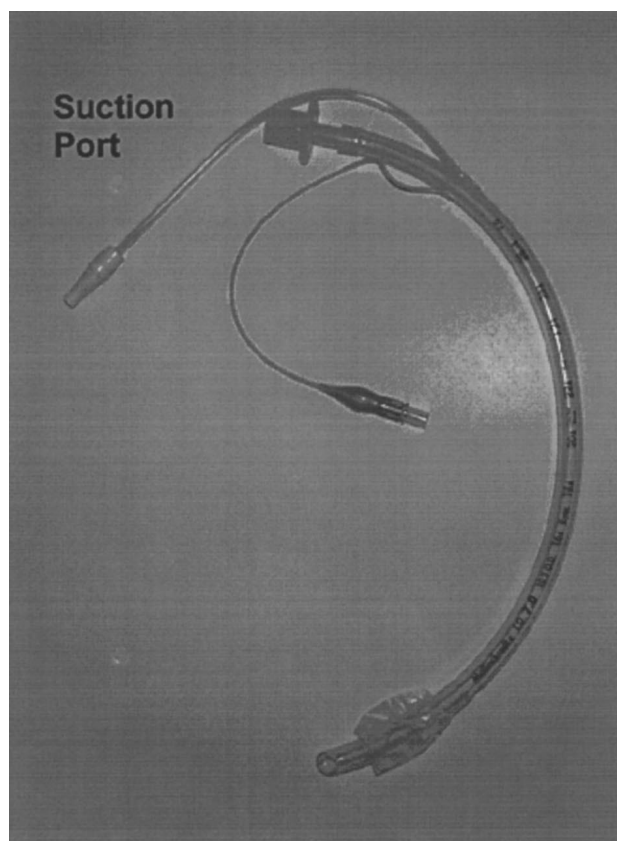


Fig. 23 A: Endotracheal tube designed to allow aspiration of subglottic secretions, which assists in prevention of nosocomial infections. B: Close-up of evacuation port.

also stimulate a hypertensive response with an increase in intracranial pressure. Local anesthetic administered down the ET can modify this response, but the larynx remains unanesthetized when medications are administered through the ET. A special ET designed with an additional injection port with multiple side holes on the outside of the tube (Fig. 24) allows local anesthetic administration to the larynx and upper airway. Uses of this special purpose tube include: head and neck surgery (to prevent coughing during head manipulation), in patients with cardiovascular

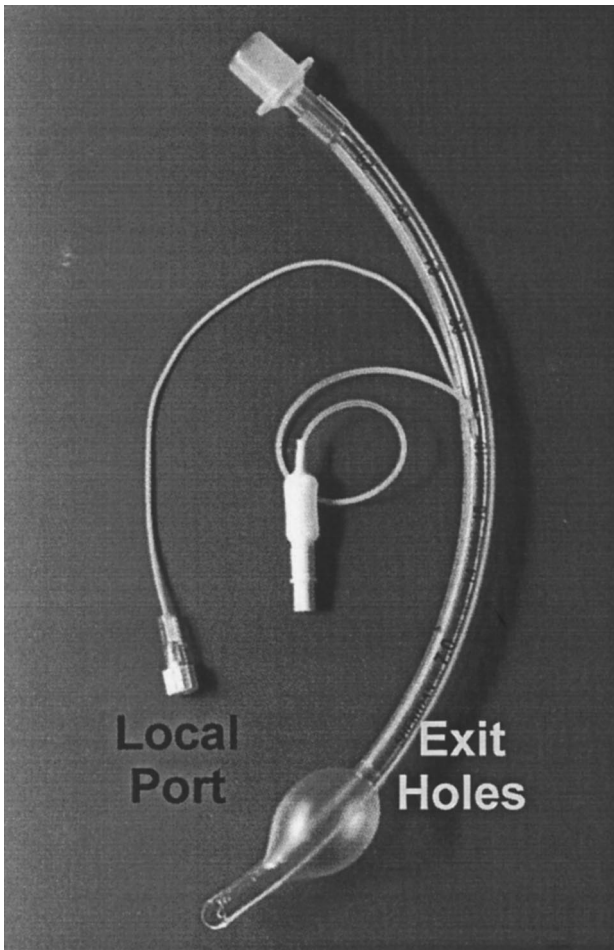


Fig. 24. This special purpose endotracheal tube has a port for injecting local anesthetic to the trachea and larynx. (Photograph courtesy of Mallinckrodt Inc.)

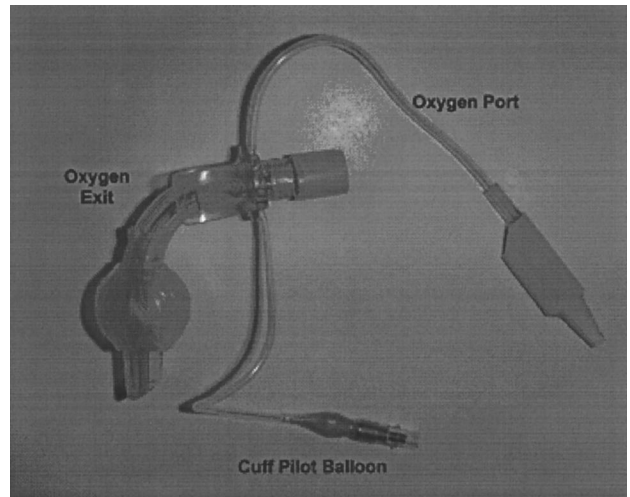


Fig. 25. Pittsburgh Talking Tracheostomy tube. Gas flow through the larynx allows phonation for patients with tracheostomies.

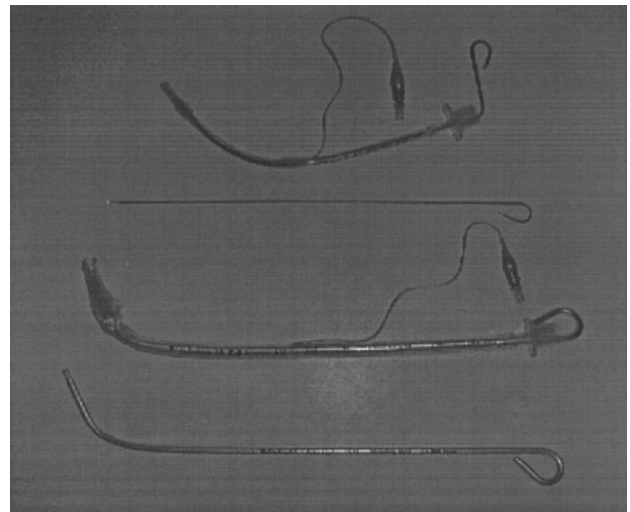


Fig. 26. A malleable stylette allows shaping the endotracheal tube to the desired curve. The tube is stiffened, which can facilitate intubation.

instability, head injury patients, and in patients in whom the tube is anticipated to be replaced electively.

The Pittsburgh Talking Tracheostomy tube (Fig. 25) is designed to allow phonation by tracheostomized patients. This tube has an extra lumen through which continuous or intermittent gas flow can pass upward through the larynx, thus allowing speech in patients who would otherwise find it difficult or impossible.

Special Tubes and Devices to Aid with Intubation

Several ET modifications to facilitate intubation are available. The ANSI standards require that ETs have a preformed curve to help with tracheal placement. During direct visualization, the larynx is usually seen to lie above the oral floor plane. The tube tip must be directed anteriorly to enter the trachea. Anterior directioning of the tip is especially important during nasal intubation. The ANSI material standards require the tube to soften at body tem-

perature to conform to this crooked anatomical course, so as to prevent undue pressure on the upper airway structures and trachea. During repeated intubation attempts, the tube may soften and not maintain the preformed curve, which further complicates intubation. The ET can be temporarily stiffened with a malleable stylette to allow anterior directioning of the tip. A typical intubation shape, like a hockey stick, is shown in Figure 26. Depending on the patient's actual anatomy, the stylette can be formed to help bypass an obstruction. Pediatric ETs are very floppy and a stylette is frequently useful in achieving tracheal intubation.

The Endotrol tube (Mallinckrodt Inc, Pleasanton, California) (Fig. 27) has an embedded string that, when pulled,

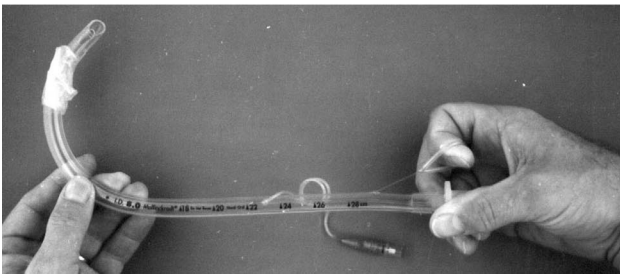
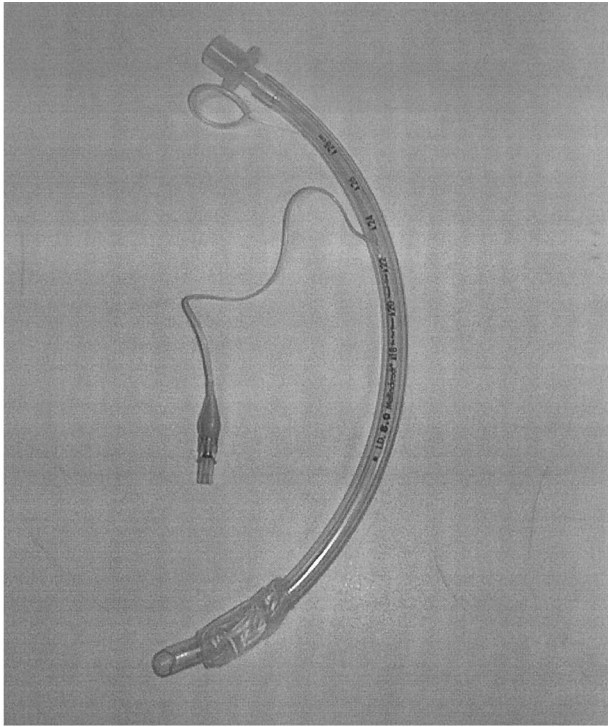


Fig. 27. The Endotrol endotracheal tube features an embedded string that flexes the tube anteriorly, facilitating intubation.

increases (or restores) the tube's curvature, thus facilitating intubation. When used with a stylette, the tip alone can be controlled and directed towards the larynx. This tube is especially useful during blind nasal intubation.⁴⁰

A modification of the stylette technique is the Flexguide, which is a combined malleable stylette and FOB. This device permits a fixed curve in the tube as well as visualization of the area in front of the ET, confirming correct tracheal placement.

Another modification of the malleable stylette is the lighted stylette (Fig. 28), which is equipped with a bright light on the tip to facilitate blind intubation.⁴¹ The lighted stylette is useful for both oral and nasal intubation, and in both adults and children.^{42,43} The tube and the lighted stylette (shaped like a hockey stick) are inserted blindly into the mouth or nose after topical analgesia or under general anesthesia. The room is darkened and transillumination of the airway allows differentiation of the esophagus from the trachea. A bright, narrow light in the midline

below the thyroid cartilage indicates that the trachea has been entered, while a diffuse glow laterally indicates that the tube is in the esophagus. With this implement, successful tracheal intubation depends on normal neck anatomy, good analgesia/anesthesia, and no interfering lesions. Since this is a blind technique, successful tracheal intubation should be confirmed with routine measures such as auscultation and measurement of exhaled CO₂. This is not an emergency airway technique, since the procedure can take a significant amount of time and must be performed in the dark (in which situation, observation of the patient's clinical status is suboptimal). This technique may be considered in patients during difficult intubation but with an easy airway or adequate spontaneous ventilation. The patient with a suspected cervical spine injury, in cervical traction, and who is breathing spontaneously is an excellent candidate for use of this technique.⁴⁴

The laryngeal mask airway can provide a route for intubation, since it usually rests directly in front of the laryngeal opening. A small (6.5–7.0 mm), cuffed tube can be inserted through the LMA and into the trachea, achieving a secure, protected airway during an emergency.⁴⁵ However, the combination must be left in place, since removal of the LMA over the ET is difficult and can result in extubation. An intubating stylette (Eshelmann Stylette or gum bougie), with its additional length, can be inserted through the tube, allowing reinsertion of a larger tube following removal of the LMA.⁴⁶ A newly-designed rigid metal LMA, the LMA-FasTrach (The Laryngeal Mask Co Ltd, United Kingdom) (Fig. 29) has a larger internal diameter and stabilizing flange that allows a special long, flexible, silicone ET to be blindly placed into the trachea, with a high success rate. The intubating LMA can then be withdrawn over the tube, using the supplied pusher or stabilizer and leaving the trachea safely intubated.

Head and Neck Surgery

Dental procedures and surgery of the head and neck pose special problems for airway management and endotracheal intubation. While special equipment is helpful in securing the airway initially, close collaboration between the anesthesiologist and operating surgeon is necessary to prevent inadvertent airway loss and patient harm during the surgical procedure. The major airway problems during these procedures are movement of the ET and kinking of the tube, causing inadequate gas exchange. While these problems can occur during any surgical procedure, they are more likely during head and neck procedures, since the tube; is often part of the sterile field and is often moved by the surgeon. Also, both visual and manual access to the ET is limited, and when problems arise they are not easily diagnosed or solved without contamination of the incision.

SPECIAL PURPOSE ENDOTRACHEAL TUBES

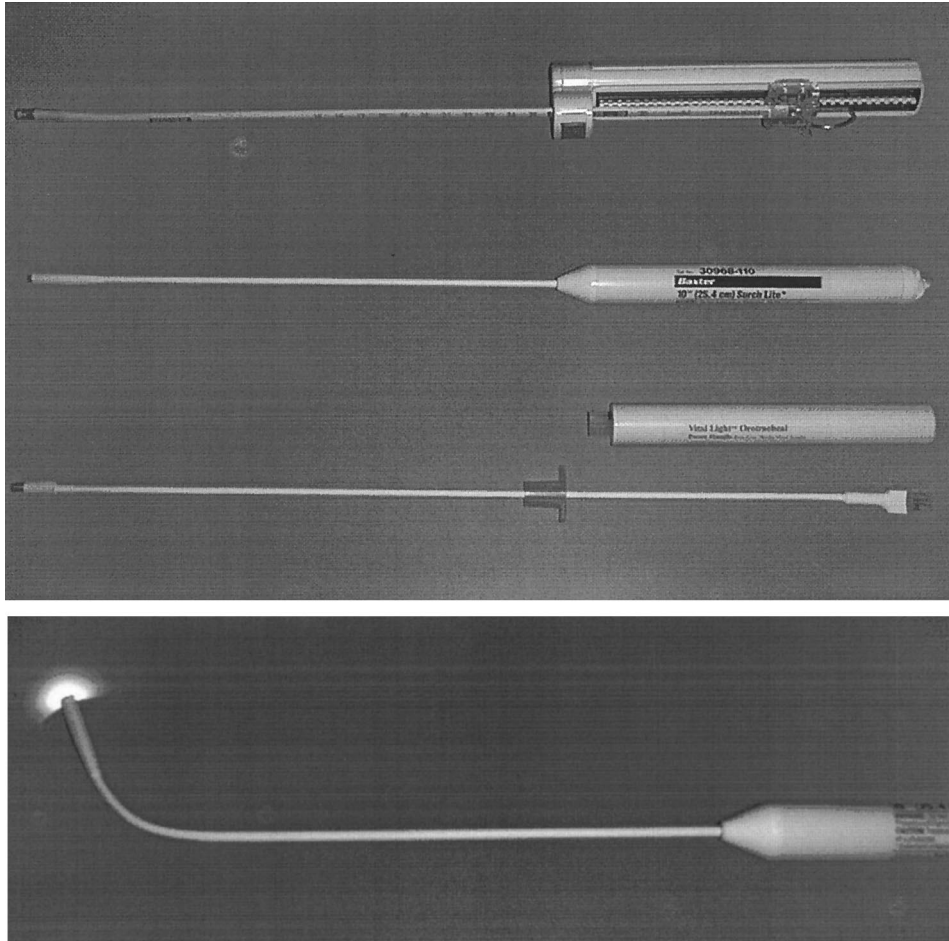


Fig. 28. Three types of malleable stylette, each with a bright light at the tip. Because the light illuminates the neck differently from the trachea and esophagus, it facilitates blind tracheal intubation.

Low profile tubes with preformed bends have been designed to reduce some of these risks. The bends can be straightened with a stylette to facilitate initial tracheal placement. One such ET is the RAE (Ring, Adair, Elwin tube, Mallinckrodt Inc, Pleasanton, California) (Fig. 30), which come in a variety of sizes, cuffed and uncuffed models, and shaped for oral or nasal intubation. The preformed bend rests at the chin or external nares, and prevents occlusion under the surgical drapes or on the field during the surgical procedure. The location of the bend is based on the diameter of the tube. The tube tip may be too long (resulting in bronchial intubation) or too short (resulting in extubation) depending on the particular patient's anatomy.⁴⁷ Passage of a suction catheter through the bend is usually difficult and may be impossible. Head extension or flexion after securing the airway can move the tip of the tube too far into, or out of, the larynx. For patients who do not fit well to the pre-formed tubes, the RAE-Flex (Mallinckrodt Inc, Pleasanton, California) tube has a wire-reinforced flexible section that can be bent to suit the patient's anatomy. The RAE-Flex tube can be used for oral

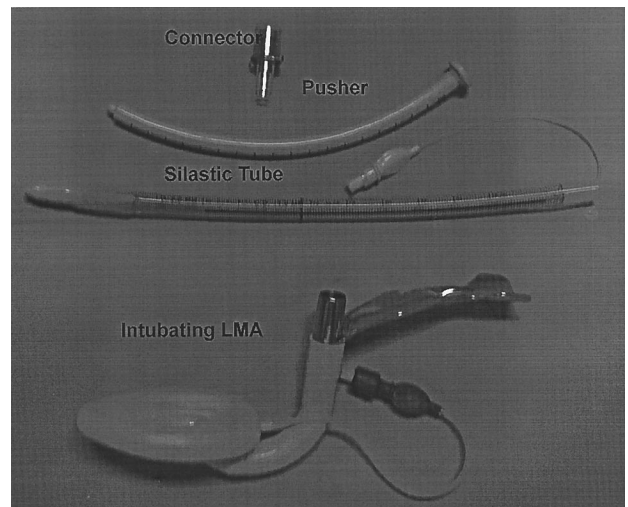


Fig. 29. The LMA-FasTrach intubating laryngeal mask airway (LMA) consists of a metal LMA, silastic tube, and stabilizers or pushers to allow the LMA to be removed, while leaving the endotracheal tube in the trachea.

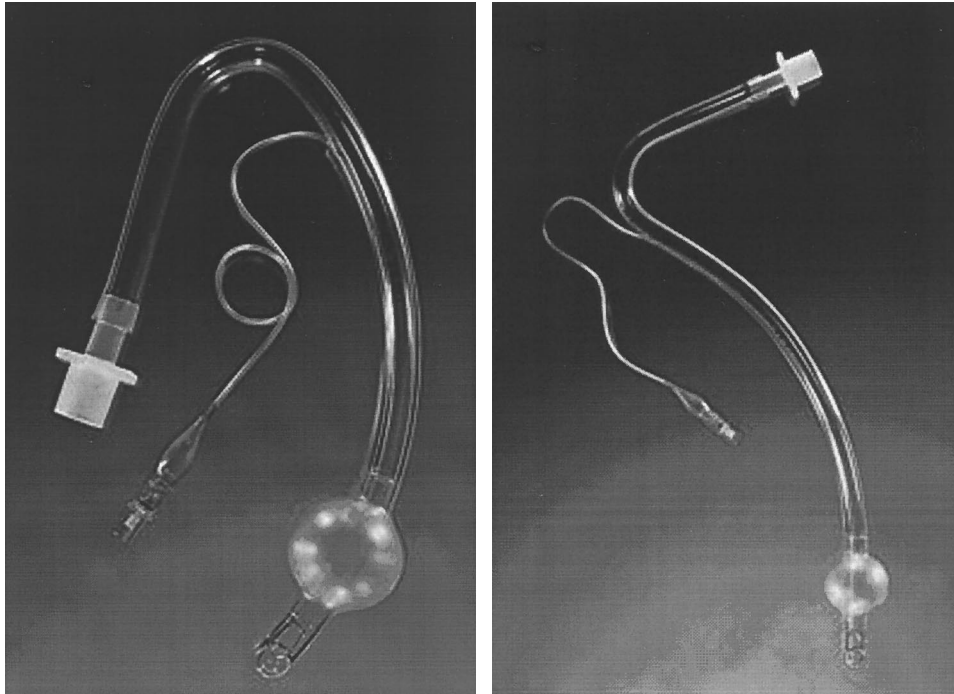


Fig. 30. Preformed RAE endotracheal tubes provide low-profile airways for head and neck procedures.

or nasal intubation. Passage of a suction catheter may be less difficult through a RAE-Flex tube than through the conventional RAE tube.

Tubes that are flexible and resist kinking are important additions to head and neck surgical procedures. Figure 31 shows how some tubes are spiral-embedded with wire or nylon fibers and are made of rubber, PVC, or silicone. They are flexible and maintain their internal diameter when bent. They also resist external compression.⁴⁸ However, if bitten or otherwise crushed, the tube may be permanently narrowed.⁴⁹ These tubes are often passed through the stoma of an existing tracheotomy, and can be placed aseptically by the surgeon during the procedure. If the tube is made of silicone, it will be very limp, making intubation difficult. Nasal intubation may be impossible because of narrow nasal passages. Accidental removal frequently occurs, and suturing the tube in place is recommended. Due to the high frequency of inadvertent extubation, these ETs are usually removed and replaced with conventional ETs at the end of the surgical procedure if continued airway cannulation is required.⁵⁰ These tubes cannot be shortened without damaging the spiral fibers and tube integrity. While this tube design solves one problem, a high degree of vigilance is necessary to prevent other problems.

Normal speech following laryngectomy is impossible. Over the past 20 years, creation of a controlled tracheo-esophageal fistula (TEF) to allow esophageal speech has been perfected. With a TEF, air from the lungs can be exhaled through the fistula into the esophagus and phar-

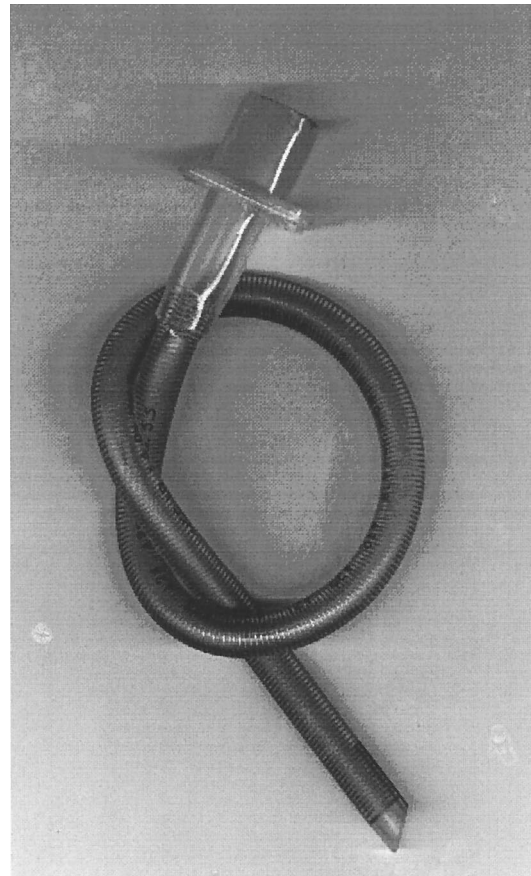


Fig. 31. This spiral wrapped endotracheal tube resists kinking.

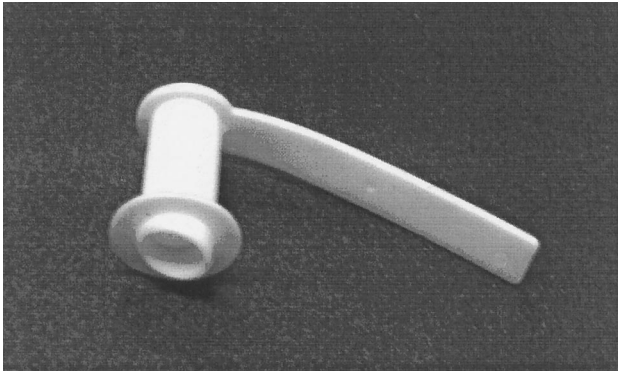


Fig. 32. The Bloom-Singer tracheal esophageal fistula (TEF) tube allows esophageal speech following laryngectomy.

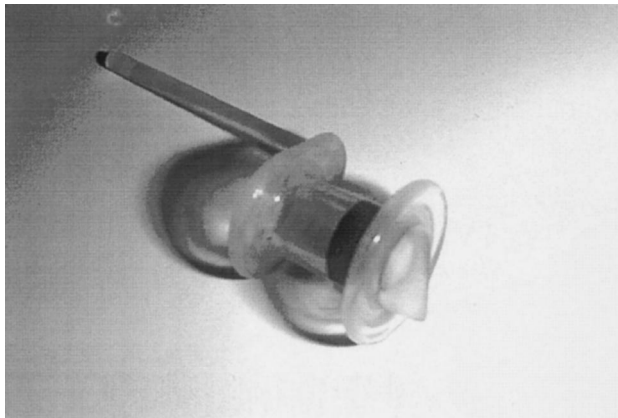


Fig. 33. The Provox II tracheoesophageal fistula (TEF) prosthesis.

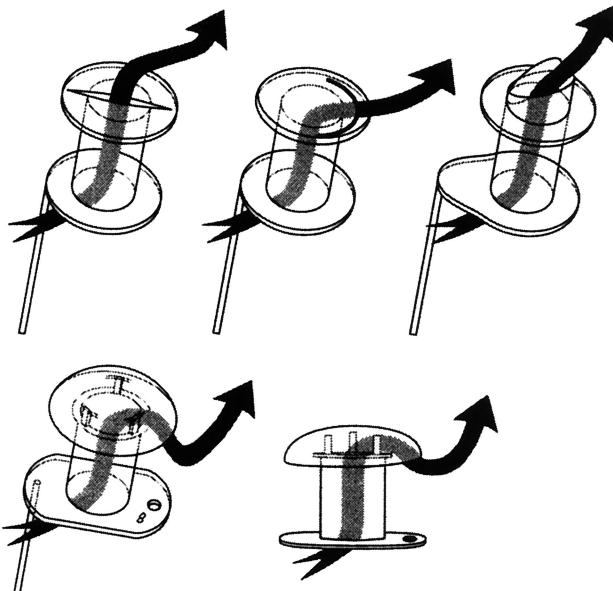


Fig. 34. Five types of tracheoesophageal fistula (TEF) prostheses developed around the Provox shape. (Modified from Reference 51, with permission.)

ynx, producing a vibration that can be articulated into verbal speech. A silicone prosthesis is used to prevent closure of the fistula, and its one-way valve reduces the likelihood of aspiration of gastric contents. To speak, the patient must manually obstruct his tracheal stoma, usually with a single digit, and exhale through the TEF. Several different prostheses have been developed. The earliest prosthesis was described by Bloom and Singer; this device (Fig. 32) is in wide use throughout the world. Another device is the Provox tube (Fig. 33). A series of these devices (Fig. 34) were developed in the Netherlands, and include the Groningen, Nijdam, and Provox variants. These can be interchanged using the unique features of each to solve individual patient problems.⁵¹ When these patients are seen clinically, the presence and function of the prosthesis should be confirmed. If intubation is required for a surgical procedure, the prosthesis can be removed or left in place. If left in place, it is necessary to confirm at the end of the procedure that it is still in place. If prolonged intubation is needed, the prosthesis can be removed to avoid pulmonary aspiration of gastric material or the device itself.

Summary

This article has described only selected special purpose ETs in common use today. There are additional devices not mentioned, which have small followings or very limited applications. Undoubtedly, further innovations will be available in the near future, but clinicians and researchers should bear in mind that very few standards protect users from poor ET designs. Thus, new devices should be carefully assessed prior to clinical application.

REFERENCES

1. Seegobin RD, Van Hasselt GL. Endotracheal cuff pressure and tracheal mucosal blood flow: endoscopic study of effects of four large volume cuffs. *Br Med J (Clin Res Ed)* 1984;288(6422):965-968.
2. Bunegin L, Albin MS, Smith RB. Canine tracheal blood flow after endotracheal tube cuff inflation during normotension and hypotension. *Anesth Analg* 1993;76(5):1083-1090.
3. Pavlin EG, VanNimwegan D, Hornbein TF. Failure of a high-compliance low-pressure cuff to prevent aspiration. *Anesthesiology* 1975; 42(2):216-219.
4. Fischer CG, Cook DR. Endotracheal tube cuff pressure in the use of nitrous oxide (letter). *Anesth Analg* 1991;73(1):99.
5. Bernhard WN, Yost L, Joynes D, Cathalis S, Turndorf H. Intracuff pressures in endotracheal and tracheostomy tubes: related cuff physical characteristics. *Chest* 1985;87(6):720-725.
6. Macrae W, Wallace P. Aspiration around high-volume, low-pressure endotracheal cuff. *Br Med J* 1981;383(6301):1220.
7. Burns SM, Shasby DM, Burke PA. Controlled pressure cuffed endotracheal tubes may not be controlled (letter). *Chest* 1983;83(1): 158-159.
8. Brodsky JB, Adkins MO, Gaba DM. Bronchial cuff pressures of double-lumen tubes. *Anesth Analg* 1989;69(5):608-610.

9. Clapham MCC, Vaughan RS. Bronchial intubation: a comparison between polyvinyl chloride and red rubber double lumen tubes. *Anaesthesia* 1985;40(11):1111-1114.
10. Brodsky JB, Benumof JL, Ehrenwerth J, Ozaki GT. Depth of placement of left double-lumen endobronchial tubes. *Anesth Analg* 1991; 73(5):570-572.
11. Lieberman D, Littleford J, Horan T, Unruh H. Placement of left double-lumen endotracheal tubes with or without a stylette. *Can J Anaesth* 1996;43(3):238-242.
12. Benumof JL. The position of a double-lumen tube should be routinely determined by fiberoptic bronchoscopy (editorial). *J Cardiothorac Vasc Anesth* 1993;7:513-514.
13. Inoue H, Shohtsu A, Ogawa J, Kawada S, Koide S. New device for one lung anesthesia: endotracheal tube with moveable blocker (letter). *J Thorac Cardiovasc Surg* 1982;83(6):940-941.
14. Vale R. Selective bronchial blocking in a small child. *Br J Anaesth* 1969;41(5):453-454.
15. Ginsberg RJ. New technique for one-lung anesthesia using an endobronchial blocker. *J Thorac Cardiovasc Surg* 1981;82(4):542-546.
16. Benumof JL, Partridge BL, Salvatierra C, Keating J. Margin of safety in positioning modern double-lumen endotracheal tubes. *Anesthesiology* 1987;67(5):729-738.
17. Yokota K, Toriumi T, Sari A, Endou S, Mihira M. Auto-positive end-expiratory pressure during one-lung ventilation using a double-lumen endobronchial tube. *Anesth Analg* 1996;82(5):1007-1010.
18. Gourin A, Garzon AA. Control of hemorrhage in emergency pulmonary resection for massive hemoptysis. *Chest* 1975;68(1):120-121.
19. Cahill BC, Ingbar DH. Massive hemoptysis: assessment and management. *Clin Chest Med* 1994;15(1):147-168.
20. Stoller JK. Diagnosis and management of massive hemoptysis: a review. *Respir Care* 1992;37(6):564-578. Discussion: 578-581.
21. Sosis MB. What is the safest endotracheal tube for Nd-YAG laser surgery? A comparative study. *Anesth Analg* 1989;69(6):802-804.
22. Sosis MB. Which is the safest endotracheal tube for use with the CO₂ laser? A comparative study. *J Clin Anesth* 1992;4(3): 217-219.
23. Sosis M, Dillon F. Reflection of CO₂ laser radiation from laser-resistant endotracheal tubes. *Anesth Analg* 1991;73(3):338-340.
24. Sprung J, Conley SF, Brown M. Unusual case of difficult extubation (letter). *Anesthesiology* 1991;74(4):796.
25. Jeckstrom W, Wawersik J, Hoffmann P, et al. Anesthesiological problems of endolaryngeal and endotracheal laser surgery. In: Rudert H, Werner JA, editors. *Lasers in otorhinolaryngology, and head and neck surgery*. *Adv Otorhinolaryngol* 1995;49:15-19.
26. Hess D, Alagar R. Methods of emergency drug administration. *Respir Care* 1995;40(5):498-512. Discussion: 512-514.
27. Barnett CC, Moore FA, Moore EE, et al. : Tracheal gas insufflation is a useful adjunct in permissive hypercapnic management of acute respiratory distress syndrome. *Am J Surg* 1996;172(5):518-522.
28. Miro AM, Hoffman LA, Tasota FJ, Sigler DW, Gowski DT, Lutz J, et al. : Tracheal gas insufflation improves ventilatory efficiency during metacholine-induced bronchospasm. *J Crit Care* 1997;12(1):13-21.
29. Levy B, Bollaert PE, Nace L, Larcan A. Intracranial hypertension and adult respiratory distress syndrome: usefulness of tracheal gas insufflation. *J Trauma* 1995;39(4):799-801.
30. Imanaka H, Kacmarek RM, Riggi V, Ritz R, Hess D. Expiratory phase and volume-adjusted tracheal gas insufflation: a lung model study. *Crit Care Med* 1998;26(5): 939-946.
31. Gowski DT, Delgado E, Miro AM, Tasota FJ, Hoffman LA, Pinsky MR. Tracheal gas insufflation during pressure-control ventilation: effect of using a pressure relief valve. *Crit Care Med* 1997;25(1): 145-152.
32. Hotchkiss JR Jr, Crooke PS 3rd, Marini JJ. Theoretical interactions between ventilator settings and proximal deadspace ventilation during tracheal gas insufflation. *Intensive Care Med* 1996;22(10):1112-1119.
33. Hoyt JD, Marini JJ, Nahum A. Effect of tracheal gas insufflation on demand valve triggering and total work during continuous positive airway pressure ventilation. *Chest* 1996;110(3):775-783.
34. Wenzel RP. Hospital-acquired pneumonia: overview of the current state of the art for prevention and control. *Eur J Clin Microbiol Infect Dis* 1989;8(1):56-60.
35. Jimenez P, Torres A, Rodriguez-Roisin R, de la Bellacasa JP, Aznar R, Gatell JM, Agusti-Vidal A. Incidence and etiology of pneumonia acquired during mechanical ventilation. *Crit Care Med* 1989;17(9): 882-885.
36. Driks MR, Craven DE, Celli BR, Manning M, Burke RA, Garvin GM, et al. Nosocomial pneumonia in intubated patients given surfactant as compared to antacids or histamine type 2 blockers. The role of gastric colonization. *N Engl J Med* 1987;317(22):1376-1382.
37. Stoutenbeek CP, van Saene HK. Prevention of pneumonia by selective decontamination of the digestive tract (SDD). *Intensive Care Med* 1992;18(Suppl 1):S18-S23.
38. American Thoracic Society. Hospital-acquired pneumonia in adults: diagnosis, assessment of severity, initial antimicrobial therapy, and preventive strategies. A Consensus Statement, November 1995. *Am J Respir Crit Care Med* 1996;151(5):1711-1725.
39. Valles J, Artigas A, Rello J, Bonsoms N, Fontanals D, Blanch L, et al. Continuous aspiration of subglottic secretions in preventing ventilator-associated pneumonia. *Ann Intern Med* 1995;122(3):179-186.
40. Asai T. Endotracheal tube for blind nasotracheal intubation (letter). *Anaesthesia* 1996;51(5):507.
41. Ainsworth QP, Howells TH. Transilluminated tracheal intubation. *Br J Anaesth* 1989;62(5):494-497.
42. Verdile VP, Chiang JL, Bedger R, Stewart RD, Kaplan R, Paris PM. Nasotracheal intubation using a flexible lighted stylet. *Am J Emerg Med* 1990;19(5):506-510.
43. Holzman RS, Nargozi CD, Florence FB. Lightwand intubation in children with abnormal upper airways. *Anesthesiology* 1988;69(5): 784-787.
44. Weis FR Jr. Light-wand intubation for cervical spine injuries (letter). *Anesth Analg* 1992;74(4):622.
45. Heath ML. Endotracheal intubation through the laryngeal mask: helpful when laryngoscopy is difficult or dangerous. *Eur J Anaesth* 1990; 4(Suppl):41-45.
46. Brimacombe J, Berry A. Placement of a Cook airway exchange catheter via the laryngeal mask airway (letter). *Anaesthesia* 1993; 48(4):351-352.
47. Black AE, Mackersie AM. Accidental bronchial intubation with RAE tubes (letter). *Anaesthesia* 1991;46(1):42-43.
48. Beckers HL. Use of a stabilized, armored tube in maxillofacial surgery. *Anesthesiology* 1982;56(4):309-310.
49. Martens P. Persistent narrowing of an armoured tube (letter). *Anaesthesia* 1992;47(8):716-717.
50. Ripoll I, Lindhold CE, Carroll R, Grenvik A. Spontaneous dislocation of endotracheal tubes. *Anesthesiology* 1978;49(1):50-52.
51. Van Den Hoogen FJ, Oudes MJ, Hombergen G, Nijdam HF, Manni JJ. The Groningen, Nijdam, and Provox voice prostheses: a prospective clinical comparison based on 845 replacements. *Acta Otolaryngol (Stockh)* 1996;116(1):119-124.

Appendix 1

**Subdivisions of the American Society for Testing and Materials
F-29 Technical Committee**

- F29.01 Division One on Anesthesia Apparatus
 - F29.01.01 Anesthesia Gas Machine
 - F29.01.02 Breathing Systems/Performance
 - F29.01.03 Connectors & Adapters
 - F29.01.04 Breathing Systems and Antidisconnect Fittings
 - F29.01.05 Pollution Control
 - F29.01.06 Anesthetic Agent Analyzers
 - F29.01.07 Lung Ventilators for Use in Anesthesia
 - F29.01.08 Gas Mixers
 - F29.01.09 Anesthesia Workstations

- F29.02 Division Two on Endoscopes and Airways
 - F29.02.01 Tracheal Tubes
 - F29.02.02 Naso/Oropharyngeal Airways
 - F29.02.03 Breathing Tubes/Bags
 - F29.02.05 Tracheostomy Tubes Adult
 - F29.02.06 Tracheostomy Tubes Pediatric
 - F29.02.07 Laryngoscopes Bulbs / Handles / Blades (Rigid)
 - F29.02.08 Laryngoscopes and Bronchoscopes (Flexible)
 - F29.02.09 Bronchoscopes (Rigid)
 - F29.02.10 Tracheal Tubes for Laser Surgery
 - F29.02.11 Suction Catheters

- F29.03 Division Three on Ventilators and Ancillary Devices
 - F29.03.01 Lung Ventilators (Other than for Anesthetic Use)
 - F29.03.03 Resuscitators
 - F29.03.04 Harmonization of Alarms
 - F29.03.06 Cutaneous Gas Monitoring
 - F29.03.07 Humidifiers
 - F29.03.08 Oxygen Analyzers
 - F29.03.09 Home Care Ventilators
 - F29.03.10 Pulse Oximeters
 - F29.03.11 Capnometers

- F29.04 Division Four on Terminology

- F29.06 Division Six on Medical Gas Supply Systems
 - F29.06.02 Oxygen Concentrators

- F29.07 Division Seven on Suction and Drainage
 - F29.07.01 Medical/Surgical Suction Systems

Discussion

Bishop: A couple of years ago I was fascinated by a description of a specialty endotracheal tube that appeared in *Anesthesiology* from the NIH [National Institutes of Health] group led by Kolobow.¹ It was a tube intended for the patient undergoing prolonged ventilation, and it was really very different from most of the tubes we have now. It used relatively high-tech material, which gave it a higher inner-diameter-to-outer-diameter ratio. It showed a lot of promise. It seemed to prevent secretions from getting past the cuff, it caused less tracheal damage in animal tests, and it seemed to be able to ventilate with acceptable pressures. The last time I talked to him, he hadn't been able to get a manufacturer to make it because they felt that it would be too expensive for a very small market. I don't know if anyone else knows what's up with that, or if other people are aware of the design, but I think it has many of the features we'd all like to see in a tube that's used for prolonged ventilation.

REFERENCE

1. Kolobow T, Tsuno K, Rossi N, Aprigliano M. Design and development of ultrathin-walled, nonkinking endotracheal tubes of a new "no-pressure" laryngeal seal design: a preliminary report. *Anesthesiology* 1994;81(4):1061-1067.

Durbin: I'm not familiar with that particular tube. There have been several thousand patents issued over the years for variations in airway devices, 99% of which never came into production. I think marketing factors are important. We've talked about one of these tubes here, the laryngeal aspirating tube. I think the device is going to face a similar future unless a clear-cut indication (value and cost-benefit) in a large patient population can be

identified. Otherwise, it will fall by the wayside as well.

Pierson:* Just to amplify on that: what you've touched on is a really important issue from the manufacturer's perspective. A manufacturer who makes millions of tubes will not invest in a new tube design that costs just as much or more to manufacture if the new model is only going to sell a few hundred copies. I believe that's one of the problems that we've had with getting some of these specialty tubes into clinical use for the intensive care unit, as opposed to using them in the operating room.

Durbin: Let's go back to the laryngeal mask airway, which everyone seems so enthusiastic about today in a number of situations. That tube was designed by Archie Brain in England ten years ago, is still made by hand, and sells for over \$200 per device. Although there are disposable models now made that are a little less expensive, they're not nearly as good. The cost has limited the application of this device, which we know beyond a shadow of a doubt is an advance in airway management.

Hurford: Clearly, cost is a big factor when we go to make a custom endotracheal tube for particular patients who have unique tracheal pathology or something like that. We can get those tubes made, but at \$100, \$200, \$300 on the run for two tubes or something like that, and certainly that's difficult. The other difficulty from a manufacturing point of view seems to be the materials that different manufacturers use. The LMA, for example, is made from latex. A company that works with latex, that's what they do. But, that has limitations, primarily because of high-pressure cuffs. So, the market is limited and the durability of latex tubes is limited. Then you're left with PVC and silastic. Both of those materials have severe struc-

tural limitations. PVC is good for certain cuff designs, but can't do the things that those wonderful cuffs that the Robertshaw right-sided tube had. When you inflated the bronchial cuff on a right-sided Robertshaw tube, the orifice that was built within that cuff expanded to a prodigious size, and that made that tube very safe and easy to place. That just can't be reproduced in any other material, so when you approach other manufacturers to try to mimic that design, they can't. So the odd designs that we sometimes see are crippled versions because of the type of material used. Lastly, you have silastic, but the problems of silastic are also rather large, and I think the Univent tube being made purely from silastic is a case in point. It's very stiff and difficult to place and control the blocker.

Thompson: I would like to emphasize that the problems you've mentioned are also a major problem in pediatrics. Any new device that looks like it has potential for use in infants and children has to overcome the hurdle of relatively low demand. As a consequence, many devices are never scaled down. Double-lumen tubes for use in children under age 7 or 8 are virtually nonexistent. I mentioned our desire to have some kind of marker that identifies proper tube depth in the trachea, but to date it does not appear to be an issue worth dealing with for the manufacturers.

Stauffer: I've been frustrated for many years trying to figure out what kind of endotracheal tube a patient in the intensive care unit actually has in place. By the time they arrive in the ICU, they have already been intubated—in the emergency room, in the field, at another hospital, in the operating room, or in the recovery room. Then the endotracheal tube is anchored with thick bands of adhesive tape. It's very difficult for me to know what kind of cuff is on the distal end of the tube. There's no labeling on the prox-

*David J Pierson MD, Division of Pulmonary & Critical Care Medicine, Department of Medicine, University of Washington, Seattle, Washington.

imal end to indicate the type of cuff. The tube size is often difficult to determine, as well. If you turn the 15 mm adapter over and shine a light on it, you might get a clue, but often the size markings are very difficult to read. I wish the tube manufacturers would help us out in that regard so that we know what kind of cuff we're dealing with and have an easier identification of the tube size. I don't know if anybody else has a similar concern, but it's a problem for me.

Durbin: I would point out that cuff compliance is variable between manufacturers. A highly compliant, high-volume cuff, means very different things in a Rüsck tube versus one from Mallinckrodt. It is essential to know who the manufacturer is and what the specifications are for tube components.

Pierson: Ray Ritz should probably have made this comment, because he used to be the manager in our hospital, but here's one anecdotal report: Since with most intubations that reach our ICU the respiratory therapists have participated as an assistant, they routinely take a tongue blade and write on it the brand and size of the tube, the date it was inserted, and the depth of insertion, measured at the teeth. They then tape that tongue blade to the ventilator so that that information is always conveniently available. It's a crude system, but useful.

Stoller: I'd like to use the Journal Conference as a forum to think about other "boutique-y" tubes that would be of value in specific niches, such as the bronchoscopy suite. Having placed the bronchoscope through the airway, one then incurs a problem of bleeding

and wants to intubate the patient while using the bronchoscope as a stylette, but not having threaded a tube over the bronchoscope in advance. So, what we need, and this is a plea to manufacturers, is a bivalved tube—a tube that actually opens up on its long axis and then could be slid over the bronchoscope already in the airway and then closed on itself and slid into the airway—a "zippered" endotracheal tube. Although I realize it would be a low-volume item, I think there are rare instances in which it would be *extremely* helpful.

Ritz: Charlie, I'm a little confused about your pressure volume curves for your endotracheal tubes. How were those done?

Durbin: Cuffs were filled with aliquots of air, allowed to equilibrate several minutes at room temperature, and the cuff pressure recorded.

Ritz: So that was just the maximum volume it took to fill the cuff before you got pressure.

Durbin: It was a deflated cuff inflated stepwise to 60 mL and then back down again.

Ritz: Right. Because it would seem like the best cuff would be one that created no pressure until it approached its critical volume. The compliance of the cuff should be high enough so that as you add appropriate volumes while it's actually in the patient, the only pressure that you measured was the tracheal wall contact pressure. I really only care about the distending pressure of the cuff when I've overinflated the cuff, or if I'm using a low-volume high-pressure cuff. So, it seems to be

a positive attribute to say I put 5 cc in a cuff and it didn't have any pressure.

Durbin: That's correct. But, you also have to recognize that there are cuffs, such as in the double-lumen endotracheal tubes, where that bronchial cuff is very small and is also potentially very high pressure. There are the red rubber cuffs, that are still in use in some institutions, where the pressure you're measuring in your connecting tube to the pilot balloon is not a reflection of the pressure against the wall. I think what you're saying is that you want one that lies against the wall and tells you what that pressure against the wall is.

Ritz: Right. It seemed to me from Dean's [Hess] presentation earlier that you still see descriptions in textbooks of minimal occlusive volume technique for managing cuffs. And as Dean eloquently pointed out, the incidence of aspiration can be relatively high with that technique. I don't see any reason to promote minimal occlusive volumes. It seems like the cuff pressure should be taken up to 25–30 cm H₂O, as long as you're talking about tracheal wall contact pressure. You need to use minimal occlusive volume if you're using low-volume high-pressure cuffs.

Durbin: That is correct. But those cuffs do exist. There are devices that have them—the percutaneous tracheostomy by Portex being one in particular, has a high-pressure, low-volume design. This design is easier to insert. If you're talking about people who are inexperienced at inserting them, the low-profile cuffs offer a theoretical advantage. These devices do exist.