Pediatric cuffed endotracheal tubes

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Abstract

Endotracheal intubation in children is usually performed utilizing uncuffed endotracheal tubes for conduct of anesthesia as well as for prolonged ventilation in critical care units. However, uncuffed tubes may require multiple changes to avoid excessive air leak, with subsequent environmental pollution making the technique uneconomical. In addition, monitoring of ventilatory parameters, exhaled volumes, and end-expiratory gases may be unreliable. All these problems can be avoided by use of cuffed endotracheal tubes. Besides, cuffed endotracheal tubes may be of advantage in special situations like laparoscopic surgery and in surgical conditions at risk of aspiration. Magnetic resonance imaging (MRI) scans in children have found the narrowest portion of larynx at rima glottides. Cuffed endotracheal tubes, therefore, will form a complete seal with low cuff pressure of <15 cm H_2O without any increase in airway complications. Till recently, the use of cuffed endotracheal tubes was limited by variations in the tube design marketed by different manufacturers. The introduction of a new cuffed endotracheal tube in the market with improved tracheal sealing characteristics may encourage increased safe use of these tubes in clinical practice. A literature search using search words "cuffed endotracheal tube" and "children" from 1980 to January 2012 in PUBMED was conducted. Based on the search, the advantages and potential benefits of cuffed ETT are reviewed in this article.

Key words: Children, cuffed endotracheal tube, microcuff tube

Introduction

Endotracheal intubation is a routinely performed technique in the conduct of anesthesia as well as for critical care management in children for protection of the airway, ease of positive pressure ventilation, pulmonary toileting, and maintenance of oxygenation. The use of uncuffed or cuffed endotracheal tubes in children have their own advantages and disadvantages [Table 1]. Uncuffed endotracheal tubes (UETTs) are traditionally used for intubation in all children under 8 years of age, irrespective of the indication and duration of intubation.[1,2] Cuffed endotracheal tubes (CETTs) in children undergoing surgery have not been very popular because of the fear that the cuff will cause airway mucosal injury, leading to sub-glottic stenosis.[3-5] Cuffed tubes are more expensive, and their benefit remains unproven.[6] Based on recent studies using magnetic resonance imaging (MRI) scans, it has been postulated that CETTs with low pressure, high volume cuff will seal the airway at the upper trachea where the posterior membranous wall can stretch and produce a complete seal with low cuff pressure of <15 cm H_2O without any increase in airway complications.[7-10] The manufacture of new endotracheal tubes with high volume low pressure (HPLV) cuff and continuing research in this field has also renewed interest in the use of cuffed tubes in children. This review will

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Table 1: Advantages of uncuffed and cuffed endotracheal tubes

Uncuffed endotracheal tubes	Cuffed endotracheal tubes
Larger ID	Allows use of lower fresh gas flow
Lower resistance to airflow	Less use of inhalational agent, so economical
Prevents increase in WOB	Reduced air pollution
Allows easy suctioning	Reduced risk of aspiration
Avoids trauma to sub-glottic region	Avoids multiple laryngoscopies and intubations
	Improved ventilation and end-tidal carbon dioxide monitoring

ID=Internal diameter, WOB=Work of breathing enable the readers to weigh the pros and cons of the cuffed tracheal tubes and to make a decision regarding their utility in day to day practice of pediatric anesthesia and intensive care.[11-14]

The search strategies for this review included search of electronic database PUBMED as well as manual search of cross references. A literature search was carried out using search words "cuffed endotracheal tube" and "children," and various articles (English) comparing UETT and CETT in children till January 2012 were reviewed. There were 5 editorials, 5 review articles, and 15 randomized controlled trials comparing UETT and CETT in children as well as those mentioning any side-effects.

Why do we need cuffed endotracheal tubes for the pediatric age group?

Selecting the correct size of an UETT is difficult in spite of availability of numerous formulae. Many a times, the introduced tube does not fit properly, leading to a large air leak, necessitating a tube change.[15] This air leak may not be evident immediately after intubation and usually manifests as the anesthetic depth increases or the patient's head is moved. An excessive air leak around the tube leads to unreliable monitoring of ventilatory parameters, exhaled volumes, and end-expiratory gases, which may be especially important in intensive care management of a child on ventilator.[16] The need to use high fresh gas flows leads to atmospheric pollution by anesthetic gases increasing the health risk to operation theater personnel.[17,18] The increased consumption of anesthetic gases also has economic implications.[19] The risk of aspiration, especially in children undergoing emergency abdominal surgeries, is also increased.[20,21] CETTs circumvent all the disadvantages of UETTs mentioned above.

The importance and need for CETTs is also dictated by the anatomy of the pediatric larynx. In a cadaveric study in infants and children, Eckenhoff *et al.* showed that the larynx is funnel-shaped with the narrowest portion of the funnel at the laryngeal exit. They also demonstrated that in children younger than 8 years, the cricoid cartilage is the narrowest point of the airway. As the child grows, the airway becomes more cylindrical, and the narrowest portion of the airway lies at the vocal cords.[9] Based on this, it was recommended that an ETT should be large enough to seal the cricoid ring but small enough to allow an air leak at pressures of 20-30 cm H_2O to ensure adequate positive pressure ventilation without causing undue pressure on the tracheal mucosa. However, Litman *et al.*, using magnetic resonance imaging (MRI) scans in spontaneously breathing children, found that the shape of the pediatric larynx was conical in the transverse dimension.[7] They demonstrated that the apex of the cone is at the level of the vocal cords, it is cylindrical in the antero-posterior (AP) dimension, and it does not change throughout development. Dalal *et al.*, using video-bronchoscopic imaging in anesthetized and paralyzed children between the age group of 6 months and 13 years, found the narrowest portion of the larynx in children to be the rima glottidis and not the cricoid cartilage.[8] Motoyama found that the rigid cricoid aperture is not entirely circular but slightly elliptical, and a tight fitting ETT causes more compression and ischemia on lateral or transverse mucosa rather than on the mucosa lining the antero-posterior segments of the cricoid ring.[10] He recommended that UETTs with smaller external diameter should be chosen rather than UETTs, which fit the cricoid opening.[10]

Using CETTs with low pressure-high volume cuff, the airway is sealed at upper trachea where the posterior membranous wall can stretch and produce a complete seal with low cuff pressure of <15 cm H_2O without any increase in airway complications. Studies have shown a decreased incidence of post-intubation croup with CETTs when the chosen tubes are 1-2 sizes smaller than UETTs.[15,22]

Why are cuffed endotracheal tubes not popular?

Poor design

CETTs are not routinely used by pediatric anesthesiologists because most of these tubes are not properly designed.[15,23-27] Ho *et al.* found reduced margin of safety of approximately 50% with CETTs, owing to the short tracheas of children.[25] According to the authors, for an UETT, the carina and the vocal cords represent the limits, within which the tracheal tube can be placed without causing carinal stimulation/ endobronchial intubation and inadvertent extubation, respectively [Figure 1]. When a CETT is used, the distal limit of placement of the tracheal tube is the carina while the proximal limit is where the proximal edge of the cuff impinges on the vocal cord.[25]

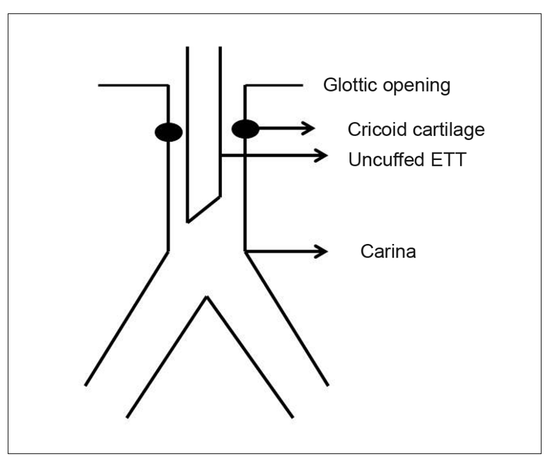

Figure 1: Placement of uncuffed endotracheal tube in the trachea

Realizing that the data available to compare the design of CETT for neonates, infants, and children in relation to age-related anatomic data is limited, Weiss *et al.* evaluated the design of pediatric CETTs from different manufacturers.[5] The authors found that the outer diameters (OD) of the CETTs varied markedly for a given internal diameter (ID), both between tubes of different manufacturers and between UETT and CETT of the same manufacturer. This variation in tracheal tube wall thickness is related to the material used for constructing the tube (PVC, polyurethane, or red rubber). Since most anesthesiologists select tube size based on ID, it is possible to force oversized tubes with risk of sub-glottic damage. In addition, the deflated cuff adds to the outer tracheal tube diameter, which may vary with cuff type and manufacturer.

None of the CETTs examined up to an ID of 4.5 mm met the requirements of high volume low pressure (HVLP) cuffs based on measurement of cuff diameters and cross-sectional cuff area at 20 cm H_2O cuff pressure.[5] To avoid high cuff pressures, HVLP cuffs are the standard of care in adults. They are based on the principle that at 20 cm H_2O cuff pressure, the cross-sectional area of the cuff corresponds to about 150% of the internal cross-sectional area of the trachea.[28] The upper limit of safety for cuff pressure in adults is 25-30 cm H_2O, but there is no data in children regarding perfusion pressures of the tracheal mucous membrane, and it is speculated that a lower cuff pressure would possibly be safe. Cuff pressures vary due to temperature, gas exchange, cuff movement, and anesthetic depth. Cuff inflation by air produces a variable intracuff pressure, which increases during the course of nitrous oxide anesthesia.[29] Bernet *et al.* in an *in vitro* study found that the external diameter of pediatric CETTs can expand to more than twice the age-corresponding tracheal internal diameter when overinflated, leading to considerable increases in cuff pressure and cuff volume.[26]

In most of the cuffed tubes, the upper border of the cuff corresponds to the upper border of the depth marking of the next larger sized UETT. Also, depth markings on different CETTs are either missing or are too high up on the shaft of the tube.[30] Thus, the cuff would lie between the vocal cords or even in the sub-glottic space if the tubes are placed according to age – related formulae for predicting depth of tube insertion. Ideally, the cuff should be located below the cricoid ring at the level of tracheal rings to avoid sub-glottic mucosal injury and its sequlae [Figure 2]. If a tube is placed below the cricoid ring and there is a long cuff, it carries the risk of endobronchial intubation. To ensure a cuff-free distance below the vocal cords to the cricoid level, the CETT should have a short cuff without a Murphy eye. Similar design problems have been encountered with preformed UETT and CETT

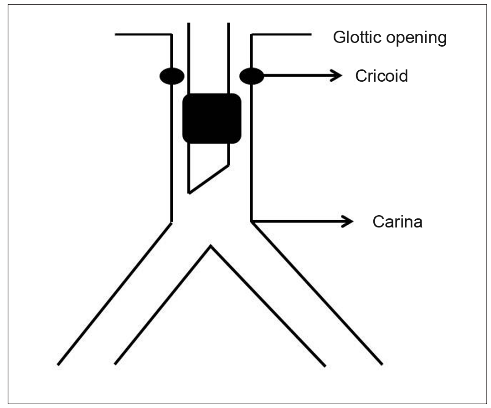

Figure 2: Ideal position of cuffed endotracheal tube

for children.[31] These tubes may lead to trans-vocal cord cuff placement when the tracheal tube is placed according to the bend because of reduced bend-to-tracheal tube tip distance and the presence of a Murphy eye and longer cuffs.

Airway injury

Holzki *et al.* reported several cases of laryngeal injury in children with CETT and according to them, incidence of airway trauma in pediatrics is high with 82% of these cases related to the use of an excessively large ETT, rather than the intubation procedure.[4] However, no study has demonstrated that a CETT, compared to UETT, causes an increased risk of airway complications provided an appropriate size is chosen and the cuff pressure is monitored. Khine *et al.* did not find an increased incidence of croup (evidence of laryngotracheal injury) in children with CETTs compared to UETTs.[15] Similarly, Murat *et al.* also could not demonstrate that CETTs were associated with increased respiratory complications.[22] Duracher *et al.* reported 6 cases of complications (dysphonia, hoarse cough, and laryngeal dyspnea) out of 204 analyzed (2.9%); 3 cases required treatment with epinephrine or corticosteroids, but none of them required tracheal intubation. In 3 cases, the cause of stridor was use of incorrectly predicted larger tube size.[32]

The chances of airway injury are high if there is a long duration of tracheal intubation. In critically-ill children admitted in PICU, Newth *et al.* did not find any difference in the incidence of post-extubation croup between the CETT and UETT groups with mean duration of ventilation being 13 days and 8 days, respectively.[14] Deakers *et al.* prospectively studied 243 patients in a pediatric intensive care unit and found that the overall incidence of post-extubation stridor was 14.9%, with no significant difference between children with UETT and CETT. They concluded that CETT intubation is not associated with an increased risk of post-extubation stridor or significant long-term sequelae.[13] However, Holzki *et al.* believe that stridor and croup are not adequate determinants of tracheal mucosal injury, and ideally all airway complications should be evaluated with endoscopy.[33] Laryngotracheal injury may be related to several risk factors like traumatic intubation, prolonged duration of intubation, use of an oversized tracheal tube, and severe hypotension during laryngoscopy.

Microcuff – a newly designed cuffed tube for pediatric patients

New cuffed endotracheal tubes (Microcuff Pediatric Tracheal Tube, Microcuff GmbH, Weinheim, Germany and Microcuff® PET; Kimberly Clark, Health Care, Atlanta, GA, USA) with improved tracheal sealing characteristics and a recommendation chart for tube size selection has been introduced in the market and will probably circumvent the above-mentioned problems.[34-41] This tube consists of an ultra-thin polyurethane cuff (10 μm), which does not form folds and channels between the cuff and the tracheal wall. The Murphy eye has been eliminated, which has allowed the cuff to be moved more distally on the CETT shaft. The cuff is short and when inflated, it expands below the sub-glottis, providing a seal with cuff pressure less than 10 cm H_2O. It has correctly placed depth markings and has low tube exchange rate [Figure 3].[37-39] A prospective, randomized, controlled multi-center trial by Weiss *et al.* has demonstrated the benefits of this tube in terms of number of tube exchanges, post-extubation stridor, and aspiration.[40] However, the cost of pediatric ETT with microcuff is several times more than those in routine use without cuff.

What do you need to do while using cuffed endotracheal tubes?

1. Selection of an appropriately-sized CETT to prevent airway mucosal injury is important. CETT should be 0.5-1.0 mm smaller than the UETT. In children >2 years, Cole's formula is used to select an UETT [ID (mm) = (age/4) + 4.0].[40] For a CETT, the most commonly used formula is that used by Khine [ID (mm) = [age/4] +3] and Motoyama [ID (mm) = (age/4) +3.5].[1,15] In newborns to infants <1 year, ID 3.0 mm CETT and in children from 1-2 years, ID 3.5 mm CETT should be used.[15] When using second-generation Microcuff PETs, Salgo *et al.* proposed a new recommendation, which allows selection of larger ID cuffed tracheal tubes than previously recommended [Table 2].[41]
2. Ideally, one should select a pediatric CETT (Microcuff tube) with a high-volume-low-pressure cuff of short length, with adequate depth markings.[38]
3. The most important aspect of CETT use in children is monitoring of intracuff pressure (P_{cuff}).[42-44] When nitrous oxide is used during anesthesia, it diffuses into the cuff leading to an increase in pressure in cuff and subsequent decrease in the tracheal perfusion pressure. Mucosal capillary pressure may be less in children (adult values are between 25-30 mmHg) because the mean arterial pressure is less in children. It becomes very important to monitor P_{cuff} during the intra-operative period and maintain it at or below 20 cm H_2O by removing excess gas. The evaluation of performance of cuff pressure pop off valve has shown that this novel device reliably prevents cuff pressure exceeding the pre-determined level of 20 cm H_2O.[45]

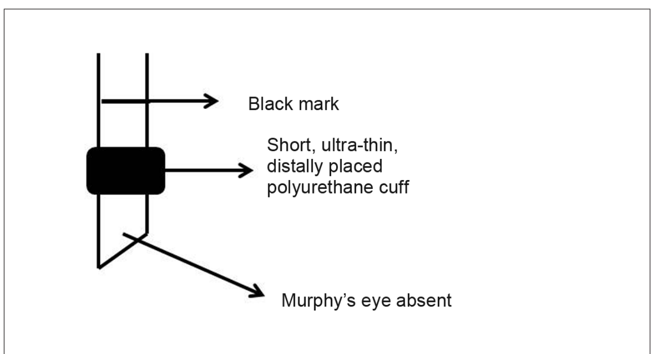

Figure 3: Microcuff endotracheal tube

CETT are especially useful in laparoscopic surgeries,[46] in conditions of full stomach to avoid aspiration, repair of a traumatic rupture of the left mainstem bronchus,[47] to occlude tracheo-esophageal fistula,[48] performance of sophisticated lung function measurement, and in the intensive care of children with severe pulmonary disease.[49]

Conclusion

CETTs offer a large number of advantages for their routine use in pediatric patients. Their use requires selection of correct-sized tracheal tube, its correct placement, and cuff pressure monitoring during the conduct of anesthesia. The increased cost of CETTS is compensated by the decrease in rate of tracheal re-intubation with different sizes of UETTs as well as a reduction in consumption of halogenated agents by ability to use low-flow anesthesia.

Table 2: Recommendations for age-based cuffed endotracheal tube size selection (mm)

Age (y)	Khine *et al.*[15]	Motoyama *et al.*[1]	Salgo *et al.*[40]
Birth to <0.5	3.0	3.0	3.0
0.5 to <1.0	3.0	3.0	3.5
1.0 to <1.5	3.5	3.5	3.5
1.5 to <2.0	3.5	3.5	4.0
2.0 to <3.0	3.5	4.0	4.0
3.0 to <4.0	4.0	4.0	4.5
4.0 to <5.0	4.0	4.5	4.5

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