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Pediatric Cuffed Endotracheal Tubes: An Evolution of Care

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ABSTRACT

Purpose: To examine the history of pediatric endotracheal intubation and the issues surrounding the change from uncuffed endotracheal tubes to cuffed endotracheal tubes, including pediatric airway anatomy, endotracheal tube design, complications, and safety concerns.

Method: Review of the literature.

Conclusions: Although the use of cuffed endotracheal tubes in infants and children remains a topic of debate, the literature supports this change in practice. Meticulous attention must be given to intracuff pressure. Cuffed endotracheal tubes designed especially for the pediatric patient may increase the margin of safety.

> "The endotracheal tube is the link between our most expensive and our most sophisticated object, our anesthesia machine, and our most delicate and most precious subject, our pediatric patients."
>
> Andreas C. Gerber, MD[1]

INTRODUCTION

The polyvinyl chloride (PVC) endotracheal tube is perhaps our least glamorous and most ubiquitous bit of equipment. Sir Ivan Magill introduced red rubber tubes of uniform internal diameter (ID) in 1930, and these remained the standard until Mr David Sheridan introduced plastic endotracheal tubes in 1959.[2]

The initial studies of the larynx of infants and children were conducted on cadaveric specimens,[3-5] and these findings have informed our airway management. The traditional view is that in children younger than 8 years, the narrowest point of the airway is at the level of the circumferential, nondistensible cricoid cartilage. As the child continues to develop, the airway becomes more cylindrical, with the narrowest portion of the airway at the level of the vocal cords.

The recommendation for the use of uncufffed endotracheal tubes in patients younger than 8 years follows from the developing airway anatomy. An endotracheal tube large enough to seal the cricoid ring, yet small enough to allow an air leak at pressures between 20 and 30 cm H_2O, should allow adequate positive pressure ventilation without exerting excessive pressure on the tracheal mucosa that could result in tissue hypoperfusion and injury.

The practice of using uncuffed endotracheal tubes has proven to be safe. Black et al[6] studied 2,953 pediatric patients admitted to the intensive care unit during a 4-year period. The children had been nasotracheally intubated with uncuffed endotracheal tubes. None of the patients in the study showed clinical symptoms of acquired subglottic stenosis.

The PVC cuff on the tracheal tube requires the tube to be sized down by one-half size to accommodate the increase in the external diameter created by the bulk of the cuff. Because small changes in diameter result in large increases in resistance, this downsizing results in an increased work of breathing during spontaneous ventilation. This requirement for downsizing is a concern, especially in the smaller sizes of tracheal tubes. Although current ventilation techniques can readily overcome this increased resistance,[7] the successful suctioning of secretions in the smaller tubes is challenging.

The shortcomings of uncuffed endotracheal tubes have been accepted and tolerated for 50 years. Given the longstanding guidelines regarding pediatric intubation, it seemed imprudent to use cuffed tubes except when lung compliance was so poor that the necessary inspiratory pressures required a greater sealing pressure.

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THE MOTIVATION TO CHANGE

Why, then, would practitioners even consider using cuffed endotracheal tubes in infants and children younger than 8 years?

First, how does one accurately choose the correct size? Numerous formulas and tables guide the practitioner. The most common is the modified Cole formula [4 + (age/4)] for children aged 2 and older, with standard recommendations for younger children, based on both age and weight.[8,9] Unhappily, patients sometimes do not conform to these formulas. Khine et al[10] found that the rate of reintubation required with uncuffed tubes is 30% in children younger than 2 years and 18% in patients 2 years or older. When the leak around the endotracheal tube is too large to allow effective positive pressure ventilation, the tube must be exchanged, necessitating additional laryngoscopy and intubation attempts.

The degree of neuromuscular relaxation and the position of the head affect the leak around an endotracheal tube.[11] Thus, when the endotracheal tube is initially placed, the leak around the tube may be within the appropriate range. As the neuromuscular blockade fully onsets or the anesthetic depth enhances relaxation, or the patient's head is moved for surgical indications, what was initially a correctly sized tube may prove to be inadequate. At best, changing the tube causes delay; at the worst, it is an impossible task because the patient is already prepped and draped and the airway is not easily and safely accessible. And, as with all procedures, the first attempt may prove to be the most straightforward.

If the leak around the tube is excessive, reliable monitoring of ventilatory parameters becomes impossible. Current anesthesia machines are equipped with ventilators that can deliver the small volumes required for newborns and infants. The exhaled volumes and the end-expiratory gases guide us in our intraoperative management. Without these readings, we are left assessing the adequacy of the delivered tidal volumes by inspection of the chest excursion. Additionally, the wave form of the end-tidal CO_2 tracing gives valuable information regarding the adequacy of pulmonary blood flow. When the endotracheal tube leak is too large, the wave form is poor, which diminishes the quality of capnography.

THE LITERATURE IN SUPPORT OF CUFFED ENDOTRACHEAL TUBES

Gopalareddy et al [12] sampled the aspirates of patients undergoing chronic ventilation in the pediatric intensive care unit for the presence of pepsin, a specific and sensitive biomarker of aspiration of gastric contents. Patients intubated with cuffed tubes were compared with those with uncuffed tubes and tracheostomies. The former group had a lower incidence of tracheal aspirates positive for pepsin than the latter group (53% versus 100%, respectively). The study was limited owing to the small sample size and poor age matching.

Khine et al[10] studied 488 full-term newborns and children through 8 years of age who required anesthesia. They found that the lungs of patients with cuffed tubes were adequately ventilated with 2 L/min fresh gas flow, whereas 11% of those with uncuffed tubes needed greater fresh gas flow. Eschertzhuber et al[13] studied the consumption and related costs of sevoflurane and medical gases in matched groups of pediatric patients, half of whom were intubated with cuffed endotracheal tubes and half with uncuffed tubes. They found that the lowest possible fresh gas flow was significantly lower in the cuffed group than the uncuffed group. The consumption of sevoflurane and the associated costs paralleled these findings. The total costs of sevofurane and medical gases were 13.4 euro per patient versus 5.2 euro per patient.

Soiling the operating room with anesthetic gases remains a concern. Khine et al[10] found that ambient nitrous oxide (N_2O) concentration exceeded 25 parts per million (ppm) in 37% of cases with uncuffed tubes and in 0% of cases with cuffed tubes. Murat,[14] in correspondence, reported on 3,434 patients younger than 8 years and 904 younger than 1 year undergoing general endotracheal anesthesia with cuffed endotracheal tubes. No respiratory complications were attributable to the tracheal tube, and no cases of subglottic stenosis were observed. Additionally operating room concentrations of sevoflurane and N_2O decreased dramatically, with attendant decreases in the cost of medical gases. The National Institute for Occupational Safety and Health recommends a maximum of 25 ppm/h. Wood et al[15] found this level to be unattainable in pediatric otolaryngological surgeries.

In 1994 Deakers et al[16] prospectively studied 282 consecutive tracheal intubations in a pediatric intensive care unit during a 7-month period. There were no standardized criteria for endotracheal tube selection, and the decision of whether to use a cuffed or uncuffed tube was left to the discretion of the physician. The patients were evaluated for postextubation stridor or significant long-term sequelae. The authors concluded that cuffed endotracheal intubation is not associated with an increased risk of laryngeal injury.[16] In 1997 the use of cuffed endotracheal tubes in pediatrics increased with the publication by Khine et al[10] that compared cuffed endotracheal tubes to uncuffed tubes in infants and children requiring anesthesia. The formula used to calculate the correct size of cuffed endotracheal tube was the Khine formula [(age/4) + 3], and the modified Cole formula was used to size uncuffed tubes.

With these formulas, 77% of uncuffed tubes were appropriately sized versus 99% of cuffed tubes. The incidence of croup was 1.2% with cuffed and 1.3% with uncuffed tubes.[10]

In 2003 Litman et al[3] examined the airways of infants and children 2 months to 13 years of age undergoing magnetic resonance imaging (MRI). They examined the dimensions and developmental changes in spontaneously breathing, deeply sedated infants and children. The authors found that the narrowest portion of the larynx is at the level of the vocal cords, although the functionally narrowest portion is at the level of the nondistensible cricoid ring. The MRI images reveal an elliptical cricoid ring; the transverse dimensions were narrower than the anteroposterior dimensions at all levels of the larynx above the cricoid ring and in most children at the cricoid ring. This finding has implications for the fitting of uncuffed tracheal tubes, which provide adequate sealing not within a circular cricoid ring, where pressure would be distributed evenly upon the mucosa, but within an ellipse, where a leak around the tube could be present despite increased pressure against areas of the mucosa.[3]

In 2004 Newth et al[17] reported their experience with 860 critically ill children requiring long-term intubation. The investigators collected data for a 1-year period for 597 children in the first 5 years of life. Of these, 210 were intubated with cuffed endotracheal tubes. Uncuffed endotracheal tubes were chosen using the modified Cole formula, and cuffed tracheal tubes were chosen one-half size smaller to accommodate the increase in external dimension from the PVC cuff. They found no significant differences in the use of racemic epinephrine for postextubation subglottic edema, the rate of successful extubation, or the need for tracheotomy between patients with cuffed and with uncuffed tubes in any age group.

The studies of Khine et al,[10] Deakers et al,[16] and Newth et al[17] were all meticulous in choosing the size of the endotracheal tubes and in assessing the cuff inflation to maintain a leak at a pressure of 20 to 30 cm H_2O. In 2006 Suominen et al[11] studied 218 children who underwent 224 operations and assessed the leak pressure and adverse events (prolonged or barking cough, obstructed or prolonged inspiration or expiration, subcostal and sternal retractions, arterial desaturation, or laryngospasm) occurring after extubation. Adverse events were more likely to occur in children with an absent air leak at a pressure of 25 cm H_2O.

THE DESIGN OF ENDOTRACHEAL TUBES USED IN PEDIATRIC PATIENTS

Even those who found the evolving literature convincing remained concerned regarding the design of the cuffed endotracheal tubes available. Weiss et al[18] examined 11 cuffed and 4 uncuffed pediatric tracheal tubes (ID, 2.5-7.0 mm) from 4 different manufacturers. They evaluated the tubes for the outer diameter of the tube, the position and largest diameter of the tube cuff inflated to intracuff pressure of 20 cm H_2O, and the position of the depth markings. Their findings were compared with age-related dimensions of tracheal anatomy and were quite striking. The outer diameters of tubes with the same internal diameter varied widely between manufacturers and between cuffed and uncuffed tracheal tubes from the same manufacturer. The diameter of the cuffs, when inflated to 20 cm H_2O, was sometimes of inadequate circumference to be useful in the child for whom they were intended, such that the intracuff pressure would have to exceed the recommended maximal inflation pressure to seal the trachea. The cuffs were frequently too long, such that when the tube tip was placed in the mid-trachea, the inflated balloon was positioned within the larynx, impinging on the vulnerable subglottis. If the tubes were placed 1 cm below the cricoid cartilage, many of the tubes were too deep within the trachea. Only 5 of 11 tubes had depth markings at all; in those that did, the markings were inappropriate for pediatric tracheal dimensions.

Dillier et al[19] presented a case of laryngeal damage caused by an endotracheal tube with an unexpectedly large external diameter and inappropriately designed cuff. The external diameter of the cuffed tube was 0.7 mm greater than an uncuffed tube of the same size from the same manufacturer. The cuff was positioned inappropriately high such that when the endotracheal tube was inserted to the usual depth, the cuff was situated within the larynx.

Before the 1960s, tracheostomy was the procedure of choice for long-term ventilation, and acquired subglottic stenosis was rarely reported.[7] The incidence of acquired stenosis increased along with the rise of tracheal intubation in pediatric patients, with an incidence of 0.7% to 8%.[20] Factors contributing to the development of subglottic stenosis include the size of the endotracheal tube, movement of the tube, length of intubation, traumatic intubation, the presence of infection during the course of intubation, and possibly gastroesophageal reflux.[21] Could an endotracheal tube designed for pediatric patients improve our chances at providing atraumatic airway management?

AN ENDOTRACHEAL TUBE DESIGNED FOR PEDIATRIC PATIENTS

In 2004 Kimberly-Clark (Dallas, TX) introduced a newly designed cuffed endotracheal tube, the Microcuff. The cuff is made of ultra-thin polyurethane (10 μm) and fills the gap between the tube and the

tracheal wall without folds and channels. The Murphy eye, a feature on other cuffed tubes, was abandoned. This feature was historically meant to give a ventilation port, should the distal end of the endotracheal tube become obstructed, and to ventilate the right upper lobe of the lung in endobronchial intubation. The elimination of the Murphy eye allowed the position of the balloon to be moved more distally on the endotracheal tube shaft. The balloon on the Microcuff tube is quite short; when inflated, it expands in the trachea, below the subglottis, providing tracheal sealing with a mean intracuff pressure of only 10 cm H_2O. Depth markings guide the correct placement of the tip of the endotracheal tube within the trachea. Dullenkopf et al[22] studied 500 children from birth (birth weight at least 3 kg) to age 13, intubated with Microcuff endotracheal tubes, and found a very low rate of tube exchange (1.6%) as well as a very low rate of airway morbidity (croup requiring therapy, 0.4%).

In 2009, Weiss et al[23] published a prospective randomized multicenter trial comparing Microcuff endotracheal tubes to uncuffed endotracheal tubes in small children. A total of 2,246 children requiring anesthesia (birth to 5 years; weight at least 3 kg) from 24 European pediatric anesthesia centers were studied. The end points were postextubation stridor and the number of tube exchanges required to find an appropriately sized tube. Postextubation stridor was noted in 4.4% of patients with cuffed and in 4.7% of patients with uncuffed tubes. Tracheal tube exchange rate was 2.1% in the cuffed and 30.8% in the uncuffed groups.[23]

Replacing the standard PVC cuff with the polyurethane cuff may confer additional advantage. Dullenkopf et al[24] found in vitro that the Microcuff endotracheal tube was significantly better than all other brands at cuff pressures of 10 to 30 cm H_2O in preventing fluid leakage past the cuff, and Miller et al[25] found that in adults, the polyurethane cuffed endotracheal tube is associated with decreased rates of ventilator-associated pneumonia.

THE CASE AGAINST

The debate over cuffed versus uncuffed endotracheal tubes continues.[26-31] Holzki and colleagues[32] are by far the most ardent detractors of cuffed endotracheal tubes in pediatrics. They contend that stridor is not an adequate end point for identifying tracheal mucosal injury and that all incidences of airway complications should be evaluated with endoscopy. They correctly maintain that symptoms of injury may not present immediately, though it is unclear if they propose that all children undergo endoscopy with extubation. They prospectively collected pictures of airway injuries incurred by intubation, though it is unclear what airway management parameters were associated with these injuries. The authors document a marked increase in the incidence of severe airway injury at their institution, coinciding with the 1997 article by Khine et al.[10] Holzki and colleagues[32] contend that as warnings about the dangers of using cuffed tubes in children appeared in the literature, this incidence declined, surging once again with the introduction of the Microcuff tubes. The findings are alarming but not repeated in the literature. It seems improbable that such a marked increase in airway trauma, were it to have occurred elsewhere, would not have been reported and is at odds with our own experience.

It is important to note that the studies with the Microcuff tubes have been conducted on term infants with a body weight of 3 kg or greater. Until such data are available, without impelling clinical concerns, we will continue not to use cuffed endotracheal tubes in premature infants or infants weighing less than 3 kg.

CONCLUSION

There is strong evidence-based support for the use of cuffed endotracheal tubes in infants and children, particularly endotracheal tubes designed especially for the pediatric airway. This challenge to traditional guidelines has engendered an energetic debate. As airway equipment for the management of the airways of neonates, infants, and children continues to evolve, this debate will ensure the very best care for our most vulnerable patients.

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