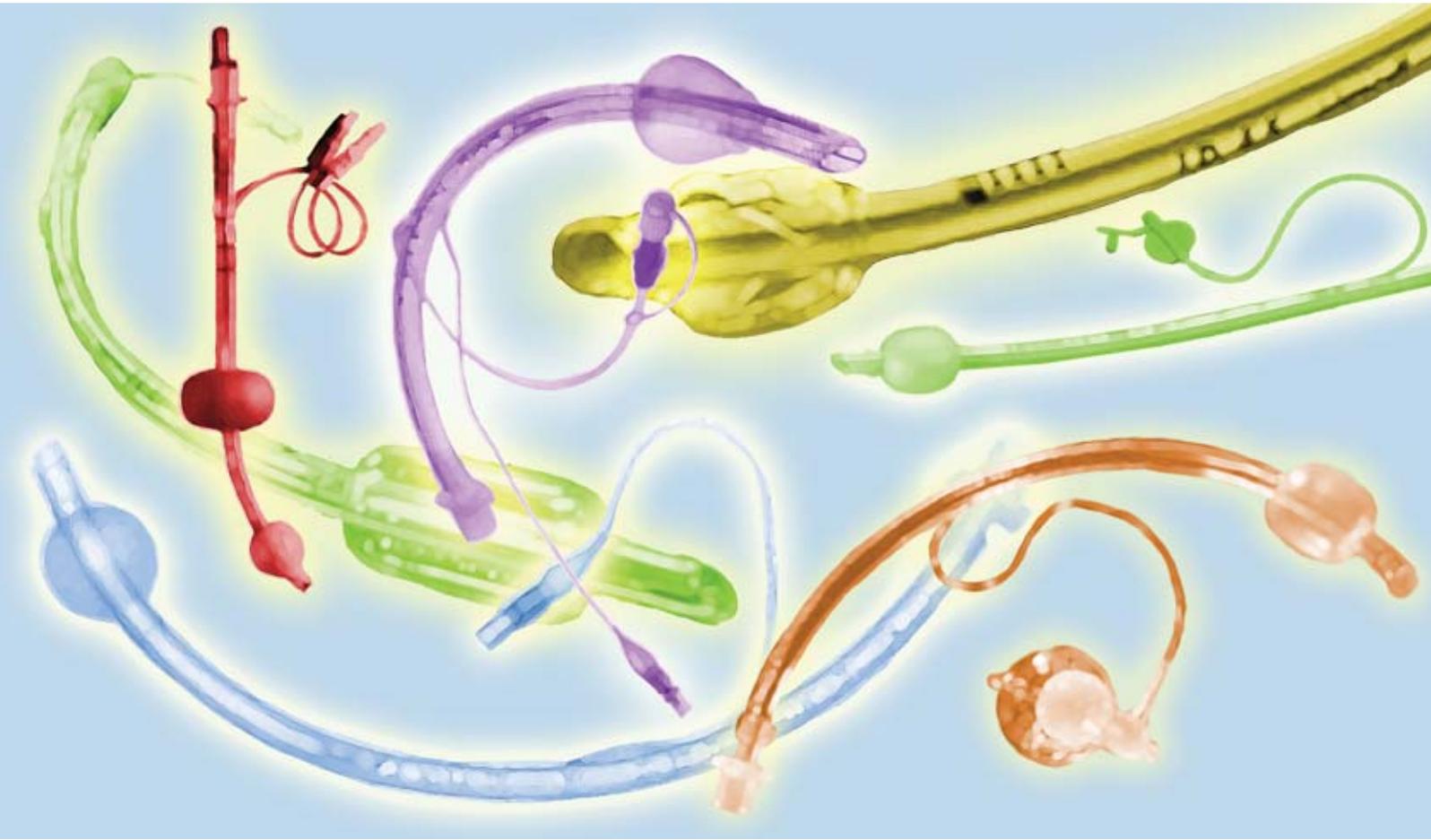


Endotracheal Tube Cuffs: Design and Function



Endotracheal tube (ETT) cuffs have advanced modestly in design since they were first introduced commercially in the mid-20th century. Until that time, ETTs were packed on either side of the subglottis by anesthetic swabs to prevent gas escape, and ribbon gauze was sewn on by hand to aid extraction at extubation.

JOAN E. SPIEGEL, MD

*Instructor in Anesthesia
Beth Israel Deaconess Medical Center
Harvard Medical School
Boston, Massachusetts*

Dr. Spiegel has nothing to disclose.

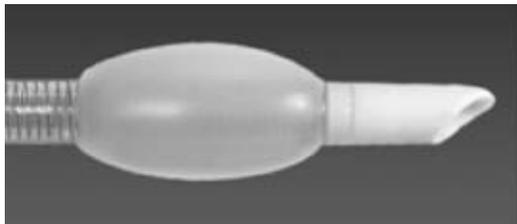


Figure 1. Top: A typical HVLP, disposable PVC cuff design (Hi-Lo, Covidien). Bottom: The HPLV cuff on the endotracheal tube used with the LMA Fastrach (LMA North America).

HPLV, high pressure-low volume; **HVLP**, high volume-low pressure; **PVC**, polyvinyl chloride

In 1926, anesthetist Arthur Guedel experimented with various rubber items, including dental dams, condoms, and gloves, to construct the first ETT cuff, testing his prototypes on animal tracheas obtained from his local butcher. Guedel's friend and fellow anesthetist, Ralph Waters, encouraged him to provide a leak-proof ETT seal that would complement Waters' closed circuit, soda-lime absorption system for positive pressure ventilation (PPV). But where was the most advantageous siting of the rubber cuff in the airway? Optimal position of the cuff was not intuitively obvious at the time.

Guedel found that a supraglottic cuff position allowed gasses to pass upward more easily; a cuff positioned at the level of the cords could not be inflated properly without disrupting its position; and placing the cuff in the mid to distal tracheal area could facilitate the passage of secretions alongside the tube and cuff.

Following rigorous experimentation in his own basement, Guedel determined the best cuff position to be just below the vocal cords. To demonstrate the effectiveness of his cuff, Guedel subjected a dog, appropriately named "Airway," to intubation and ventilation in an underwater tank via a Waters' circuit. The dog emerged unharmed through several successful demonstrations to earn a position as a family pet in the Waters' home.

Cuff System, Design, and Material

The American Society for Testing and Materials (ASTM) specifies requirements for the proper design of both ETTs and cuffs. The ASTM specifies a maximum distance from the tip of the tube to the end of the cuff, which varies with tube size. The end of the cuff must not impinge the opening of the Murphy eye; it must not herniate over the tube tip under normal conditions; and the cuff must inflate symmetrically around the ETT.¹

All cuffs are part of a cuff system consisting of the cuff itself plus a means of inflation, which typically includes a lumen in the wall of the tube, an external tube (portion that is visible outside the patient), a pilot balloon, and a valve.

The principal function of the ETT cuff is to ensure proper sealing between the patient's trachea and the cuff itself to ensure that minimal leakage occurs around it during PPV. An important but less obvious function of the ETT cuff system is to center the tube in the trachea and inflate uniformly around the ETT so that the tip is less likely to traumatize the mucosal lining. Proper inflation of the ETT cuff is thus critical for patient safety. Cuff pressure must be high enough to seal the trachea to prevent aspiration of oropharyngeal secretions and avoid air leaks to the atmosphere. It also must be low enough to allow adequate perfusion of the tracheal mucosa.² A consequence of insufficient sealing of the ETT cuff is micro-aspiration or frank aspiration and resultant nosocomial pulmonary infections. Complications of an excessive cuff pressure seal (>40 cm H₂O) include postextubation pain, necrosis, bleeding, stenosis, tracheal rupture, and tracheoesophageal fistulae.³⁻⁷

Low- and High-Pressure Cuffs

In the 1960s, endotracheal cuffs were made of red rubber and classified as high pressure-low volume (HPLV). Today, HPLV cuffs are made of nondisposable silicone, and high volume-low pressure (HVLP) cuffs are made of tissue-compatible polyvinyl chloride (PVC) or polyurethane (Figure 1). What are the differences?

The HPLV cuff has a small diameter at rest and a low residual volume, which is the amount of air that can be withdrawn from the cuff after it has been allowed to equilibrate with atmospheric pressure. For sealing in the trachea, the HPLV requires a high intracuff pressure to overcome the low compliance of the cuff itself. The cuff makes a small area of contact with the trachea and deforms the trachea to a circular shape.¹

When a high-pressure cuff contacts the tracheal wall, intracuff pressure does not change and measurements of pressure within the cuff and of the tracheal mucosa will not be consistent.

One concern associated with the cuffs is possible ischemic damage to the mucosal wall with prolonged use. Another potential problem is that the cuffs may inflate in a noncircular fashion and cause the ETT to injure the trachea.

Some advantages of high- versus low-pressure cuffs are their reusability and lower overall cost, and lower incidence of sore throat. They also may provide better protection against aspiration than low-pressure cuffs. In addition, because the cuffs deflate to sit very close to the ETT, the tube and cuff are more easily visible during intubation.

When using a non-disposable HPLV ETT with a silicone cuff, such as that within the LMA Fastrach (LMA North America), it is prudent to pay careful attention to cuff pressure; however, the lack of routine manometer use makes this difficult. Knowlson and Bassett demonstrated that proper inflation in the HPLV cuff could be achieved by inflating the cuff to the minimal volume that sealed the trachea—the minimal occlusion volume (MOV).⁸ MOV is achieved by inflating the cuff just above the point where a seal is achieved by listening for a leak following intubation at peak inspiratory pressures (PIP) during PPV.

An HVLP cuff comprises a thin compliant wall that, when inflated, adapts and conforms easily to the irregular borders of the tracheal wall. A significant advantage of high-volume cuffs over low-volume cuffs is that, provided the wall of the cuff is not stretched, the intracuff pressure will correlate closely with tracheal mucosal pressure (Wilder, 1996).¹ Although HVLP cuffs are associated with fewer complications than HPLV cuffs, the devices may cause serious tracheal injury if the intracuff pressure is maintained within the steep part of the pressure-volume curve (the ideal range being 20-30 cm H₂O).⁹

Volume, Pressure, and Sealing Characteristics

The purpose of the ETT cuff is to provide a seal at a pressure high enough to prevent aspiration but not impede blood flow in the trachea. Clinicians frequently

Table 1. Ideal Intracuff Pressures For Adults Using Traditional PVC Cuffed Tubes

Pressure	cm H ₂ O	mm Hg
Ideal	20-30	15-22
High	>40	30
Low	<20	15

PVC, polyvinyl chloride

From references 15 and 16.

inquire as to the volume of air required to inflate an ETT cuff. However, the more important question should be one of how much pressure will be exerted on the mucosa when the cuff is properly inflated.

Conventional HVLP cuffs require about 20 cm H₂O to seal the trachea. Microaspiration still can occur at pressures up to 60 cm H₂O, so guidelines depend on clinical requirements. Pressure limits for routine cuff inflation are determined in part by the blood pressure of the capillaries supplying the trachea, which is approximately 48 cmH₂O.¹⁰ An intracuff pressure greater than 34 cm H₂O results in decreased perfusion to the trachea, whereas total obstruction of tracheal blood flow occurs at about 50 cm H₂O.² A review of the literature suggests 20 cm H₂O to be a reasonable lower limit of cuff pressure in adults when using HVLP PVC cuffs. The consensus regarding acceptable maximum cuff pressure ranges from 25 to 40 cm H₂O in adults (Table 1.)

The margin of error for overinflating cuffs is not large, and clinicians do not adequately understand the relationship between volume and pressure in this setting.¹¹⁻¹³ An exponential increase in pressure with rising volume is expected with a high-pressure ETT at lower volumes of air, but can occur with high volumes even in HVLP cuffs. For HVLP cuffs, a linear relationship exists between volume and pressure within the cuff over a range of sealing pressures. In 2009, Hoffman et al demonstrated this phenomenon using intubated canines. They calculated a Spearman rho correlation of volume and pressure of 0.97 or 97%, validating a near-perfect linear relationship.¹⁴

However, volume necessary to achieve a cuff pressure of 20 to 30 cm H₂O varies considerably between patients, regardless of tube size and patient morphometric characteristics. Measuring cuff pressures therefore is still necessary.

When using nitrous oxide (N₂O) during general anesthesia, particular attention should be paid to changes in cuff pressures.² The increase in cuff pressure varies directly with the partial pressure of N₂O and time, and inversely with cuff thickness. The gas will expand the resting inflated cuff over time during the administration



Figure 2. Foam cuff tube.



Figure 3. Laser-Flex tracheal tube with double cuff (Covidien).



Figure 4. TaperGuard (Covidien).

of general anesthesia, with the greatest change occurring after the first hour of anesthesia. The perceived benefit of adding N_2O to the cuff when first delivering anesthesia is questionable because the gas will diffuse out of the cuff as easily as into it when the concentration of inspired N_2O is decreased, resulting in unwanted loss of cuff pressure and sealing.¹⁷

Newer cuff designs claim to allow less N_2O to diffuse into them over time by virtue of their design and/or material. The Profile Soft-Seal (Smiths Medical) is theoretically impervious to diffusion of N_2O because it contains a plasticizer with a high gas barrier and high compliance. One study comparing this cuff with traditional PVC devices revealed that although the design clearly inhibits an increase in cuff pressure when N_2O is used, the underlying mechanism is not from the reduction of diffusibility into the cuff but rather the higher compliance of the thinner cuff of the Profile Soft-Seal.¹⁸

UNIQUE CUFFS

Foam Cuff Tubes

A foam-filled cuff (Bionva Adult Fome-Cuf, Smiths Medical) is an HVLP device that expands following intubation, becoming completely devoid of air (Figure 2). Once expanded, it passively conforms to the contour of the trachea. Although the cuff will not cause tracheal injury, the risk for aspiration with these tubes is a concern.¹

Laser-Flex Tracheal Tube Cuff

These tubes and cuffs are designed for use with carbon dioxide and potassium-titanyl-phosphate lasers (Figure 3). Two PVC cuffs at the distal end are inflated using separate tubes. The distal cuff can be inflated if the proximal one is damaged. These cuffs are designed to be filled with saline.

Changes in Cuff Design To Improve Tracheal Sealing

CONTOUR

Newer cuff designs may improve tracheal sealing to reduce microaspiration and possibly ventilator-associated pneumonia (VAP). During PPV, ETT cuffs tend to autoseal, some better than others. Increased pressure in the trachea produces retrograde compression in the distal part of the cuff and moves air within the cuff toward the upper end of the device, creating a seal. The result is fewer subglottic secretions leaking past the cuff.

Some cuff designs seal the trachea better than others, and there is some suggestion that changes to the contour of the cuff itself leads to better self-sealing during PPV (Table 2). The TaperGuard (Covidien) ETT features a specially contoured PVC cuff that adheres better to the trachea during PPV and reduces subglottic secretions escaping past the cuff (Figure 4). One study found a 90% reduction in microaspiration with the TaperGuard compared with the Hi-Lo cuffed tube.^{19,20} The mechanism of the improved sealing of the TaperGuard tube cuff is presumably because it is taper-shaped, it allows the cuff diameter to match the diameter of the

Table 2. Examples of Commonly Used ETTs^a

ETT	New Design Elements	Recommended Use	
Combitube (Covidien)	A unique airway rescue device not meant for prolonged intubation. Its cuff system is forgiving; the cuffs may be inflated and patient may be ventilated regardless of where the tube was placed. May reduce aspiration similar to LMA Proseal.	It is especially useful for patients in whom direct visualization of the vocal cords is not possible, as in patients with massive airway bleeding or regurgitation, limited access to the airway and in patients in whom neck movements is contraindicated.	
Hi-Lo (Evac) (Covidien)	Hi-Lo is a common ETT for routine surgeries. Evac addition provides superior leak prevention around cuff in in vitro studies and reduces VAP via separate ETT suction port.	Operating room and chronically intubated patients (Evac).	
Lo-Pro (Covidien)	Improved visibility of the tube during intubation due to close sealing of cuff against tube.	For short and medium length intubations. Good for nasal intubations.	
Microcuff (Kimberly Clark)	Ultra-low-pressure cuff design that claims superior sealing within the trachea at pressures of 10 cm H ₂ O. Polyurethane cuff is ultra-thin, yet highly puncture-resistant.	Adult elongated cuff design may provide superior sealing. For children, the short, distally placed cuff is ideal; good for all chronically intubated patients as it may reduce VAP.	
SealGuard (Evac) (Covidien)	Ultra-thin polyurethane material of the cuff and tapered design may reduce microaspiration and VAP. Polyurethane cuffs may more easily auto seal during PPV.	Similar to TaperGuard, but incorporates a polyurethane cuff that seals the trachea at low pressures.	
Soft Seal (Smiths Medical)	Highly compliant, plasticized ETT PVC cuff that reduces increases in cuff pressure from N ₂ O.	Prolonged surgeries.	
TaperGuard (Evac) (Covidien)	PVC material shaped into unique taper design that seals the trachea better than traditional cuff shape.	Chronically intubated patients as it may reduce VAP.	

ETT, endotracheal tube; N₂O, nitrous oxide; PVC, polyvinyl chloride; VAP, ventilator-assisted pneumonia

^a Newer designs address contour of cuff and subglottic secretion control.

trachea at some point along the cuff and thus markedly reduces the microchannels at the sealing zone. In another improvement, the TaperGuard Evac ETT consists of the tapered cuff design and allows for the drainage of secretions through an integrated suction lumen. The TaperGuard Evac ETT is associated with a significant reduction in the risk for VAP compared with non-subglottic suctioning tubes.¹⁹

POLYURETHANE

The architecture of the trachea is nonuniform, non-cylindrical, irregular, and D-shaped. When a cuff with redundant PVC material is inflated, tiny channels are created that encourage pooling or collection of secretions within the folds. (The HVLP cuff is 1.5-2 times the diameter of the trachea when fully inflated.) VAP can occur as a result of these secretions. In order to prevent microaspiration and VAP, intracuff pressures as high as 50 cm H₂O have been used to seal PVC cuffs. Cuff material made of ultrathin (10 micron) polyurethane, instead of the traditional polyvinylchloride (50-80 micron) allows sealing of cuff in the lumen of the trachea at pressures of 15 cm H₂O or lower. This effect may result from the polyurethane material draping over the irregular tracheal mucosal contours, perhaps similar to the way plastic wrap seals food. The SealGuard

(Covidien) tube incorporates the same tapered cuff design as the TaperGuard but is made from polyurethane rather than PVC. Similarly, the Microcuff (Kimberly Clark) creates an effective seal at intracuff pressures of 15 cm H₂O, and has been shown to reduce VAP by 43% when compared with traditional PVC cuffs.²¹ The use of polyurethane cuffs has been shown to reduce the incidence of early VAP in cardiac patients compared to use of traditional cuffs.²²

Monitoring Cuff Pressure

The aneroid manometer is the most commonly used device for monitoring cuff pressures (Table 3). Manometers are precise and accurate but cumbersome to use, expensive, require calibration, and pose an infection risk to patients if not properly cleaned. Pressure-limiting valves are attached to the proximal end of the inflation tube, where they act as a reservoir for excess pressure within the cuff and keep intracuff pressures within a preset range, usually around 25 cm H₂O. The drawback of these valves is their inability to change pressure limitations, a problem when higher sealing pressures are needed. The latest technologies for controlling pressure include electronic regulators designed specifically for ETTs. These devices seem to solve the problem of cuff management, but they have some drawbacks. One

Table 3. Devices That Measure, Limit, or Control ETT Cuff Pressure

Aneroid manometers	Precise and accurate; must be calibrated; may transfer infectious agents unless cleaned; some need complex set up using tubing and stopcocks. Intracuff pressures can be lost during set up if not careful.	
Lanz pressure-regulating valve	Limits intracuff pressure to approximately 30 cm H ₂ O. May not be useful in children because cuff sealing pressures should be lower than adults. May not form a seal when high-ventilatory pressures are present.	Hi-Lo cuff with Lanz valve 
Brandt tube system	Useful during long periods of anesthesia using N ₂ O as intracuff pressure is stabilized via a large pilot cuff reservoir and an internal pressure regulating valve.	
Smiths Pressure Easy Cuff Controller (right) VBM Cuff Controller (left) TRACOE cuff pressure control (not pictured)	Electronic devices that automatically keep pressure within set limit. Need to be set according to PIP. Costly.	

ETT, endotracheal tube; N₂O, nitrous oxide; PIP, peak inspiratory pressure

in vitro study, for example, found that the regulators may interfere with the self-sealing mechanism of HVLP cuffs when set pressures are lower than peak inspiratory pressures.²³ In addition, if the distal end of the tubing, which has a standard luer connection, is connected inadvertently to a blood line, a fatal air embolus could be delivered.

Endotracheal Cuff Use in Children

Children under the age of 8 years were a demographic previously considered ineligible to receive cuffed ETTs. The clinical consensus seems to be shifting, however. The practice of using cuffed tubes in children under age 8 now is considered safe, as long as pressure is strictly monitored.²⁴ Advantages of cuffed tubes in children are similar to those of adults: improved monitoring of end-tidal gas, reduced risk for aspiration, ability to use high inflation pressures and low fresh gas flows, decreased pollution in the operating room, and avoidance of repeat laryngoscopy. However, placing cuffed tubes in children also requires the use of an ETT with a small internal diameter, which limits suctioning capability.²⁴ Table 4 provides a set of recommendations for proper use of cuffed ETTs in children.

The recently introduced Microcuff ETT for children has a short, ultra-thin polyurethane cuff located away from the subglottic region—a cuff-free subglottic zone—an important feature for children because it is the narrowest portion of the glottis and thus vulnerable to cuff-induced damage (Figure 5). The cuff also effectively seals the tracheal wall at pressures as low as 10 cm H₂O by virtue of the thin polyurethane, in both children and adults.

Some major recent improvements in ETT cuff design have offered clinicians real choice between these devices depending on the clinical setting. A recent trend among ETT makers is to pay particular attention to cuff contour, material, and the prevention of cuff-related injury, microaspiration, and VAP. With the increasing use of cuffs in children under age 8, newer cuff design has played an important role in assuring safety and reducing the number of re-intubations associated with uncuffed tubes.

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Table 4. Recommendations for the Use of Cuffed ETTs in Children

1. After tracheal intubation, an air leak around the tube must be present at 20 cm H₂O positive airway pressure with the cuff uninflated.
2. The cuff should be carefully inflated using a manometer until air leakage disappears. Cuff pressure should not exceed 20 cm H₂O.
3. Cuff pressure should be continuously monitored and should be reduced if it exceeds 20 cm H₂O.
4. The cuff should not be actively deflated except for tracheal extubation. If cuff inflation is unnecessary, the cuff should be released with a manometer to avoid creation of membrane folds.

ETT, endotracheal tube
Source: Kimberly Clark



Figure 5. Microcuff (Kimberly Clark) pediatric endotracheal tube.

Note the more distally placed polyurethane cuff.

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