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REVIEW

Upper airway obstruction and sepsis following endotracheal intubation in paediatric cardiac surgical patients in South Africa

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Background: Endotracheal intubation and mechanical ventilation are associated with potential complications in children. The role of cuffed versus uncuffed endotracheal tubes (ETTs) remains controversial. We aimed to compare the incidence of obstructive airway complications and the development of sepsis between cuffed and uncuffed ETTs, as well as other risk factors associated with these complications.

Methods: This is an observational and quantitative study that retrospectively reviewed charts of patients younger than 12 years undergoing cardiac surgery and requiring cardiopulmonary bypass (CPB) of any duration and postoperative ventilation for at least four hours between January 2017 and July 2018 at a central hospital in KwaZulu-Natal. Data collected included demographics, airway assessment, previous intubations, type and size of ETT, difficulty with intubation, duration of surgery and CPB, duration of intubation and ventilation, ETT change, presence of upper airway obstruction postextubation, and the presence of sepsis. The severity of airway complications was determined according to the interventions necessary. The chi-square test was used to analyse risk factors associated with interventions. A multivariate logistic model was then used to identify independent factors.

Results: Of the 155 patients included, 68.4% were intubated with cuffed ETTs, and 48% had some form of sepsis during the postoperative period. Stridor was found in 48.4%, with the majority (93%) requiring nebulisation. Adjusted odds ratios (OR) of variables affecting airway complications showed that the only significant factor was ETTs that were too large for the airway (OR 3.42; CI 1.55–7.56; $p = 0.002$). The only factors that significantly increased sepsis were duration of intubation > 3 days (OR 15.46; $p < 0.001$) and duration of ventilation > 3 days (OR 17.44; $p < 0.001$).

Conclusion: The use of cuffed ETTs neither increased airway obstruction complications, nor influenced the outcome of sepsis. Cuffed ETTs that are sized correctly are safe to use within the paediatric population presenting for cardiac surgery, including its extended use during the postoperative period.

Keywords: cuffed endotracheal tubes, paediatric intensive care, ventilation, paediatric cardiac surgery

Introduction

Endotracheal intubation and mechanical ventilation are associated with numerous potential complications, including upper airway obstruction or stridor, tracheal stricture formation, and ventilator-associated pneumonia (VAP). Subglottic stenosis, a complication following intubation, has harmful effects, particularly within the paediatric population, thus warranting all possible steps to minimise this risk. The incidence of stridor in cardiac intensive care units (ICU) varies from 3.5–30.2%.[1] The incidence of postintubation stridor among paediatric patients in KwaZulu-Natal, South Africa, is unknown.

Traditionally, uncuffed endotracheal tubes (ETTs) were advocated for intubation in paediatric patients during anaesthesia and in the ICU setting to prevent inflammation and subsequent tracheal stenosis from cuff pressure on the mucosa. With the narrowest part of the paediatric airway being at the level of the cricoid cartilage, an uncuffed ETT would produce a seal at this level, thus making a cuffed tube unnecessary. However, in young children, the cricoid is elliptical rather than round, which could lead to an audible leak, even if a larger size uncuffed ETT was used, falsely reassuring attending physicians.[2] There has been a shift towards the use of cuffed ETTs in paediatric patients to decrease the incidence of airway complications following intubation.

There are several advantages to using cuffed ETTs in the operating room.[1] These include optimising ventilation by decreasing the leak and allowing for positive end-expiratory pressure (PEEP), more accurate capnography, better ventilation of children with severe asthma and bronchiolitis with flow resistance by accurately measuring and displaying compliance, reduced operating room pollution by using lower fresh gas flow rates, and a decreased incidence of aspiration.[3-5] Additionally, the use of cuffed tubes almost eliminates the need for repeat laryngoscopy and tube exchange. In contrast, uncuffed tubes has a reintubation rate of 23%.[3,4] The incidence of postoperative respiratory complications in paediatric patients intubated with cuffed ETTs compared to uncuffed ETTs was not increased in the postanaesthetic unit.[6]

The confirmation of the safety of cuffed ETTs in paediatric patients has led to its increased use by paediatric anaesthesiologists. In 2009, a survey among anaesthetists in the UK showed that 5% of paediatric intensivists and 7% of paediatric anaesthetists used cuffed ETTs.[7] The use of cuffed ETTs has subsequently increased. A 2014 study showed that 35.5% of anaesthesiologists routinely

used cuffed ETTs in neonates.[8] The use of cuffed ETTs in paediatric patients was more prevalent among junior faculty. However, 60% of doctors did not check cuff pressures.

The use of cuffed ETTs in the cardiac ICU setting has been less well described. However, the safety of its use in the ICU has been established. Deakers et al.[9] showed that the overall incidence of postextubation stridor in the cardiac ICU was 14.9%, and the use of cuffed ETTs was not associated with an increased risk of postextubation stridor nor with any significant long-term sequelae. In a meta-analysis done by Shi et al.,[3] the use of cuffed ETTs in children reduced the need for tracheal tube exchanges and did not increase the risk for postextubation stridor compared to uncuffed ETTs.

Prevention of aspiration is important in an ICU setting. Aspiration may predispose the patient to VAP, with a consequent delay in extubation in, for example, paediatric cardiac surgery patients.[10] Aspiration, indicated by pepsin positivity in tracheal aspirates, was significantly less in the cuffed group compared to the uncuffed and tracheostomy groups in a cardiac ICU study.[11]

The complications related to both cuffed and uncuffed tubes have led to the improved design of ETTs with a low-pressure, high-volume cuff. These Microcuff® tubes are producing a paradigm shift worldwide.

There are no local data regarding the incidence of airway complications in relation to cuffed and uncuffed ETTs in our population. Our use of cuffed ETTs in the paediatric cardiac unit has increased since 2017. The aim of this study was to compare the incidence of stridor with the use of cuffed versus uncuffed ETTs, as well as sepsis related to endotracheal intubation, in a South African cohort of paediatric cardiac surgery patients, which would allow for recommendations for the future management of these patients.

Methods

This was a quantitative, observational study, retrospectively reviewing the records of paediatric patients undergoing cardiac surgery between January 2017 and July 2018 at Inkosi Albert Luthuli Central Hospital (IALCH), KwaZulu-Natal, South Africa. IALCH, a central quaternary referral hospital, is the only hospital in KwaZulu-Natal which offers paediatric cardiac surgery in the state sector. Approximately 200 children undergo cardiac surgery here annually and are managed in the cardiac ICU postoperatively.

Approval was obtained from the Biomedical Research Ethics Committee (BE341/19), the KwaZulu-Natal Department of Health and IALCH. Data were collated from the electronic records that were searched consecutively and retrospectively from January 2017 to July 2018. The data from eligible study participants were then extracted into a Microsoft Excel spreadsheet. The collected data were kept confidential in a password-protected database, and patients were de-identified following data collection.

All children younger than 12 years, including neonates, who underwent cardiac surgery requiring cardiopulmonary bypass (CPB), who were managed in the cardiac ICU postoperatively and who required postoperative ventilation for a minimum of four hours, were included in the study. Paediatric patients who were managed in other ICUs postoperatively and those who did not require CPB during surgery were excluded from the study.

Data that were collected include patient baseline demographic data; preoperative data including airway assessment and previous intubations; intraoperative data including the type and size of ETT inserted, difficulty with intubation, duration of surgery and CPB; postoperative data including duration of ventilation, duration of intubation and a documented change of ETT in the ICU. To evaluate the appropriateness of chosen ETT size, the calculation for uncuffed ETTs was age/4+4 (Modified Cole),[12] and for cuffed ETTs was age/4+3.5 (Motoyama).[13] The Cormack-Lehane grading scale[14] was used to grade laryngoscopy.

Outcome data that were collected include presence of upper airway obstruction postextubation and the presence of VAP. Stridor, a surrogate marker for upper airway obstruction, was classified as mild (requiring adrenaline nebulisation), moderate (requiring reintubation), or severe (requiring Ear, Nose and Throat [ENT] intervention). Management was as per standard unit protocol. Saline nebulisations are administered to all paediatric patients postextubation. Adrenaline is ordered by the attending physician on observation of stridor. VAP and sepsis were considered when these were clinically diagnosed by the treating physician, documented on file and warranted treatment. Patients who did not meet the criteria for VAP but developed pneumonia in hospital were labelled as nosocomial pneumonia. Patients who had clinical markers of sepsis but not pneumonia and were treated appropriately were labelled as having nosocomial sepsis.

Data analysis

The aim was to compare the incidence of upper airway obstruction in paediatric patients who had cuffed ETTs to those who had uncuffed ETTs. A binary logistic regression model, relating the demographic characteristics and the likelihood of having stridor or not, was used. A minimum sample size of 152 was determined with a statistical power of 80%, using a logistic regression model and considering a type 1 error = 0.05, type 2 error = 0.2, odds ratio (OR) 1.8, and the assumption of normal population distribution.

Patients were initially categorised into two groups: airway intervention (stridor requiring adrenaline nebulisation, reintubation and/or surgery) and no airway intervention. Risk factors associated with the intervention were analysed using a chi-square test. A multivariable logistic model was then used to identify independent factors associated with the intervention. The model included cuffed/uncuffed ETTs plus other factors with an unadjusted p-value < 0.3. Risk factors with a p-value < 0.3 in the unadjusted model were included in an adjusted model. Factors associated with VAP and sepsis were also assessed similarly. All

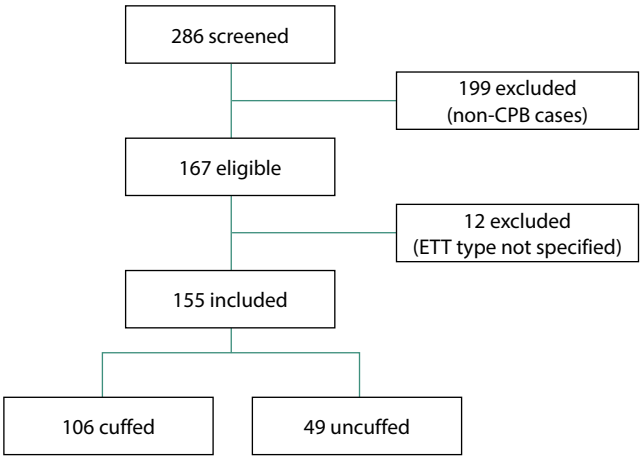

Figure 1: Flow diagram detailing the recruitment process

Table I: Demographics and characteristics of study sample (n = 155)

Characteristic	*n* (%)
Male	83 (53.5%)
Age	
< 1 month	5 (3.2%)
≥ 1 month–1 year	28 (18.1%)
≥ 1–5 years	60 (38.7%)
≥ 5–≤ 10 years	50 (32.3%)
> 10 years	12 (7.7%)
Weight (kg)	
< 5	23 (14.9%)
≥ 5–≤ 10	36 (23.4%)
> 10–≤ 15	32 (20.8%)
> 15	63 (40.9%)
Not documented	1 (0.6%)
Type of surgery	
Atrial septal defect	17 (11.0%)
Ventricular septal defect	56 (36.1%)
Valve surgery	10 (6.5%)
Tetralogy of Fallot	45 (29.0%)
Total anomalous pulmonary venous return (TAPVR)	5 (3.2%)
Double outlet right ventricle	4 (2.6%)
Arterial switch	4 (2.6%)
Other surgery	14 (9.0%)
Syndrome	
No	124 (80.0%)
Yes	31 (20.0%)
Anticipated difficult airway at preoperative airway assessment	
No	153 (98.7%)
Yes	2 (1.3%)
History of previous intubations	
0	133 (85.8%)
1	19 (12.3%)
2	2 (1.3%)
3	1 (0.6%)

analyses were conducted using SPSS statistical package version 26.0. (IBM, New York, USA).

Results

The process of determining the study sample is shown in Figure 1. Of the final study sample of 155 patients, 68.4% were intubated with cuffed ETTs.

Table I presents the characteristics of the study sample. The mean age was 3.96 years, ranging from 2 weeks to 11 years. The mean weight was 14 kg, ranging from 2.6–70 kg.

The intraoperative and postoperative data are presented in Table II. Only one case had the cuff pressure documented on the

Table II: Intraoperative and postoperative data

Variable	*n* (%)
Intraoperative	
Endotracheal tube	
Cuffed	106 (68.4%)
Uncuffed	49 (31.6%)
Appropriateness of ETT size	
Correct size	82 (53.2%)
Bigger	48 (31.2%)
Smaller	24 (15.6%)
Not described	1 (0.6%)
Laryngoscopy grade (Cormack–Lehane)	
Not documented	21 (13.5%)
1	121 (78.1%)
2	11 (7.1%)
3	2 (1.3%)
Duration of operation	
≤ 4 hours	106 (68.8%)
> 4 hours	48 (31.2%)
Not documented	1 (0.6%)
Duration of cardiopulmonary bypass	
< 2 hours	88 (59.5%)
2 hours	60 (40.5%)
Not documented	7 (4.5%)
Postoperative	
Duration of ventilation	
≤ 3 days	118 (78.1%)
> 3 days	33 (21.9%)
Not documented	4 (2.5%)
Duration of intubation	
≤ 3 days	112 (74.2%)
> 3 days	39 (25.8%)
Not documented	4 (2.5%)
Number of tube changes in ICU	
0	149 (96.1%)
1	5 (3.2%)
2	1 (0.6%)

Table III: Intervention for upper airway obstruction and categories of sepsis

Outcome	*n* (%)
Airway intervention for upper airway obstruction	
None	80 (51.6%)
Mild – nebulisation	70 (45.2%)
Moderate – reintubation	4 (2.6%)
Severe – surgery	1 (0.6%)
Diagnosis	
No sepsis	80 (51.6%)
Nosocomial sepsis	42 (27.1%)
Nosocomial pneumonia	26 (16.8%)
Ventilator-associated pneumonia	7 (4.5%)

anaesthetic chart. Two of the patients had anticipated difficult airways and a videolaryngoscope was available in theatre.

The outcome data are shown in Table III. The paediatric patient with severe upper airway obstruction resulting in surgery had Trisomy 21 and demised from upper airway obstruction while in the high care ward after being extubated post tracheal dilatation. One paediatric patient in the reintubation group sustained vocal cord paralysis, had a flexible nasal endoscopy which showed bilateral cord palsies and later had a tracheostomy performed. The other three of the four paediatric patients in

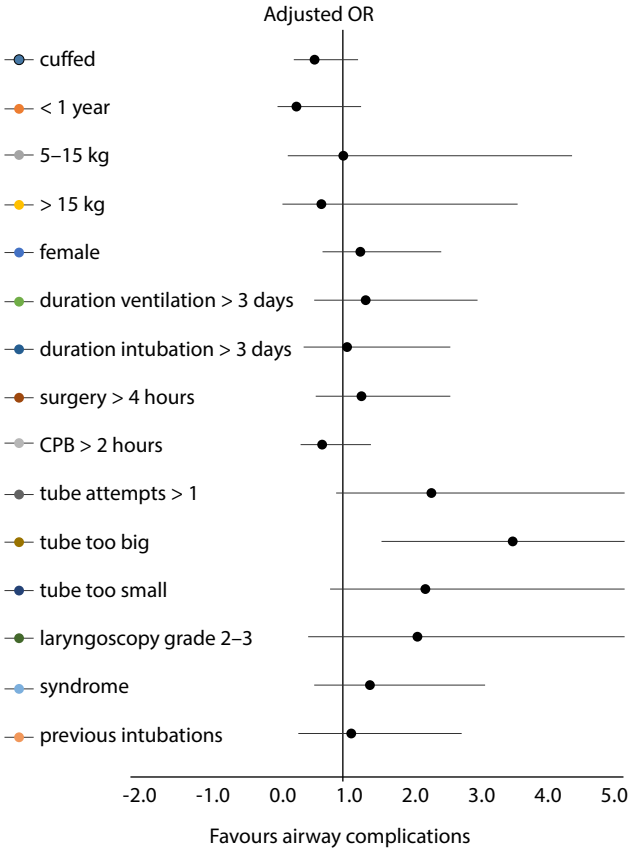

Figure 2: Adjusted odds ratios of variables affecting development of upper airway obstruction
kg – kilogram, CPB – cardiopulmonary bypass

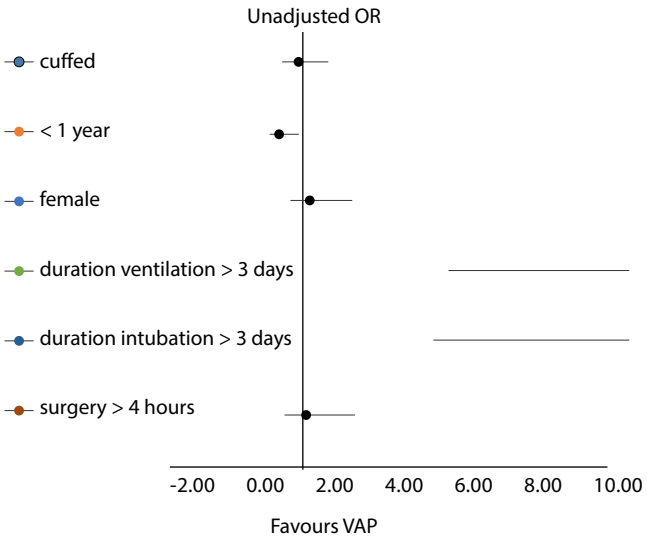

Figure 3: Unadjusted odds ratios of variables affecting diagnosis of any sepsis

the reintubation group failed a trial of adrenaline nebulisation and were reintubated in the ICU. These three patients were all extubated successfully thereafter and discharged. Three patients were reintubated for lower respiratory tract infections and were included in the no intervention group.

It was difficult to differentiate between patients with sepsis, pneumonia and VAP. These terms were often used interchangeably and were not consistent in the records. Combining these groups resulted in 48% of paediatric patients having some form of sepsis during the postoperative period.

The adjusted ORs of variables affecting airway complications are shown in Figure 2 (and supplementary data Table IV). Cuffed ETTs had an OR of 0.6 for causing airway complications. However, once adjusted, the OR was 0.75 with a *p*-value of 0.57. Paediatric patients > 1 year old or weighing > 15 kg had a lower chance of having an intervention compared to paediatric patients < 1 year old or weighing < 15 kg. However, once these were adjusted for confounders, they were statistically insignificant. The only significant factor was ETTs that were inappropriately sized and too large for the airway based on the standard formulae used. The duration of surgery did not influence the incidence of airway complications, nor did the duration of ventilation.

Figure 3 (and supplementary data Table V) represents the different variables affecting the development of any form of sepsis in the ICU. Nosocomial sepsis, nosocomial pneumonia and VAP were grouped together as any sepsis. The only factors that led to a statistically significant increase in sepsis were duration of intubation of more than 3 days (OR 15.46; $p < 0.001$) and duration of ventilation of more than 3 days (OR 17.44; $p < 0.001$). The type of ETT used was not associated with the occurrence of sepsis.

Discussion

We aimed to compare the incidence of stridor with the use of cuffed versus uncuffed ETTs, as well as sepsis related to endotracheal intubation in a South African cohort. Cuffed tubes

were not found to increase the airway obstruction and did not influence the outcome of sepsis.

In paediatric patients who had cardiac surgery and were ventilated postoperatively, we found that the incidence of postoperative airway complications was 48%. While most of these were mild and required only adrenaline nebulisation, the incidence is higher than that of stridor quoted from other prospective studies, which ranged from 10–30.2%.[9,15] One possibility for the increase in stridor is the unit's practice of using uncuffed tubes which were too large for paediatric patients.

Our results indicated that the incidence of upper airway complications was not statistically different when cuffed ETTs were used. This finding is similar to findings in the study done by Newth et al.,[16] who studied 860 critically ill children, including patients in a cardiac ICU and a cardiothoracic ICU and found that the use of cuffed tubes was not associated with an increased risk of subglottic oedema. Our findings were similar despite a greater than twofold average increase in the duration of intubation (1.65 days vs 3.8 days).

In our study, almost one third of paediatric patients were intubated with an ETT bigger than the calculated size. This led to a greater than three times higher rate of airway complications. This finding emphasises the importance of using correctly sized ETTs in paediatric patients. Other studies have confirmed that complications are related to size rather than intubation technique.[17,18]

Cuff pressure monitoring is imperative when using cuffed ETTs to prevent overinflation of the cuff and the resultant mucosal ischaemia.[19] The Microcuff® tubes seal at low pressures of 11–15 cmH_2O, thus needing low pressures to provide good sealing of the airway.[20] Cuff pressure monitoring, although a standard of care in our hospital, was poorly documented. The impact of abnormal cuff pressures on complications could thus not be determined. Therefore, the importance of cuff pressure monitoring and recording needs re-emphasis in our setting.

Even though the number of patients needing reintubation for upper airway obstruction in our study was small, all reintubations were in the uncuffed tube group. Both Khine et al.[1] and Weiss et al.[4] reported the same finding and it was previously noted in a meta-analysis where the use of cuffed ETTs in paediatric patients reduced the need for tracheal tube exchanges.[3] The only patient in our study that needed tracheal dilatation for subglottic stenosis had an uncuffed ETT. Reintubations in ICU have been associated with a higher risk of VAP,[21] but the small number of reintubations in this study may have prevented replicating this finding. The number of previous intubations did not affect this cohort's incidence of airway complications. This could also be because of the small number of patients in this group.

Longer durations of surgery and CPB may theoretically increase the rate of airway complications via prolonged periods of lower perfusion pressures and inotrope administration, which could affect mucosal perfusion and lead to subsequent ischaemia. Other studies were unable to conclusively show this.[22,23] The duration of surgery or CPB, however, did not affect the incidence of airway complications in our study.

The use of cuffed tubes in the ICU did not affect the incidence of VAP or sepsis in our study, similar to a meta-analysis in 2013.[24] This is contrary to a previous study that indicated a lower incidence with cuffed ETTs.[11] This may reflect the difficulty of differentiating between VAP and other causes of sepsis in ICU patients and the difficulty with a retrospective study. An increase in the incidence of pneumonia was found with an increased duration of intubation and ventilation, which would be expected. Our finding that children younger than one year were at a higher risk of postoperative pneumonia is supported by other work showing that these patients have a higher incidence of VAP compared to older patients.[25]

Other factors that could potentially influence the duration of ventilation, including sedation and analgesia, were not studied.

Study limitations

This was a single centre study in a single ICU. The results may not be generalisable to a broader population. As this was a retrospective study, we relied on the adequate record-keeping of the perioperative events and the postoperative stay for our data. We also relied on the attending doctor's clinical assessment which may not necessarily have been objective and consistent, especially with the clinical definitions used for the diagnosis of VAP and nosocomial pneumonia. Cuff pressures were not documented intraoperatively or in the ICU, even though such monitoring is a standard of care in the unit.

Conclusion

Correctly sized, cuffed ETTs are safe to use in the paediatric population presenting for cardiac surgery, including their extended use in the postoperative period. This, the first study in a paediatric cardiac surgery cohort in South Africa, will reassure perioperative physicians and allow for recommendations for the use of cuffed ETTs in paediatric patients. The further benefit of cuffed ETTs in reducing VAP in paediatric patients needs to be confirmed in more extensive prospective trials.

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Conflict of interest

The authors declare no conflict of interest.

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Ethical approval

Approval for this study was granted by the University of KwaZulu-Natal Biomedical Research Ethics Committee (BE341/19).

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