



# Cuffed tubes for infants and children in anaesthesia and intensive care: Why we should change to cuffed tubes in paediatric airway management

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## Abstract

*Cuffed tubes provide a sealed airway with all its advantages. Traditional paediatric airway management considered cuffed tubes not appropriate for small children. Possible airway trauma was the main argument against cuffed tubes. In the last years several studies have shown that cuffed tubes are a safe alternative to uncuffed ones. The Microcuff\* PET is a designated paediatric cuffed tracheal tube with correct anatomical design and a novel cuff made of ultra thin polyurethane foil. The Microcuff\* PET has been extensively studied and found safe and functional. The studies included the largest randomized controlled multicenter trial comparing cuffed versus uncuffed tubes in small children.*

*Keywords: Children, cuffed endotracheal tube, infants*

## Introduction

Since almost 50 years paediatric intensivists and anaesthetists have used uncuffed tubes in infants and children and have lived with the handicaps of uncuffed tubes. In adult anaesthesia and intensive care cuffed tubes are routinely used since approximately the same time. The paradigm to use uncuffed tubes in infants and children and the condemnation of the cuff are in fact not very logical and should be reconsidered in view of new scientific evidence and technical developments. In the last few years it has been shown that cuffed tubes can safely be used in infants and children<sup>1-5</sup> and that in paediatric airway management there is no need anymore to forego the benefits of a sealed airway.

## Historical evolution

After perilaryngeal intubation began to replace tracheotomy in paediatric airway management<sup>6,7</sup> it rapidly became apparent that severe subglottic airway damage would result if oversized tubes were introduced through the larynx. The pathophysiologic

mechanism for this damage obviously was compression of the mucosa between the tube and the circular cricoid cartilage leading to necrosis, ulceration and later to cicatrice stenosis. The anatomical description of the infant larynx as funnel – shaped with the cricoid being the narrowest part by Eckenhoff<sup>8</sup> backed this mechanism. While oversized tubes led to mucosal compression undersized tubes led to difficult ventilation. As a consequence of this, the well known rule was formulated that in children the correct sized tube should pass without resistance through the larynx and should have a slight leak at an inflation pressure of 20 to 25 cm of water.<sup>9</sup> This rule of course applied to uncuffed tubes. The cuff had become the culprit and obsolete in traditional paediatric airway management because there is no leak when it is inflated, in addition a cuffed tube will behave like an oversized if the cuff is over inflated. However up to date no study has ever shown cuffed tubes to be more harmful compared to uncuffed.<sup>10</sup> Eckenhoff's conception of the funnel-shaped infant larynx in the meantime has been questioned by Litman et al,<sup>11</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 elliptic structure.

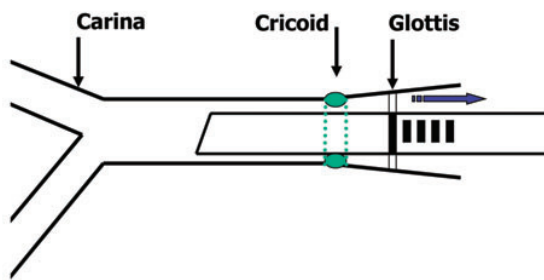
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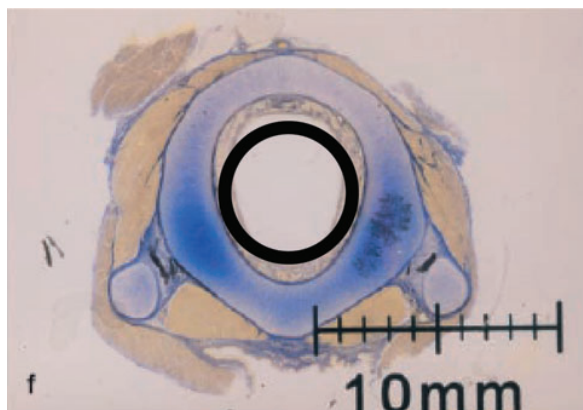


## Disadvantages of airway management with uncuffed tubes

Traditional airway management with uncuffed tubes and a slight leak prevented airway damage by oversized tubes, however mild airway damage in form of postintubation stridor and sometimes more severe damage in form of dorsolateral ulcerations and granulations still did occur. With uncuffed tubes of all things the most delicate part of the paediatric airway, namely the cricoid, is misused for obtaining an acceptable connection between the ventilator and the patient ("cricoidal sealing"). Figure 1 schematically shows how an uncuffed tube ideally should fit into the larynx. Figure 2 shows how an uncuffed tube drawn to scale will lie in the cricoid.



**Figure 1.** Schematic drawing of cricoidal sealing with uncuffed tubes. Between the tube and the cricoid ring there is a small leak anterior allowing escape of gases.



**Figure 2.** Cross-section through the cricoid cartilage with an uncuffed tube inserted. The tube drawn exactly to scale. Note the small anterior leak and the compression of the mucosa in the dorso-lateral areas.

Finding the correct sized tube is the critical point when using uncuffed tubes. Despite simple<sup>12</sup> and sophisticated<sup>13</sup> formulas finding the correct sized tube is not easy and tube exchange rates of up to 30% are the rule.<sup>2,5,14</sup> An additional difficulty is the mismatch between the round tube and the elliptic cricoid. Tube exchange is undesirable because it can cause airway damage by itself; it also makes airway management hazardous in patients with a full stomach, limited respiratory reserves and in emergency situations.

The presence of a leak is no guarantee against pressure lesions; the leaking area is normally limited to the anterior part of the cricoid. Due to its bending every tube will cause pressure in the dorsal part of the cricoid; sometimes the tip will also cause pressure anterior in the trachea. Because the cricoid is not round most of the dorsal pressure will be exerted in the dorsolateral parts of the cricoid (Figure 2).

The main disadvantage of uncuffed tubes however is the fact that they will only provide a more or less loose connection between ventilator and patient. This results in:

- Variable and imprecise ventilation depending on the leak and the compliance of the lungs. In extreme cases of very low compliance and large leaks ventilation can become very inefficient.
- Imprecise respiratory monitoring. The highly sophisticated monitoring provided by modern anaesthesia and intensive care respirators cannot be utilized.
- Need for high fresh gas flow with pollution of the anaesthesia working environment and higher cost.
- Risk of pulmonary aspiration of gastric content.<sup>15</sup> Pulmonary aspiration has long been disregarded by paediatric anaesthetists and intensivists because it has a low mortality in children. However the associated morbidity cannot be ignored.

## Benefits of uncuffed tubes

Uncuffed tubes are cheaper compared to cuffed. Uncuffed tubes are selected with a larger inner diameter (ID) (usually + 0.5 mm). Larger tubes have less tendency to kink and obstruct and are easier for suctioning. Their resistance is lower which is most relevant for the smallest tubes (i.e. ID  $\leq 3.5$  mm) and when spontaneous breathing is used. Modern ventilating or assisting modes can easily overcome the higher resistance.



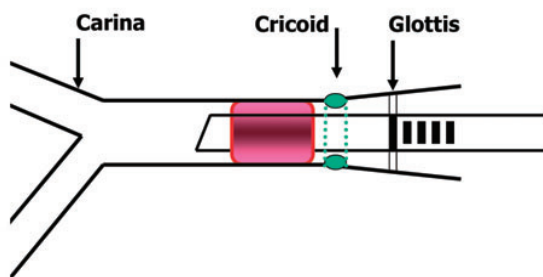
## Benefits of airway management with cuffed tubes

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 (see Figure 3). Figure 4 shows the cuff of a cuffed tube in the trachea.

This results in:

- Constant ventilation despite changing lung compliance. Constant ventilation is required for endoscopic surgery, neurosurgery and ventilation of patients with head trauma. Sophisticated techniques of ventilation and weaning like IMV, BIPAP etc. are feasible.
- Precise monitoring of end-tidal gas and vapour concentrations. Sophisticated monitoring provided by modern ventilators like  $VO_2$ , compliance, resistance etc.
- Low or minimal flow anaesthesia techniques saving costs and minimizing environmental pollution are feasible.
- Pulmonary aspiration and risk of ventilator associated pneumonia are minimized.

When using cuffed tubes deliberately a half size smaller tube is inserted through the larynx. This tube will cause less or no pressure in the cricoid. The gap between the smaller tube and the wall is filled in with an inflatable cuff in the trachea. The pressure that the cuff exerts on the mucosa can be exactly measured and controlled in high volume – low pressure cuffs. The pressure is exerted in the slightly distensible trachea and not in the rigid cricoid ring. The pressure is distributed on the whole



**Figure 3.** Schematic drawing of tracheal sealing with cuffed tube. The sealing occurs below the cricoid in the trachea.

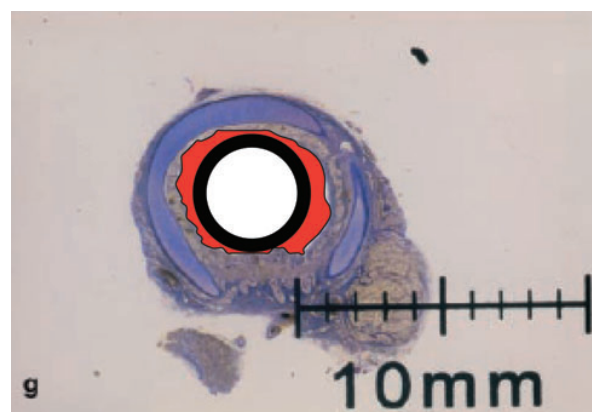
circumference of the airway. The tube shaft and tip are centred within the airway. Since a cuff can accommodate various sizes and shapes of trachea tube exchange is rarely necessary. It is important however to note that cuff pressure must be controlled because cuff over-inflation is possible due to the small cuff volumes. Further nitrous oxide diffusion causes rapid increase to dangerous pressure levels if not controlled and corrected.

## Disadvantages of cuffed tubes

Cuffed tubes are more expensive; the smaller tubes are more difficult to suction and their resistance is higher. Many of the commercially available cuffed tubes have major flaws and shortcomings in their design. These tubes have incorrect depth markings, too long cuffs, high pressure – low volume cuffs and too long tips.<sup>16</sup> Many of them are not designated paediatric cuffed tubes but down sized adult tubes. The paradigm of traditional paediatric airway management has largely hampered the development of good paediatric cuffed tubes.

## Microcuff\* PET cuffed paediatric endotracheal tube

With the goal to build a new, anatomically correct and safe cuffed endotracheal tube for children we have engaged in a joint venture with Microcuff GmbH,



**Figure 4.** Cross-section through the trachea with a cuffed tube inserted. The tube is drawn exactly to scale. The inflated cuff (red) seals the airway; the pressure is exerted on the whole circumference. Due to the membranous dorsal wall the trachea is slightly distensible.



Weinheim, Germany. According to our vision the new tube should meet the following specifications.

- Clear insertion depth mark to be positioned at the level of the vocal cords. Four additional marker bars to help correct positioning in cases where the vocal cords are difficult to see or when the tube originally has been introduced too far.
- Insertion depth equal to 2/3 of the shortest trachea of the relevant age group.
- Short distally placed cuff in order to obtain a subglottic cuff free zone.
- Short tip omitting the Murphy eye.
- Sufficient margin of safety against endobronchial intubation during flexion of the head and during surgery with capnoperitoneum.
- Sufficient margin of safety against extubation during maximal extension of the head.
- High volume - low pressure cuff able to seal the airway at a cuff pressure below 20 cm of water.

Size selection according to age was based on the formulas produced by Motoyama<sup>12</sup> and Khine et al.<sup>2</sup> Corresponding dimensions for the tube were extracted from anatomical and radiological data.<sup>17</sup> Figure 5 shows the relative position of depthmark, cricoid, cuff and tip in neutral head position. Figure 6 is a diagram depicting the dimensions for the various age groups. The Microcuff\* PET was built according to these specifications.

The cuff of the Microcuff\* PET differs from conventional cuff in that it is made from ultra thin (10 µm) polyurethane foil instead of the much thicker (50-70 µm) polyvinyl chloride or polyethylene foils.

Because polyurethane foil is so thin it adds very little to the outer diameter of the tube and is gentle to the tissue. Despite its thinness its physical strength measured by burst pressure, is two to three times that of polyvinyl chloride. The ultra thin polyurethane cuff drapes to the respiratory mucosa and to itself without folds and fissures similar to household wrap and this results in outstanding sealing properties at very low pressures. Figure 7 illustrates the different behaviour of ultra thin polyurethane foil and thicker polyvinyl chloride foil.

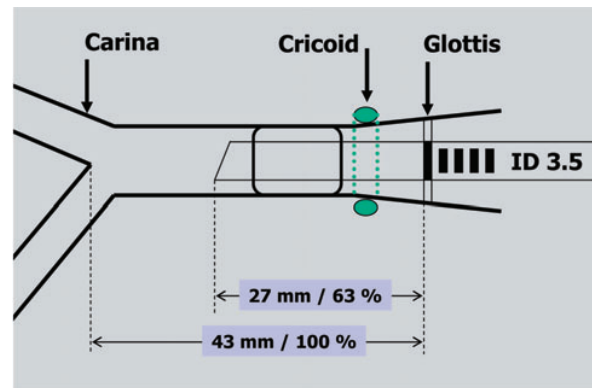


Figure 5. Design of an "ideal" 3.5 ID cuffed tube.

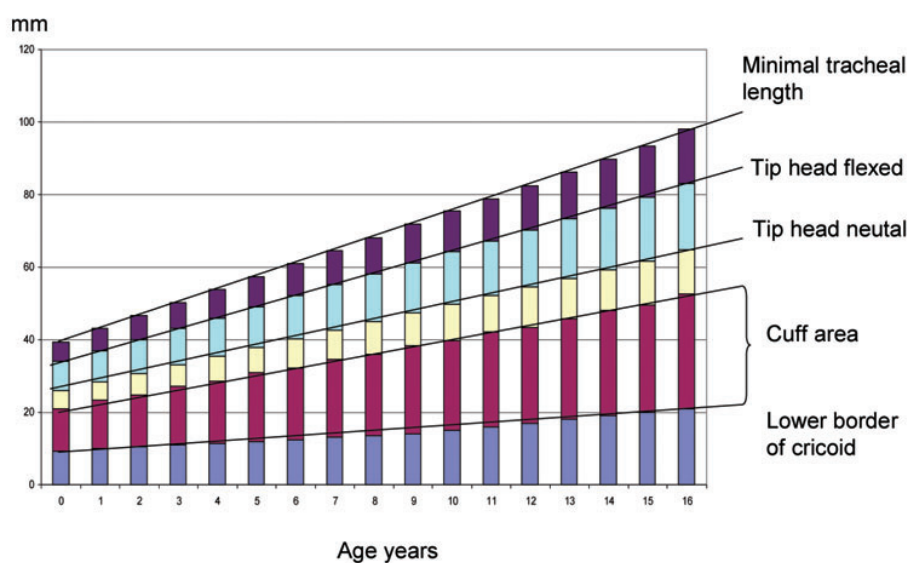
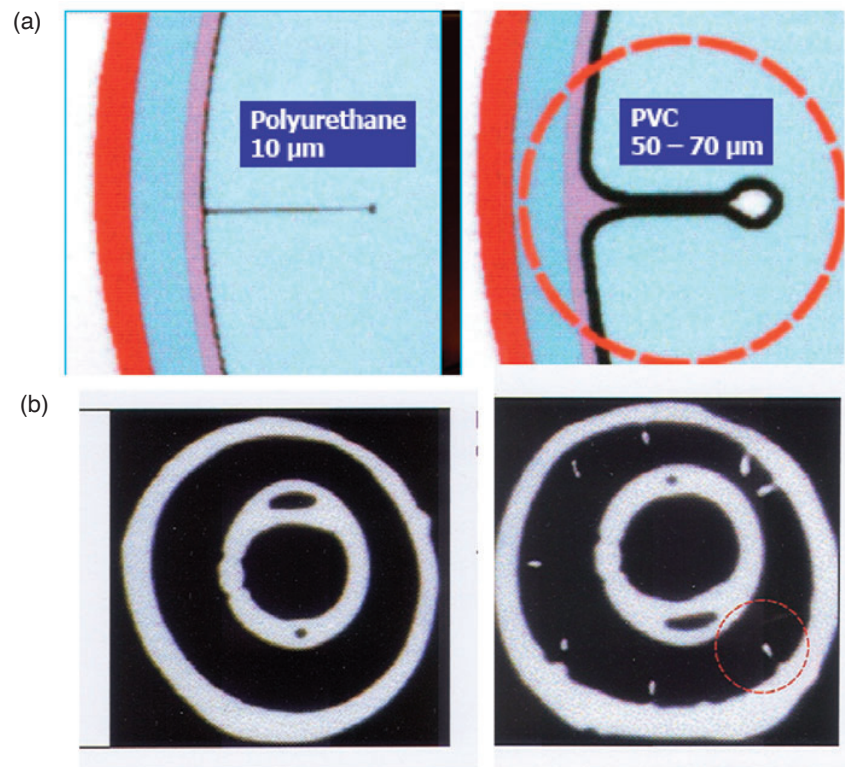


Figure 6. Dimensions of tracheal tubes according to age.



**Figure 7.** (a) Schematic cross-section through a Microcuff\* and a conventional cuff. The ultra thin polyurethane foil folds without fissures, the thicker polyvinylchloride cuff folds with fissures. (b) CT-scan demonstrates leakage of radio-opaque dye through the fissures of the polyvinylchloride cuff. No leakage through the Microcuff\*.

### Clinical evaluation of the Microcuff\* PET

In several clinical studies we have investigated whether the dimensions of the Microcuff\* PET fulfilled the above listed prospects, whether reliable sealing at pressures below 20 cm of water was possible and whether use of the Microcuff\* PET would not result in unexpected airway damage.

- With fiberoptic control in 250 patients ranging from birth to 16 years the tube tip was found to be correctly placed in the trachea when the tube was inserted according to the depthmark.<sup>18</sup>
- The size recommendation was found to be correct in 98.4% of 500 patients ranging from newborn to 16 years. In only 8 out of the 500 the tube was found to be too large (i.e. had no air leak at 20 cm of water with the cuff deflated).<sup>19</sup>
- During laparoscopic surgery in 46 children from 2 months to 15 years the tube tip did not migrate endobronchially with capnoperitoneum and head down tilt.<sup>20</sup>
- Movements of the tube during extension and flexion of the head did not result in accidental extubation or endobronchial intubation. This was investigated in 100 children during cardiac catheterization.<sup>21</sup>
- In 166 children intubated with a preformed RAE Microcuff\* PET safe tube tip position was found in all, however due to insertion to the bend few critically low and high positions were encountered.<sup>22</sup> Similar results with preformed tubes were obtained by Jordi-Ritz.<sup>23</sup>
- Average sealing pressure was found to be 9.7 cm $\pm$  2.5 cm in the study on 500 children, in no child a cuff pressure >20 cm water was required for sealing.<sup>19</sup>
- In our studies we found a rate of postintubation stridor of 1.8% which compares favourably to other studies.





- In none of our studies did we encounter unexpected or long-term adverse effect.
- Preliminary results of a large prospective, controlled multicenter trial<sup>5</sup> in 24 paediatric units in Europe with 2249 small children ranging from newborns to 5 years of age confirmed the positive results mentioned above.
- Tube exchange rate cuffed versus uncuffed was 2.1% vs 29.9%.
- Postintubation stridor rate cuffed versus uncuffed was 4.4% vs 4.7%.
- The mean sealing pressure was 10.6 cm $\pm$ 4.3 cm water.

## Discussion

Because of all the important advantages that sealed airways have compared to leaky airways, cuffed tubes would be used for airway management in children if paediatric anaesthetists and intensivists could become confident that cuffed tubes are in fact safe and do not cause airway damage. Modern anaesthesia and intensive ventilators are capable of sophisticated modes of ventilation and monitoring and they can be operated in low flow modes under the condition that the airway is sealed. Constant ventilation despite changing compliance is mandatory for brain injured patient for endoscopic surgery etc. Multiple tube exchange is undesirable because it is a cause of airway damage and sets critically ill patients at risk for aspiration and hypoxia. Especially for rapid sequence induction and emergency intubations, having a reliable size recommendation, which allows to pick the right size tube at first go would be most helpful.<sup>24</sup> And there are patients, like severe burned patient in which using uncuffed tubes is clearly not adequate.<sup>25</sup> Professional bodies like the American Heart Association<sup>26</sup> and ILCOR,<sup>27</sup> the European counterpart, recognize the new evidence and state in their 2005 guidelines that cuffed tubes are a safe, in certain cases a preferred alternative for infants and children. Earlier studies comparing various brands of cuffed tubes with uncuffed ones have found only advantages in the cuffed group, despite the fact that those tubes were less than ideal.<sup>2,3,28</sup> The Microcuff\* PET is a cuffed tube specifically designed for use in infants and children with correct anatomical design and a cuff capable of sealing at very low cuff pressures. The Microcuff\* PET has been extensively tested in all age groups from infants to 16 years of age and has been

found highly functional and safe. So far most of the experience with cuffed tubes has been made during relatively short intubations for anaesthesia. There are only two studies<sup>28,29</sup> comparing cuffed versus uncuffed tubes in intensive care patients. Both studies have corroborated the safety of cuffed tubes in children even when in these study other cuffed tubes, less ideal than the Microcuff\* PET were used. The study by Deakers et al<sup>29</sup> differs from the others in that in this study an exceptionally high incidence of postintubation stridor (15%) was found though in the cuffed and in the uncuffed group. In our intensive care unit, which has a large number of cardiac surgery patients, Microcuff\* PET tubes have been used in almost all patients since three years. The results we have seen so far are consistently positive.

The smallest Microcuff\* PET available at present has an inner diameter of 3.0 mm and outer diameter of 4.3 mm. This tube is recommended for term neonates only. Neonatologists using more and more sophisticated ventilators would be very interested in a sealed airway also. In order to build cuffed tubes that can be used in premature infants physical and technical limitations in tube design must be overcome.

Cuffed tubes can be safely used in term neonates and children of all ages if one caveat is respected. Paediatric anaesthetists and intensivists must be aware that control of cuff pressure is mandatory, it must become clinical routine, else airway damage as was seen earlier with oversized tubes will recur.

## Declaration of interests

Dr. Gerber together with Dr. Weiss have designed the Microcuff\* PET. Currently Dr. Gerber has a consulting and research agreement with Kimberly Clark Corporation.

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