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Clinical Consequences

Cuffed tracheal tubes: guilty now proven innocent

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Introduction

The debate whether to use cuffed or uncuffed tracheal tubes for children is a longstanding one that has, historically, largely been based on opinion instead of scientific evidence. In 2018, Chambers et al. reported a randomised controlled trial of cuffed vs. uncuffed tracheal tubes in children undergoing elective surgery [1]. They concluded that cuffed tubes made ventilation more effective and reduced adverse peri-operative respiratory events. In this part of the 'Clinical Consequences' series published in *Anaesthesia*, we will discuss recent insights into the anatomy of children's airways and we will incorporate Chambers et al.'s study into the growing evidence that cuffed tracheal tubes are better for children.

Are children's airways funnel shaped?

Children's airways have conventionally been described as funnel shaped, with the circumferential, non-distensible, cricoid cartilage being the narrowest part. The origins of this description can be traced back to a seminal paper by Eckenhoff in 1951 [2]. While performing direct laryngoscopy, he observed that the cricoid ring appeared to be smaller than the glottis and concluded that "*in the infant, the plate is inclined posteriorly at its superior aspect, so that the larynx is funnel shaped with the narrowest point of the funnel at the laryngeal exit*". He also noted that the entire cavity of the larynx below the rima glottidis was lined by columnar epithelium, which was prone to fluid infiltration and oedema. These observations initiated the routine use of uncuffed tracheal tubes for children, as it was assumed that cuffs would injure the larynx that could, in turn, result in oedema and subglottic stenosis after tracheal extubation.

It is difficult to choose a tube diameter that fills the airway at the cricoid ring without damaging the mucosa, while allowing ventilation at 20–30 cmH_2O pressure before bypass of air. The easy age-based Cole formula has often been used to select uncuffed tracheal tube diameter, but it selects the 'correct' tube size in only 50–75% of instances [3–6]. In addition, it does not adjust for height or weight. For example, the Cole formula would be expected to select tracheal tubes too large for many children below the 5th centile for weight and height, who often have smaller tracheal diameters. Consequently, there has been increased focus on alternative methods for predicting tube size, such as airway ultrasonography and finger size [4, 7].

Recent in-vivo studies, questioning the accepted wisdom of the funnel-shaped airway, have led to a 'funnelist' vs. 'non-funnelist' debate [8, 9]. Children's cricoid cartilages are elliptical on MRI and CT scans, with the anteroposterior axis being widest [10, 11]. Anteroposterior leakage of air around an uncuffed tube might still be coincident with increased lateral mucosal pressure. Dalal et al. performed cross-sectional measurements of the larynx at the glottis and superior aspect of the cricoid using video bronchoscopy in 128 anaesthetised children with neuromuscular blockade, aged 6 months–13 years [12]. They concluded that the glottis was narrower than the cricoid cartilage in children, as it is in adults, with the airway being cylindrical rather than funnelled. An important caveat is that static in vivo studies

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do not account for the pliability of the upper airway structures or the dynamic effects of unconsciousness and drugs on the tone of upper airway muscles.

Does the evidence support increased use of cuffed tubes?

Cuffed tracheal tubes might facilitate efficient reliable ventilation and accurate capnography; reduce pollution from anaesthetic vapours; decrease the frequency of tube exchange; reduce the rates of pulmonary aspiration and minor postoperative complications, such as sore throat [13]. Cuffed tracheal tubes might also cause subglottic stenosis, particularly in vulnerable groups, such as critically ill neonates and older children.

Cuffed tracheal tubes were originally made from rubber or polyvinyl chloride. Weiss et al. evaluated 11 cuffed paediatric tubes from four manufacturers and found widespread variation in their outer diameters for given internal diameters [14]. Intubation depth was marked in only five out of 11 tubes and the distance from distal depth marking to tube tip was often greater than the age-related minimal tracheal length. None of the tubes met the requirements for a high-volume low-pressure cuff. Unsurprisingly, laryngeal injury and airway trauma were associated with the use of cuffed paediatric tracheal tubes [15]. In 2008, Flynn et al. reported that cuffed tracheal tubes were used routinely by one in 20 respondents who worked in UK paediatric intensive care units or the anaesthetic departments of specialist paediatric hospitals [16].

In response to these problems, Weiss et al. developed a tube made from polyurethane with an ultra-thin, high-volume low-pressure cuff, which provided an adequate seal at 10 cmH_2O pressure (Microcuff™, Halyard Healthcare, GA, USA). There was no Murphy's eye and, therefore, the cuff was located more distally than previous designs [17, 18]. This research group published a large randomised controlled multicentre trial after a preliminary study [19, 20]. They allocated 2246 children (neonates to 5 years old) to tracheal intubation with an uncuffed tracheal tube or with a Microcuff tube, limited to a maximum cuff pressure of 20 cmH_2O. The cuffed tube reduced the rate of tube changes from 31% of children to 2% of children and reduced the rate of unreliable capnography from 4% to 1%, whereas the 5% rate of stridor after extubation was unaffected.

The study by Chambers et al. [1] was a unique, mechanistic study that investigated the effects of cuffed and uncuffed tubes on leakage and tidal volume – outcomes not addressed by a Cochrane systematic review in 2017 [21]. One-hundred and four children aged 0–16 years were randomly allocated to tracheal intubation with cuffed or uncuffed tubes. The primary outcome was the difference between inspiratory and expiratory tidal volumes.

Following induction of general anaesthesia, the authors measured five inspiratory and expiratory tidal volumes under both volume-controlled and pressure-controlled ventilation modes. They calculated leakage from the difference in the mean inspiratory and expiratory volumes. Following this, a standardised recruitment manoeuvre was performed and the procedure was repeated three times at 10-min intervals. The study does have limitations. There was no standardisation of anaesthetic drugs, in particular, neuromuscular blockers, which could influence leak and tidal volumes. Only one brand of cuffed tubes was evaluated. Different ventilation modes and different anaesthetic machines may have provided different measurements. However, despite these limitations, the study protocol is simple, pragmatic and easy to reproduce and refine should other investigators wish to replicate the study.

Chambers et al. found that cuffed tubes reduced leakage when ventilation was volume controlled or pressure controlled. Cuffed tubes reduced the number of intubation attempts and tube exchanges and the combined rates of peri-operative respiratory complications, which included severe persistent coughing, desaturation $< 95\%$, sore throat and hoarse voice.

Building on the findings from the study by Chambers et al., Thomas et al. [22] performed an in-vitro study to compare work of breathing and airway pressures through cuffed and uncuffed tracheal tubes in five neonatal and paediatric lung models. The authors hypothesised that the age-matched 0.5-mm smaller internal diameter of cuffed tubes would increase work of breathing during spontaneous ventilation or require higher inspiratory pressures during mechanical ventilation. Cuffed tracheal tubes were associated with increased work of breathing and higher peak inspiratory pressures. However, differences in work of breathing and distal inspiratory pressures were almost completely neutralised by applying pressure support ventilation with automatic tube compensation. This has important implications for critically ill children, who are often under-represented in clinical trials.

Inadequate ventilation through uncuffed tracheal tubes has been reported outside the operating theatre. A retrospective case review of 213 children referred to a paediatric critical retrieval service over a 3-year period observed that inadequate ventilation more often

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triggered repeat laryngoscopy and urgent tracheal tube replacement in children intubated with an uncuffed tube: no cuffed tubes required replacement [23]. The UK Resuscitation Council advocates that the trachea of infants and children (but not neonates) should be intubated with appropriately-sized cuffed tubes by trained staff, with monitoring of cuff pressure and confirmation of tube placement [24]. Based on a single retrospective study, they advocate cuffed tubes in clinical situations such as facial burns, which are associated with poor lung compliance and high airway resistance [25]. We anticipate that the findings of these recent studies will be incorporated into future updates of Advanced Paediatric Life Support guidelines.

Subglottic stenosis

Subglottic stenosis after tracheal extubation remains an important long-term outcome of interest, the incidence of which is 0.3% to > 11%. Retrospective studies in critically ill neonates and children have observed no differences in the incidence of acquired subglottic stenosis between cuffed and uncuffed tracheal tubes [26, 27]. Risk factors for developing subglottic stenosis are: multiple intubation; incorrectly sized tracheal tube; low birth weight; underlying clinical condition and duration of mechanical ventilation, rather than the type of tube used [27–29]. A recent retrospective study of 5309 children admitted to critical care, of whom 3361 were ventilated with a high-pressure low-volume cuffed tube, reported only eight patients with

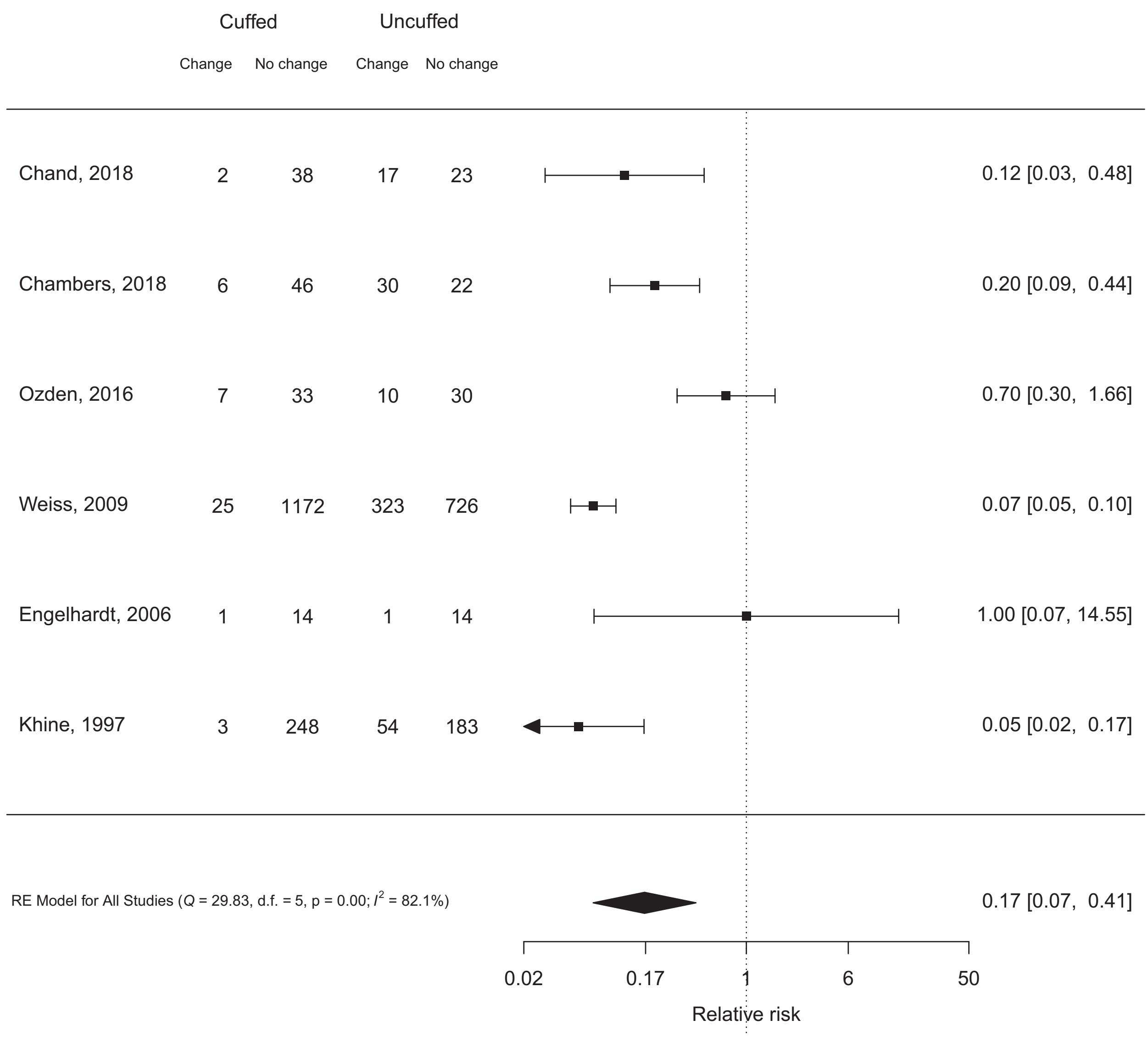

Figure 1 Forest plot of rates of exchange of cuffed or uncuffed tracheal tubes in six randomised controlled trials.

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acquired subglottic stenosis [30]. Five of these patients required major airway correction surgery and all had been born prematurely, initially intubated with uncuffed tubes in an external neonatal intensive care unit. There were no cases of subglottic stenosis requiring surgical correction in children initially intubated with a cuffed tube. Although promising, these findings are subject to the usual limitations of retrospective studies. Weiss and Gerber are currently conducting a prospective multi-centre study testing equivalence of subglottic stenosis in children (1 month–16 years) requiring intubation for > 24 h with either cuffed or uncuffed tubes (NCT02350933). The study has completed recruiting participants and the results are eagerly awaited.

An updated meta-analysis

We systematically searched for and reviewed 10 randomised controlled trials in children [1, 20, 31–38] in whom cuffed tracheal tubes were changed one-sixth as often as uncuffed tubes, relative risk (95%CI) 0.17 (0.07–0.41), $p < 0.001$ (Fig. 1) [1, 20, 31, 32, 34, 38]. Sore throat was also less common after intubation with cuffed tubes, RR (95%CI) 0.32 (0.16–0.65), $p < 0.001$ [1, 36]. The rates of laryngospasm [1, 20, 36–38] and stridor [20, 31, 32, 38] were similar when tracheas were intubated with cuffed or uncuffed tubes, RR (95%) 1.20 (0.85–1.70) and 0.78 (0.46–1.35), $p = 0.64$ and $p = 0.19$, respectively.

Conclusion

Since the survey by Flyn et al. in 2008 [16], there appears to have been a clear shift towards the use of cuffed tracheal tubes. An electronic survey in 2015 indicated that half of UK paediatric anaesthetists regularly used cuffed tracheal tubes in infants or older children [39]. A survey of 805 members of the USA Society of Pediatric Anaesthesia in 2016 reported that 85% used cuffed tubes more than uncuffed tubes in children older than 2 years, whereas 60% used cuffed tubes more than uncuffed tubes in full-term neonates [40]. This change in practice has occurred gradually over the past decade and evidence-based medicine is no stranger to time lags in translational research. The initial use of uncuffed tubes was largely based on anatomical and physiological considerations, many of which have now been debunked. It is unlikely we will ever know the potential harm that may have been caused by these questionable premises. Factors driving this change are multifactorial and include improvements in tracheal tube design, better anaesthetic machines and ventilatory strategies, and perhaps most importantly, the undertaking of well-designed clinical trials.

We think that the study by Chambers et al., along with the results of our updated meta-analysis, will further increase the regular use of cuffed tracheal tubes in children. The higher costs of cuffed tubes are likely to be offset by the lower rate of tube exchange and reduced anaesthetic gas wastage and pollution [31]. The use of cuffed tracheal tubes requires us to reliably measure and control cuff pressure. We believe that standards should be established to improve our poor compliance with these tasks [41]. Future research might establish whether children are better after their tracheas are intubated with tubes in which the cuff is inflated with alkalinised lidocaine rather than air or saline [42]. Particular attention should be paid to children in whom subglottic stenosis is more likely, for instance critically ill, small and premature neonates and infants.

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