Original Article

Endotracheal tube cuff position in relation to the cricoid in children: A retrospective computed tomography-based analysis

ABSTRACT

Background: The use of cuffed endotracheal tubes (ETT) has become the standard of care in pediatric practice. The rationale for the use of a cuffed ETT is to minimize pressure around the cricoid while providing an effective airway seal. However, safe care requires that the cuff lie distal to the cricoid ring following endotracheal intubation. The current study demonstrates the capability of computed tomography (CT) imaging in identifying the position of the cuff of the ETT in intubated patients.

Methods: In this retrospective study, the ETT cuff position was examined on the sagittal plane images of neck and chest CT scans of 44 children. The position of the proximal and the distal aspect of the ETT cuff inside the trachea was recorded in relation to the vertebral levels. The vertebral levels were used to estimate the location of the cricoid ring and its relationship to the cuff.

Results: The vertebrae were used as the primary landmarks to define the position of the cricoid and its relationship to the cuff of the ETT. Correlating vertebral levels with the cricoid for different age groups, the proximal (cephalad) edge of the ETT cuff was below the cricoid in 41 of 44 patients (93%). The ETT cuff was deep in 6 patients, below the 1st thoracic vertebra, with 2 ETTs in the right mainstem bronchus.

Conclusion: This is the first study demonstrating that the cuff of the ETT and its position in the trachea can be identified on CT imaging in children. The ETT cuff was below the level of the cricoid in the majority of patients irrespective of the patient's age as well as the size, make, and type of ETT.

Key words: Computed tomography imaging, cricoid ring, endotracheal intubation, endotracheal tube cuff, pediatric airway, trachea.

Introduction

The debate regarding the use of cuffed and uncuffed endotracheal tubes (ETTs) in infants and children has generally been settled in favor of the use of cuffed ETTs. The past 10 years have witnessed this change in clinical practice in both operating rooms and intensive care units (ICUs). Clinical studies have demonstrated several advantages of cuffed over

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uncuffed ETTs including enhanced efficacy in sealing the airway for positive pressure ventilation, prevention of aspiration, a decreased need for ETT exchange, and a decreased incidence of sore throat.[1-5] The entire cuff of the ETT in children ideally should be located below the cricoid ring to avoid injury to the subglottic structures and its potential sequelae.[6] To facilitate the correct anatomic location of the ETT cuff within the airway, the Microcuff® ETT was designed with a more distal placement of the cuff to ensure placement beyond the cricoid and subglottic region following endotracheal intubation.[7]

In contrast to the cricoid ring, the tracheal rings are incomplete, providing some distensibility thereby limiting pressure injury from an inflated cuff. Since the posterior membranous wall of the trachea can stretch and thereby limit the impact of intracuff pressure on the mucosa, positioning the ETT cuff below the cricoid ring may provide some protection from mucosal injury, when the intracuff pressure is elevated.[7,8] The location of the ETT cuff at or above the cricoid ring may be associated with mucosal injury and recurrent laryngeal nerve damage, manifesting as hoarseness/dysphonia, throat pain, or stridor following tracheal extubation. Clinical studies have demonstrated that endotracheal intubation may result in damage to both the glottic and the subglottic areas with the injury typically at the posterior aspect of the glottic plane and the subglottic area.[9-12] Autopsy studies in children have revealed damage at various points along the entire larynx following prolonged endotracheal intubation, with the most severe damage occurring at the level of the cricoid and the vocal cords.[13,14]

Despite the assumption that a high intracuff pressure is responsible for mucosal injury by applying pressure at the cricoid and subglottic region, there are no imaging studies defining the location of the ETT cuff in children following endotracheal intubation. The current study aimed to evaluate whether computed tomography (CT) imaging could be used to identify the position of the ETT cuff in relation to the vertebral levels following endotracheal intubation. As earlier studies have reported, the vertebral levels were used to estimate the location of the cricoid ring and its relationship to the cuff of the ETT. We hypothesized that the position of the ETT cuff in the trachea would be variable, with variation based on the make and manufacturer of the ETT.

Methods

After obtaining IRB approval, this retrospective observational study was performed at Sidra Medicine (Doha, Qatar). Date of IRB approval was June 17, 2020. The study included patients ranging in age from 1 month to 10 years of who underwent neck and chest CT imaging that required general anesthesia and endotracheal intubation. The data were identified and retrieved from the picture archive and communicating systems (PACS) of the Department of Radiology. As a retrospective study, the study protocol did control the process of endotracheal intubation including the type of ETT used, medications used for the induction and maintenance of anesthesia including neuromuscular blocking agents, or the technique of laryngoscopy. Standard clinical methods including the presence of exhaled end-tidal carbon dioxide and equal bilateral breath sounds were used to confirm the position of the ETT. Endotracheal intubation occurred in various locations, including the pediatric and neonatal ICUs, the radiology suites, and the operating rooms. The CT scans were performed with the head and neck in the neutral position as deemed necessary by the imaging protocols. Exclusion criteria included patients with a history of airway pathology, previous tracheostomy, the presence of a mediastinal mass, diaphragmatic hernia, extra-pulmonary and intrathoracic masses, preterm infants, and patients with genetic/chromosomal syndromes.

All imaging acquisitions were made using two identical computed tomography scanners with identical imaging protocols and configuration (SOMATOM Definition Flash, Siemens Healthineers AG, Erlangen, Germany). Acquired data were transferred to the standalone workstation (syngo. via, Siemens Healthineers AG, Erlangen, Germany, Software version VB30A_HF06) for evaluation. Sinogram Affirmed Iterative Reconstruction (SAFIRE) at Level 3 was used on all images. Radiographs with a thickness of 0.6 mm and at the 0.4 mm of the interval were used for assessment in default multi-modality reading mode. Images were reconstructed using the soft kernel (I30), with the abdomen window on default settings. Two pediatric anesthesiologists evaluated the CT scans in consensus with each other. The upper and lower edges of the cuff of the ETT were identified in the sagittal, axial, and coronal images simultaneously to identify the extension of the cuff (cephalad and distal margins) in relationship to the vertebral levels [Figure 1].

Statistical analysis

Demographic data as well as the characteristics and the size of the ETT were summarized as medians, ranges, and interquartile ranges (IQR); or counts with percentages. The upper (cephalad) cuff edge, lower (caudad or distal) cuff edge, and the number of vertebrae spanned by the cuff were correlated with the patient's age using Spearman coefficients. Cuff position and number of vertebral levels spanned by the cuff were compared according to the ETT type using rank-sum tests. Data analysis was performed in Stata/SE 16.1, and a two-tailed $P < 0.05$ was considered statistically significant.

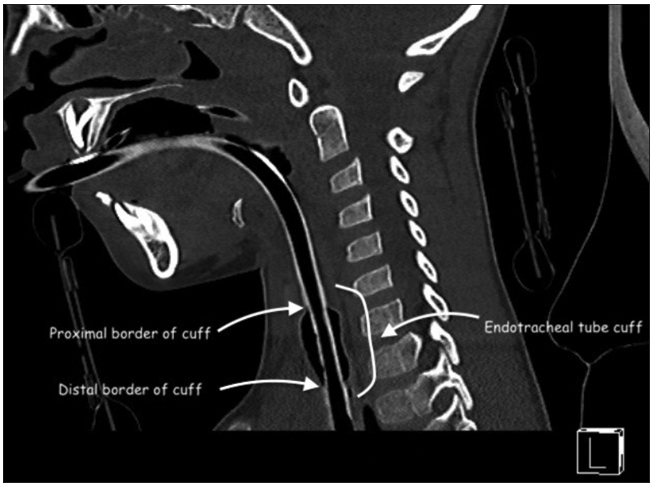

Figure 1: Sagittal computed tomography image of a 4-year-old patient showing the location of the cuff of the endotracheal tube in relationship to the vertebral bodies

Results

The study cohort included 44 patients (26 males and 18 females), with a median age of 22 months (IQR: 6, 62) and a median weight of 12 kilograms [IQR: 7, 18; Table 1]. The Microcuff® ETT (Haylard Health) with a polyurethane cuff was used in 22 (50%) patients and an ETT with a polyvinylchloride (PVC) cuff (Mallinckrodt) was used in 22 patients. The median ETT size for the entire study group was 4.5 (IQR: 3.5, 5). In 17 of 44 patients (39%), the ETT cuff spanned the distance from the 7th cervical vertebrae (C7) to the 2nd thoracic vertebrae (T2). The median level of the cuff's top (cephalad) edge was C7 (IQR: C6, C7) and the median level of the cuff's bottom edge was T2 (IQR: T1, T2). The number of vertebrae spanned by the cuff was 3 (IQR: 3, 3). Older age was not associated with the vertebral level of the proximal edge (rho = -0.11, $P = 0.471$) or distal edge of the cuff (rho = 0.03; $P = 0.847$). However, older age was associated with a greater number of vertebrae spanned (rho = 0.31; $P = 0.042$).

The proximal end of the cuff was at or above the 5th cervical vertebral (C5) in 5 patients (11%), 2 with the Microcuff® ETT and 3 with the ETT with a PVC cuff. The cephalad edge of the cuff was at or above the level estimated to represent the lower edge of the cricoid according to age in only 3 patients in the study cohort [Tables 2 and 3, Figure 2]. This included one patient whose trachea was intubated with a Microcuff® ETT and two patients with a PVC ETT. In 6 patients, the proximal end of the cuff was deep, at or below the 1st thoracic vertebra (T1), with 2 ETTs noted to be positioned toward or in the right mainstem bronchus.

When considering the middle of the 4th cervical vertebrae (C4) as the lower border of the cricoid ring for children less than one year of age,[15] none of the patients in our study who were less than one year had the cuff above the lower margin of the cricoid. In contrast, for the age group of 1-2 years of age, assuming that the middle of the 5th cervical vertebrae (C5) to be the lower border of the cricoid), one patient had the cuff at or above the cricoid. For the age group above two years, two patients had the cuff at or above the cricoid [Table 2].

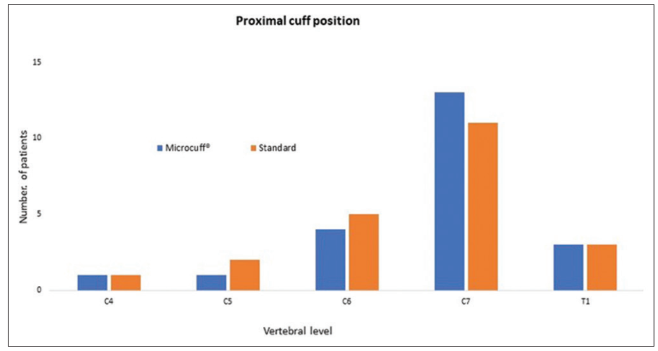

Figure 2: Position of the cephalad edge of the cuff in relationship to the vertebral bodies in the study cohort of 44 patients. The position of the Microcuff® endotracheal tube is shown in blue while the cuff of the polyvinylchloride endotracheal tube is shown in orange

Table 1: Patient Characteristics and Cuff Position in the Study Cohort

Variable	*n* (%)	Median	IQR	Range
Age (months)		22	6, 62	1, 159
Age category				
<1 year	17 (39%)			
1-2 years	6 (13%)			
>2 years	21 (48%)			
Gender				
Female	18 (41%)			
Male	26 (59%)			
Weight (kg)		12	7, 18	3, 62
ETT type				
Microcuff®	22 (50%)			
ETT with polyvinylchloride cuff	22 (50%)			
ETT size		4.5	3.5, 5	3, 6.5
Vertebral levels of ETT cuff				
Proximal		C7	C6, C7	C4, T1
Distal		T2	T1, T2	C7, T3
Number of vertebral bodies spanned		3	3, 3	2, 4
Specific levels spanned				
C4-C7	2 (5%)			
C5-C7	3 (7%)			
C6-T1	8 (18%)			
C6-T2	1 (2%)			
C7-T1	7 (16%)			
C7-T2	17 (39%)			
T1-T3	6 (14%)			

ETT, endotracheal tube; IQR, interquartile range

Comparing cuff location by ETT type (Microcuff® vs. PVC ETT), the median vertebral level of the proximal cuff was C7 in the Microcuff® group (IQR: C6, C7) and C7 in the PVC ETT group (IQR: C6, C7), 0.938. The median vertebral level of the distal cuff edge of the cuff was T2 in both groups with similar interquartile ranges (T1, T2), $P = 0.901$. The median number of vertebrae spanned by the cuff was 3 with the Microcuff® ETT (IQR: 3, 3) and 3 with a PVC ETT (IQR: 3, 3), $P = 0.974$. [Table 3].

Discussion

The current study demonstrates the feasibility of using CT imaging to identify the position of the ETT cuff in relationship to the cervical and thoracic vertebrae. Furthermore, the results demonstrate that in the majority of patients, regardless of the type of ETT used, the proximal end of the cuff was below the level of the 5th-6th cervical vertebrae, a level that has anatomically been shown to correlate with the cricoid ring. Comparing the cervical vertebral levels with the proposed position of the cricoid ring, we conclude that irrespective of the make or size of the ETT, the age of the patient, or the methodology used for the confirmation of ETT position, the proximal end of the ETT cuff resides below the cricoid ring in the majority of patients.

It is challenging and generally impossible to specifically visualize the cricoid ring on CT images. Therefore, for this study, we used the relationship of the cricoid ring with vertebral levels that have been described as early as 1885 by various authors.[15-17] The initial observations showed that the lower end of the cricoid corresponded to the 5th cervical vertebrae in children up to 6 years of age. Similarly, Roche *et al*.,[15] reported that the lower end of the cricoid was at the level of the body of the 4th cervical vertebra in fetal life and the middle of the body of the 5th cervical vertebra by the two years of age. They also noticed that the level continued to change rapidly so that by 13 years of age, the cricoid was at the inferior aspect of the 6th cervical vertebra. Westhorpe, using lateral radiographs, evaluated the position of the larynx in relation to the cervical vertebrae and found that the inferior border of cricoid was at the C4 cervical vertebrae at birth and the middle of the C5 vertebrae at ten years of age.[17] In our cohort of patients, the ETT cuff was at or below the 5th cervical vertebrae in 88% of the patients and below the 6th cervical vertebrae in 68% of the patients. Hence in the majority of patients, the proximal (cephalad) end of the cuff was below the cricoid.

The tracheas of infants and children are relatively shorter than adults. Therefore, proper positioning of the ETT is important to avoid not only endobronchial intubation but also high placement of the cuff that can result in accidental tracheal extubation or injury to the cricoid and subglottic area.[9-14,18,19] The incidence of malpositioning of the ETT within the trachea is high, as standardized formulae cannot account for the interpatient variability of airway and trachea characteristics.[20-22] When the ETT cuff lies at the cricoid or subglottic area, damage may occur related to the duration of use, the pressure within the cuff, and the exact position within the airway. Although the ideal location of the ETT cuff inside the airway has not clearly been identified, because the cricoid and subglottic regions are relatively non-distensible when compared to the lower aspects of the airway, it is generally recommended that the cuff be placed below the cricoid. This placement allows the cuff to lie in an area where the open posterior aspect of the trachea allows some distensibility if the cuff is overinflated while providing ample distance for the end of the ETT to lie in the mid-trachea above the bifurcation of the trachea, thereby avoiding endobronchial intubation.

ETTs with intubation depth marks have been shown to ensure a cuff-free subglottic area with a sufficient margin distally to

Table 2: Cuff Position in Relationship to the Cricoid Ring by Age Group*

Characteristic	Age<1 year	Age 1-2 years	Age>2 years
Vertebral level of the lower border of the cricoid+	Middle of C4	Middle of C5	Middle of C5
Above lower border of the cricoid	0	1	2
Below lower border of the cricoid	17	5	19
Total	17	6	21

*Position of the proximal (cephalad) end of the endotracheal tube cuff in relationship to the cricoid ring. +Vertebral level used to estimate position of the cricoid.

Table 3: Comparison of Cuff Position Between Microcuff® and Standard Endotracheal Tube

		Microcuff®, $n=22$	Standard ETT, $n=22$	P
Vertebral level of the cuff	Top	C7; (C6, C7); C4-T1	C7; (C6, C7); C4-T1	0.938
	Bottom	T2; (T1, T2); C7-T3	T2; (T1, T2); C7-T3	0.901
Vertebral levels spanned by the cuff		3; (3, 3); 2-4	3; (3, 3); 2-4	0.974

Data are listed as median; (IQR); range. IQR, interquartile range; ETT, endotracheal tube prevent endobronchial intubation.[14] However, there are no uniform standards for the placement of these markings on the ETTs with significant variation across different manufacturers of currently used ETTs. Although there are formulas for calculating the depth of ETT placement such as the Morgan formula (depth of placement at the incisors = 3 × ETT ID size in mm) to prevent endobronchial intubation, no such methods exist to determine the depth of the ETT cuff.[23] Therefore, proper clinical judgment is necessary to ensure the correct placement when using cuffed ETTs. Most clinicians tend to accept a tube position as long as breath sounds are heard equally on both sides of the thorax. The issue of placing the cuff of the ETT below the cricoid in the subglottic region is not generally considered during endotracheal intubation.

In our study, we noted no difference when comparing two commonly used types of ETTs, the Microcuff® ETT and PVC ETTs [Table 1]. In addition to offering a potentially safer cuff for prolonged endotracheal intubation, the more distal cuff position of the Microcuff® ETT has been suggested to provide a secondary margin of safety by allowing for more distal placement and thereby ensuring a cuff free subglottic area with avoidance of the cricoid. In our limited cohort, the proximal end of the cuff was found at or above the C5 level in only 5 of 44 patients (11%), 2 with a Microcuff® ETT and 3 with a PVC ETT. However, when considering the level of the cricoid extrapolated from the vertebral level and age, the cuff was found above the level estimated to represent the lower edge of the cricoid by age in only 3 patients in the study cohort, thereby limiting the ability to discern differences in cuff position between these two types of ETTs. The preliminary data suggest that the placement of the cuff on the shaft of the ETT may not impact its location in relationship to the cricoid.

The major limitation of the study was the small sample size of the cohort related to availability of CT imaging in patients who had an ETT in place. The study cohort was also affected by the need to include only those CT images with optimal image quality as we had to ensure visibility of the cuff of the ETT as well as vertebral bodies, resulting in a further decrease in sample size. As this was a retrospective study, we had no control over the methodology used by the individual practitioners for the choice of ETT, medications and technique of endotracheal intubation, and technique used to confirm the correct location of the ETT within the trachea. In fact, in two of the patients, the ETT was noted to be deep in the airway, located near or within the right mainstem bronchus.

In conclusion, the current study demonstrates the feasibility of using CT imaging to identify the cuff of the ETT and its relationship to the vertebral bodies as a means of identifying the location of the cricoid ring and subglottic region of the airway. The ETT cuff was below the level of the cricoid in the majority of patients irrespective of the patient's age as well as the size, make, and type of the ETT. In general, the cuff of the ETT should be below the cricoid ring as it is the only complete ring of the airway and therefore may be the area at highest risk of damage from a cuff. Larger studies in various age ranges are needed to confirm our findings and provide additional information regarding the position of the cuff within the trachea following routine endotracheal intubation in children. These data would provide further information that is needed to guide the appropriate design of ETTs to ensure that the cuff is located at the optimal position along the shaft of the ETT.

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Conflicts of interest
There are no conflicts of interest.

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