



## “AN EVOLUTION OF ENDOTRACHEAL TUBES IN PEDIATRIC PRACTICE”: A REVIEW ARTICLE

### Anaesthesiology

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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. Cuffed endotracheal tubes may be of advantage in special situations like laparoscopic surgery and in surgical conditions at risk of aspiration. 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. This review article is to summarize the historical aspects, literature and to make comparisons about the advantages and disadvantages of uncuffed, cuffed and microcuffed endotracheal tubes used in paediatric anaesthetic practice.

### KEYWORDS:

children, uncuffed, cuffed, microcuffed, endotracheal tube

### INTRODUCTION

Few things in anaesthesia are as delicate and as vulnerable as the paediatric airway. In our smallest patients, the airway must be protected to allow adequate ventilation but must also be handled with utmost care to ensure no injury occurs to the laryngo-tracheal structures. Although the introduction of the laryngeal mask airway has been a major breakthrough in paediatric and adult anaesthesia, the vast majority of major surgical procedures carried out in newborns and infants still require tracheal intubation in order to provide safety for the patient and optimal conditions for both the anaesthesiologist and the surgeon<sup>1</sup>.

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 uncuffed endotracheal tubes and cuffed endotracheal tubes in children till January 2017 were reviewed.

### ANATOMY

Infants have a relatively large head, short neck, and large tongue. The larynx is higher in the neck (C3-4) than in the adult (C5-6) and is placed more anteriorly. The epiglottis is large, floppy and U-shaped. The narrowest part of the airway in an adult is the level of the vocal cords, and in a paediatric patient it is the level of the cricoid cartilage. If an adult endotracheal tube were to be used in an infant the cuff would sit at the level of the cricoid cartilage, which is the narrowest point, so when the cuff was inflated it would immediately cause damage to the cricoid and trachea.<sup>2</sup>

The cricoid ring is functionally the narrowest part of the paediatric airway up to eight years of age. The cricoid has long been considered a circular structure.

Evidence to the contrary reveals the cricoid to be ellipsoid in shape (transverse dimensions are narrower than anteroposterior dimensions) which has some important clinical implications.

As paediatric cricoid dimensions are considered to be ellipsoid, a round tube tends to lodge itself posteriorly. This may result in excessive pressure being placed on the posterolateral walls of the cricoid, and the air leak may be from the anterior part of the cricoid lumen. Thus, even with an adequate leak, one may still precipitate airway damage.<sup>3</sup>

The anatomical description of the infant larynx as funnel - shaped

with the cricoid being the narrowest part by Eckenhoff backed this mechanism.<sup>2</sup>

Eckenhoff's conception of the funnel-shaped infant larynx in the meantime has been questioned by Litman et al,<sup>4</sup> who found in MRI studies that the narrowest part of the larynx in spontaneous breathing paediatric patients is at the glottic level. Litman et al further demonstrated that the cricoid ring is not a circular but an elliptical structure.

### HISTORICAL ACCOUNT OF ETT USE IN PAEDIATRICS

Endotracheal intubation was rarely attempted in children before the 1940's because available tubes were not of proper material or design. Long term ventilation of paediatric patient's necessitated tracheostomy, a forebonding invasive procedure in the 1960s. The development of soft and pliable polyvinyl chloride ETs in the early 1960s was a technological leap, promoting a dramatic change in the respiratory management of pediatric patients.<sup>5</sup>

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.<sup>6</sup>

First generation of tracheal tubes (TTs) made out of red rubber with a low volume- high pressure cuff had significant potential to cause harm to the larynx and trachea both in adults and in children.

The subsequent development of TTs made out of much less irritant plastic materials with high volume-low pressure (HVLP) cuffs solved this problem for adult patients as well as paediatric population.<sup>1</sup>

### UNCUFFED ENDOTRACHEAL TUBE

Uncuffed endotracheal tubes have been used in paediatric anaesthesia for the last five decades. They are plastic disposable tracheal tubes made of polyvinyl chloride (PVC).

### Advantages of Uncuffed Endotracheal Tubes

The traditional teaching of using an Uncuffed ETT in infants is based upon studies of cadaveric specimens of children (4 months-14 years), which showed that the airway of an infant/child is funnel shaped, and that the narrowest part is the circumferential, non-distensible cricoid cartilage which is circular in shape. Therefore, an Uncuffed ETT which fits snugly through the cricoid, leaving some space to allow an air leak at a peak inspiratory pressure (PIP) of 20-25 cm H<sub>2</sub>O should provide a sufficient seal, making a cuff

unnecessary.<sup>7,8,9</sup>

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 20-25 cm H<sub>2</sub>O to ensure adequate positive pressure ventilation without causing undue pressure on the tracheal mucosa.<sup>10</sup>

The advantages of Uncuffed ETT are as follows:

1. Presence of an air leak - not compressing the tracheal mucosa against the non-distensible cricoid ring.
2. This negates the need to monitor cuff pressures
3. Uncuffed tubes are self-sealing at the point of the cricoid cartilage.
4. In the absence of a cuff, larger tube diameters can be used which leads to easier suctioning of secretions and lowers the resistance in spontaneous ventilation.
5. Uncuffed endotracheal tubes are also a cheaper option which is an important consideration in public hospitals in particular.

### Disadvantages of Uncuffed Endotracheal Tubes

Recent research on the paediatric airway refutes traditional teachings.

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.<sup>11</sup> They demonstrated that the apex of the cone is at the level of the vocal cords, it is cylindrical in the anteroposterior (AP) dimension and it does not change throughout development.

Dalal et al., using videobronchoscopic imaging in anaesthetized 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.<sup>12</sup>

Motoyama found that the rigid cricoid aperture is not entirely circular but slightly elliptical.<sup>13</sup>

All three studies came to similar conclusions:

The cricoid is not round, but an elliptical structure with the transverse dimensions being narrower than the anteroposterior dimensions.

The narrowest part of the larynx is not the cricoid but the glottis/subglottic region and the paediatric airway is more cylindrical like in adults, rather than funnel shaped.

The cricoid being elliptical means that when an uncuffed tube is inserted into the non-circular lumen of the cricoid to give a reasonable seal, the pressure exerted on the lateral walls of the cricoid is unknown and could be considerable.

Disadvantage of Uncuffed ETT includes:

#### 1. Airway damage

Tight fitting ETT causes more compression and ischemia on lateral or transverse mucosa rather than on the mucosa lining the anteroposterior segments of the cricoid ring.<sup>10</sup>

If undersized for age, uncuffed ETTs may move up and down in the airway and damage delicate mucosal surfaces (movement trauma). That leads to airway pathology may range from submucosal mucous gland hyperplasia to superficial ulceration, and/or to deep ulceration into the perichondrium or cartilage. Upon healing, fibrous scar tissue contracts to form glottic or subglottic stenosis.<sup>4</sup>

A large study by the Zurich group (2009) involving 2200 intubated paediatric patients revealed the tube exchange rate to be 2.1% with microcuff endotracheal tubes and 30.8% in uncuffed tubes.<sup>1</sup> This supports earlier discussion about uncuffed tubes having a higher exchange rate potentially leading to further complications.

#### 2. Airway leak

Upon insertion of an ETT, standard anaesthetic practice is to demonstrate a leak at a PIP of 20–25 cm H<sub>2</sub>O to ensure the ETT is not too tight. However, this is rarely done in neonatal practice. It is also quite a common conception in neonates to be happy with no leak as this improves ventilation. Tidal volume (VT)-targeted ventilation is commonly used in neonates. Tidal volume measurement and control become inaccurate in the presence of substantial airway leak. Although newer ventilators now offer leak compensation, Keszler claims that this is an imperfect solution given the large fluctuation in the ETT leak over time and that auto-triggering and failure to breathe terminate in flow-cycled modes are likely to occur with substantial ETT leaks. Leak varies with time, position, level of sedation/ muscle relaxation, and with change in compliance of the lungs.<sup>14</sup>

#### 3. Selection of tube

Selecting the correct size of an Uncuffed ETT 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. This air leak may not be evident immediately after intubation and usually manifests as the anaesthetic depth increases or the patient's head is moved.<sup>15</sup>

#### 4. Monitoring

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.<sup>16</sup>

#### 5. Atmospheric pollution

The need to use high fresh gas flows leads to atmospheric pollution by anaesthetic gases increasing the health risk to operation theater personnel.<sup>17,18</sup>

#### 6. Economic implications

The increased consumption of anesthetic gases also has economic implications.<sup>19</sup>

#### 7. Aspiration

The risk of aspiration, especially in children undergoing emergency abdominal surgeries is also increased.<sup>20,21</sup>

Minimising the ETT leak provides more efficient ventilation, maintenance of positive end expiratory pressure, maintenance of constant minute ventilation, stabilising gas parameters, more reliable respiratory monitoring, and decreases risk of pulmonary aspiration.

Cuffed endotracheal tubes (CETTs) circumvent all the disadvantages of uncuffed endotracheal tubes (UETTs) mentioned above.

### CUFFED ENDOTRACHEAL TUBES

Over 15 years ago, several authors suggested using the newer HVLP PVC cuffed ETTs in infants and children <8 years of age. The use of a cuffed ETT allows adjustment of the cuff to enable adequate sealing of the airway with an estimation of the pressure exerted on the tracheal mucosa.<sup>22</sup>

In a small survey of United Kingdom pediatric critical care and anaesthesia specialists, only 5% of PICU and 7% of anesthetic responders used cuffed tubes routinely. The most common reason cited in both groups for not using the cuffed tubes was that there was minimal perceived benefit to be gained over using an uncuffed tracheal tube.<sup>23</sup> In a survey of 200 French pediatric anesthesiologists (130 responses), the cuffed endotracheal tube was used routinely by 25% of respondents for more than 80% of their patients, while more than 37% of respondents used them in fewer than 20% of the cases.<sup>24</sup>

#### Advantages of using cuffed ETTs

Cuffed tubes provide a sealed airway allowing precise, lossless and reliable transmission of gases, vapours and pressures ("tracheal

sealing"). Despite a sealed airway no pressure is exerted in the larynx itself

This results in:

- Constant ventilation despite changing lung compliance (Constant ventilation is required for endoscopic surgery, neurosurgery and ventilation of patients with head trauma).
- Precise monitoring of end-tidal gas, vapour concentrations and also VO<sub>2</sub>, compliance, resistance etc.<sup>25</sup>

CETT are especially useful in laparoscopic surgeries, in conditions of full stomach to avoid aspiration, repair of a traumatic rupture of the left mainstem bronchus, to occlude tracheoesophageal fistula, performance of sophisticated lung function measurement, and in the intensive care of children with severe pulmonary disease.

Advantages of CETT are:

### 1. Decreased Reintubation rates

Unlike the uncuffed tube, a leak following endotracheal intubation can be corrected with the titration of air into the ET cuff, avoiding a repeated tube exchange.

A number of studies have reported significantly reduced reintubation rates when using cuffed ETTs.

Khine et al showed reintubation rates of 0% with cuffed ETT use compared with 30% with uncuffed ETT use in infants (0–2 years) ( $p < 0.0001$ ). Dullenkopf et al showed that the tube exchange rate with cuffed ETTs was only 1.6% in 500 children (birth–16 years).

Salgo et al showed a reintubation rate of 2.6% with cuffed ETT use in 150 children (birth–5 years).

Weiss et al showed reintubation rates of 2.1% with cuffed ETTs and 30.8% with uncuffed ETTs in 2246 children (birth–5 years) ( $p < 0.0001$ ).<sup>22</sup>

### 2. Lower clinically significant air leak/improved ventilation

ETT should be large enough to seal the cricoid ring but small enough to allow an air leak at pressures of 20–30cm H<sub>2</sub>O to ensure adequate positive pressure ventilation without causing undue pressure on the tracheal mucosa. This has not been studied in great detail. Dorsey et al reported clinically significant air leaks at a rate of 1.8% with cuffed ETTs and 27% with uncuffed ETTs in 228 intubation events in 145 burns patients (0–10 years) ( $p = 0.003$ ).<sup>22</sup>

### 3. Decreased rates of aspiration and ventilator-associated pneumonia

Cuffed ET tube volume can be easily adjusted during operative period, maintaining a minimal leak and the presence of cuff may reduce the risk of aspiration. Miller et al found that in adults ( $n = 3207$ ), the polyurethane cuffed ETT is associated with significantly decreased rates of ventilator-associated pneumonia ( $p = 0.032$ ).

Gopalaireddy et al sampled ETT aspirates in 27 patients (4 months–19 years) undergoing ventilation in a PICU. The group with cuffed tubes had a lower incidence of aspirates positive for pepsin than the uncuffed group (53% vs 100%,  $p < 0.05$ ).<sup>22</sup>

### 4. Decreased fresh and volatile gas use

A number of studies have shown significantly reduced rates of fresh and volatile gas consumption with cuffed ETT use, which decreases patient cost and pollution of the atmosphere. This could be particularly relevant with nitric oxide use in neonates, as well as a reduction in consumption of halogenated agents by ability to use lowflow anesthesia.<sup>22</sup>

### 5. Less airway damage

For cuffed ETTs, a smaller diameter tube (0.5 mm less than uncuffed ETT) is selected which does not wedge within the delicate cricoid

and could make intubation less traumatic. The cuff makes its seal in the trachea where there are U-shaped cartilages and a muscular dorsal wall which allow for some distension, in contrast with the rigid cricoid ring where the uncuffed ETT makes its seal.

Inflating the cuff may ease the tube tip away from the anterior wall reducing tube tip damage and cause less movement of the ETT in the airway. There is also less exposure to repeated intubations to find the right sized ETT.<sup>22</sup>

## DISADVANTAGES OF CUFFED ENDOTRACHEAL TUBE

### 1. Selection of Endotracheal tube

Selection of an appropriately sized Cuffed ETT to prevent airway mucosal injury is important and it should be 0.5–1.0mm smaller than the Uncuffed ETT.

For a Cuffed ETT, the most commonly used formula is Khine [ID (mm) = [age/4] + 3] and Motoyama [ID (mm) = (age/4) + 3.5].

In newborns to infants <1 year, internal diameter (ID) 3.0 mm CETT and in children from 1–2 years, ID 3.5 mm CETT should be used. 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.<sup>10</sup>

Age (Y)	Khine et al.	Motoyama et al.	Salgo et al.
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

Outer diameter (O.D) differs by as much as 0.9mm among ETs different manufacture. These differences in OD lead to unintended selection of an oversized ET and likelihood of laryngeal or subglottic damage. The smallest Microcuff ET available I.D 3.0 mm and O.D 4.3 mm and these tubes are recommended for term neonates only. There are no available microcuff tubes for premature infants.

### 2. Cuff pressure monitoring

The most important aspect of Cuffed ETT use in children is monitoring of intracuff pressure ( $P_{cuff}$ ). 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 25–30mmHg) because the mean arterial pressure is less in children therefore it becomes very important to monitor  $P_{cuff}$  during the intraoperative period and maintain it at or below 20 cm H<sub>2</sub>O by removing excess gas.<sup>10</sup>

Bernet et al showed that small amounts of inflated air led to a rapid increase in cuff pressure and volume.

Cuff pressure inflation and monitoring should be done with a handheld manometer attached to a syringe set-up. Cuff pressure has been shown to change with head position, N<sub>2</sub>O use and altitude on transport. During aerial transport of a patient, air in cuff will expand at altitudes and compress the mucosa therefore we have to repeatedly remove air to restore minimum seal and also note that as aircraft descends, we have to add a bit of air to the cuff.

### 3. Resistance

The relationship between radius and resistance is described by the Hagen-Poiseuille equation:  $Q = nPr^4/8l$

Where, Q = Flow in Liters/second

n = Viscosity in Pascals

P = Pressure in Pascals

r = Radius of the tube in meters

$l$  = Length of the tube in question in meters

A main concern of cuffed ETT is to use an ETT smaller than the uncuffed equivalent. The difference of 3.0 mm tube compared to 4 mm causes three-fold increase in airway resistance.

This increases the tube resistance in the smaller sizes & lead to

- ✓ Higher ventilator pressure requirements and
- ✓ Harder work of breathing on weaning from the ventilator
- ✓ Increased episodes of tube blockage and
- ✓ More difficult suctioning

#### 4. Positioning

The ET cuff will move cephalad with neck extension, caudad with neck flexion and Position of the ET is rhythmically altered with ventilatory movement.

A simple adage to recall is to remember that the "tube follows the chin."

No doubt, an endoscopically positioned cuffed tube with closely monitored control of cuff pressure and tube movement would be unlikely to cause difficulties. For individual clinical situations particularly in intensive care there might be clear benefit, but in a rapid turnover operating list with healthy patients this might not be a feasible or sensible option.

In a comprehensive in vitro investigation of various cuffed endotracheal tubes, Weiss et al. concluded that most cuffed pediatric tubes are poorly designed, particularly in the smaller sizes. They observed that with the tube tip in midtrachea, many cuffs were positioned within the larynx and, if the cuff was inserted 1 cm below the cords, many of the tube tips were dangerously deep within the trachea.<sup>26</sup>

When the adequacy of the design of readily available PVC cuffed ETTs was investigated by Weiss et al they found that there was a marked variation between ETTs from different manufacturers with regards to: cuff diameter; position of the cuff with regards to the ETT tip; presence of a depth marking and distance from the depth marking to the tube tip. They concluded that most cuffed ETTs were poorly designed and that a better designed cuffed ETT was required.<sup>22</sup>

#### 5. Increased airway damage

Increased airway damage is due to oversized outer tube diameter, inadequately designed cuffs, wrongly positioned or missing depth marks and cuff over inflation.

Sharp edges of a fully deflated cuff will cause Nasal mucosal injury and significant bleeding. This is of little significance in routine cases.

But it becomes important consideration in coagulopathies (e.g. hepatic transplant) and anticoagulation is necessary (e.g. heparinisation for cardiopulmonary bypass in surgery for congenital heart disease).

Holzki et al show trauma secondary to overinflated cuffs causing circular necrosis leading to cicatricial subglottic stenosis. They also show documentation of trauma seen from the cuff being inflated in the larynx and from the sharp shoulder of certain cuffed ETTs where the cuff joins the ETT shaft. They criticise studies of cuffed versus uncuffed ETTs in children for not having any endoscopic evidence to substantiate their recommendations.<sup>22</sup>

#### 6. Cost

"Cuffed tubes remain many times more expensive than uncuffed tubes and are likely (to) remain so. On this basis alone it can be hard to justify the routine use of the cuffed tube provided equipoise between the two techniques remains."

Finally, uncuffed endotracheal tubes are the cheaper option which is

an important consideration in public hospitals in particular.<sup>26</sup>

#### MICROCUFF ENDOTRACHEAL TUBES

In 2004, microcuff endotracheal tubes were invented with improved design over previously used cuffed paediatric tubes. The improved design includes the following features:

Microcuff tubes are specially designed cuffed tubes meant for the paediatric population. The cuff of the Microcuff tracheal tube differs from the conventional cuff in that, it is made from ultra-thin (10  $\mu$ m) polyurethane foil instead of the much thicker (50–70  $\mu$ m) PVC or polyethylene foils. The Murphy eye has been eliminated, which has allowed the cuff to be moved more distally on the tracheal tube shaft. The cuff is short and when inflated, it expands below the sub-glottis providing a seal with cuff pressure <15 cm H<sub>2</sub>O. The airway is sealed at upper trachea where the posterior membranous wall can stretch and produce a complete seal, rather than at the cricoid level. Thus, the problem that the cuff will cause airway mucosal injury, leading to sub-glottic stenosis is circumvented.

Selection of an appropriately-sized cuffed endotracheal tube is important to prevent airway mucosal injury.<sup>27</sup>

In a randomised controlled multicentre study of more than 2000 patients, Weiss et al., concluded that Microcuff tracheal tubes can be safely used in children if cuff pressure is controlled and size selection criteria followed.<sup>28</sup> Mean sealing pressure in their study was 10.6 ( $\pm$ 4.3) cm H<sub>2</sub>O. Though the upper limit of safety for cuff pressure in adults is 25–30 cm H<sub>2</sub>O, there is no data in children regarding perfusion pressures of the tracheal mucous membrane, and it is believed that a lower cuff pressure would possibly be safe.

Several studies have confirmed the safety of the cuffed endotracheal tube with respect to airway complications, as long as an appropriate size is chosen and the cuff pressure is monitored.

In a study of 204 patients, Duracher et al. reported 6 cases of complications (dysphonia, hoarse cough, and laryngeal dyspnea) and attributed those to the use of an incorrectly predicted larger tube size.<sup>29</sup> Incidence of stridor with Microcuff tube in study by Weiss et al. was 4.4% and tracheal tube exchange rate was 2.1% in the cuffed and 30.8% in the uncuffed groups.<sup>28</sup>

#### CONCLUSION

Paediatric airways are the most delicate of all our patients, Endotracheal tubes provide the gold standard of airway protection. The upmost care should be taken to ensure that they are provided with the most suitable endotracheal tube and that no trauma is sustained on their developing airway and lungs.

Both cuffed and uncuffed ETTs have advantages and disadvantages associated with their use. Routine use of uncuffed tubes in both pediatric anesthesia and intensive care has been demonstrated over many years.

A trend towards the increased use of cuffed ETTs in the paediatric population is evident, especially in certain clinical situations such as high aspiration risk, low lung compliance and where precise ventilation and carbon dioxide control is important.

The newly introduced microcuffed paediatric endotracheal tube with correct anatomical design and a novel cuff with improved tracheal sealing may encourage increased safe use of these tubes in clinical practice.

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