Original Article

# Correlation between correctly sized uncuffed endotracheal tube and ultrasonographically determined subglottic diameter in paediatric population

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## ABSTRACT

**Background and Aims:** Conventional age-based formulae often fail to predict correct size of endotracheal tube (ETT). In this study, we evaluated usefulness of ultrasound in determining appropriate tube size and derived a formula which enables us to predict correct tube size. **Methods:** A total of 41 American Society of Anesthesiologists' physical status 1 and 2 children in the age group of 2–6 years, undergoing elective surgery under general anaesthesia with uncuffed ETT were included in the study. Ultrasonography (US) was used to measure the subglottic diameter after induction of anaesthesia. The trachea was intubated with an ETT that allowed an audible leak between 15–30 mmHg. Pearson's correlation was used to assess the correlation between US measured subglottic diameter (US-SD) with diameter of ETT used. Linear regression was used to derive a formula for predicting ETT size. **Results:** We found that US-SD and patient's age correlated well with actual ETT OD (r: 0.83 and 0.84, respectively). Age-based formula, ETT ID = (Age/3) +3.5 [r: 0.81] had better correlation with actual ETT OD than conventional age-based Cole's formula, i.e., ETT ID = Age/4 + 4 [r: 0.77]. Our results enabled us to derive a formula for selecting uncuffed ETT based on US-SD. **Conclusion:** Our study concludes that although US-SD correlates with actual tracheal tube used and may be useful in choosing appropriate size ETT, there was no difference in number of correct predictions of ETT size by US measurement, universal formula, and locally derived formula.

**Key words:** Paediatric airway, subglottic diameter, ultrasound

## INTRODUCTION

The correct selection of endotracheal tube (ETT) size is important in the paediatric population as their airway is fragile and prone to post-intubation complications.[1] Intubation of paediatric patients with an ETT size that is too small may result in insufficient ventilation, poor reliability of end-tidal gas monitoring, leakage of anaesthetic gases into the operating room and an enhanced risk of aspiration. Conversely, ETT that is too large can cause upper airway injury and has the potential to result in subsequent subglottic stenosis.[2]

Age-based formulae such as Cole's formula [ETT inner diameter = (age/4)+4] for selection of uncuffed tube are used to estimate optimal ETT size. The protocol in our Institute is based on a modified Cole's formula, ETT inner diameter = (age/3)+3.5. Several formulae which are in use often fail to predict the correct ETT size.[3,4] In addition, most of these formulae were



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developed in a western population and may not be universally applicable.[5]

Ultrasonography is a simple and non-invasive real-time tool available at the point of care and has proven to be of value in assessing airway anatomy. The narrowest diameter of the upper airway in paediatric patients is the subglottic region.[3,4] The transverse diameter of the cricoid region is smaller than its anteroposterior diameter and hence ultrasound measurement of the transverse diameter at the level of cricoid can be used for predicting the appropriate size of ETT.[3,4,6]

This study was undertaken to find the correlation between subglottic diameter as measured by ultrasonography and uncuffed ETT chosen to intubate children less than 6 years of age and to derive a formula for selection of tube based on subglottic diameter. We also attempted to compare the two age-based formulae for their accuracy in predicting the size of ETT needed to intubate these patients.

## METHODS

We conducted an observational study in accordance with the principles of the Declaration of Helsinki between July 2014 and July 2015 after obtaining approval from the Institute Ethics Board (JIP/IEC/2014/1/224, dated 3.3.2014). This study was registered in the Indian clinical trial registry (CTRI/2015/04/006879). Children between the age of 2 and 6 years of ASA physical status 1 and 2 posted for elective surgery under general anaesthesia were included in the study. Written informed consent from the parents or legally accepted representative was obtained. Children with laryngeal or tracheal pathology, anticipated difficult airway, neck mass, children at risk of aspiration or those with unstable cardiopulmonary condition were excluded from the study.

Intraoperative monitoring included pulse oximeter, non-invasive blood pressure, end-tidal carbon dioxide and electrocardiogram. Anaesthetic induction was either inhalational or intravenous based on the preference of the attending anaesthesiologist. The agents used included thiopentone, propofol, sevoflurane and fentanyl. Patients were allowed to breathe spontaneously through a face mask with titrated doses of sevoflurane and 100% oxygen to facilitate identification of airway structures. A 5–13 Hz linear ultrasound probe (S-ICU, Sonosite Fujifilm Corporation) was placed in the anterior region of the neck with the head in neutral position and the neck slightly extended. Scanning was performed with B mode on, beginning along the midline from identifying the hyoid bone as a superficial, hyperechoic and curvilinear structure, with posterior acoustic shadowing in the transverse view. The probe was gently moved caudally with a slight cephalad angle. The true vocal cords were then identified ultrasonographically as paired hyperechoic structures that move with respiration. These form the medial edge of the paired triangular hypoechoic vocal muscles. Then, the probe was gently moved caudally to visualise the cricoid as a rounded, arch-like hypoechoic structure with hyperechoic edges. After administering muscle relaxant, subglottic diameter was measured ultrasonographically while mask ventilation was interrupted to minimise fluctuation in tracheal diameter. The transverse air column diameter was measured at the level of cricoid cartilage. All measurements were performed by the same observer. At the first instance, ETT size was chosen according to the preference of the attending anaesthesiologist. Then, a standardised method for assessing leak was performed to identify the correct size of ETT. The ETT size was considered appropriate and clinically fit if there was an audible leak when the airway pressure was increased to 15 cm of $H_2O$. If the leak occurred at less than 15 cm of $H_2O$, the tube was considered small and trachea was reintubated with an ETT of size greater by 0.5 mm. If there was no audible leak till 25 cm of $H_2O$, the tube inserted was considered large and trachea was reintubated with an ETT of size smaller by 0.5 mm. If $SpO_2$ fell below 95% during measurement, ventilation was resumed with mask. The procedure was abandoned if measurement exceeded 30 s. The ETT used was Rusch Safety Clear, Teleflex Medical, Kernen, Germany.

Following parameters were noted: Transverse diameter at the level of cricoid as measured by ultrasonography (SD), inner diameter (ID) and outer diameter (OD) of the ETT finally placed which was considered appropriate using leak test, leak pressures with the final ETT *in situ*, ETT internal diameter (ETT ID) based on Cole's formula (ETT ID = [age/4] +4 in mm; formula 1) and the corresponding outer diameter (OD), and on age-based formula followed in our institute (ETT ID = [age/3]+3.5; formula 2) and the corresponding outer diameter (OD).

Age, weight, height, ETT size and diameters measured by ultrasound were expressed as mean ± SD. Pearson's correlation was used to assess the correlation between age, measured diameters, and ETT outer diameter derived from the two age-based formulae with final appropriate size ETT outer diameter. Linear regression was used to derive a formula for the correct ETT inner diameter based on ultrasound-derived measures. Linear regression was also used to derive a formula based on age. Bland Altman assessment for agreement was used to assess the degree of agreement between the ultrasound derived measurements and the age-based formulae with the actual ETT placed.

Sample size was estimated to be 41 using 'n master' software for testing two-sided hypothesis assuming the correlation between USG-measured subglottic diameter and OD of final appropriate size ETT to be 0.4, alpha of 95% and power of 80%.

## RESULTS

A total of forty-three patients aged between 2 to 6 years were enrolled in the study. Two patients were excluded from the study as the leak pressures obtained after the final ETT insertion were less than 15 mm $H_2O$. It was decided not to change the tube as the duration of the surgical procedure was short. The final analysis included 41 patients (6 males and 35 females). The mean age of the included patients was 3.1 years (SD, 1.3), mean height was 92.8 cm (SD, 10.0) and mean weight was 14.3 kg (SD, 3.3) [Table 1]. All the ET tubes used in our study were from the same manufacturer. The outer diameter of tubes of sizes 4, 4.5, 5 and 5.5 are 5.5, 6.2, 6.9 and 7.5 mm, respectively.

Good correlation was seen between the actual ETT OD and ultrasound-measured diameters, age, age-based formula 1 (ETT OD) and age-based formula 2 (ETT OD). Age-based formula 2 correlated better than formula 1 with the final ETT OD [Table 2]. Regression analysis gave the equation for predicting ETT ID based on ultrasound measurements as (0.63 × U/S measured diameter) – 0.36 and OD was (0.87 × U/S measured diameter) – 0.47. Formula-derived using age for predicting the ETT ID was (0.25 × Age) +3.75 and for ETT OD was (0.34 × Age) +5.17. Height and weight did not show a good correlation with final ETT OD [Table 2].

Based on these derived formulae, we estimated the appropriate size ETT (ID and OD) to be placed based on the age groups [Table 3].

The correct prediction of tracheal tube size was not significantly different with the formula derived from the ultrasound-measured diameter, formula 1 or formula 2 [Table 4].

Bland Altman analysis showed a bias of 1.45 mm [limits of agreement (LOA), 1.55–1.35 mm] for ultrasound-derived measurements. Age-based formula 1 showed a bias of 0.20 mm (LOA, 0.089–0.31) while formula 2 had a bias of -0.022 (LOA, -0.135–0.091).

Out of the 41 children, 25 children were intubated in the first attempt successfully. Tube had to be changed to a bigger size owing to significant leak in 10, and to a smaller tube in 6 children. There were no instances of replacing the tube a third time in any of the children. We did not measure the time taken to intubate.

## DISCUSSION

During recent years, several studies explored the possibility of utilising ultrasound-guided ETT size selection in paediatric age group.[3,4,7] However, all these studies were performed in a western population. It is well known that ultrasound measurements vary significantly depending on the ethnicity of the child, hence the need for this study. In addition, predicting the outer diameter of the ETT may be a better guide for choosing ETT size than the internal diameter as predicted by traditional formulae. This is because, for a similar internal ET diameter, the outer diameters often

**Table 1: Age-wise distribution of mean height, weight, actual ETT OD, ETT OD based on formula 1 and 2, and ultrasound-measured subglottic diameter**

| Patient characteristics | Age (y) | | | |
|---|---|---|---|---|
| | 2-3 | >3-4 | >4-5 | >5-6 |
| Number of patients | 26 | 6 | 5 | 4 |
| Weight (kg) | 12.4±1.7 | 16.5±2.0 | 17.75±2.0 | 18.84±4.1 |
| Height (cm) | 87.6±6.3 | 98.2±3.1 | 105±8.7 | 103±14.6 |
| Actual ETT OD (mm) | 6.0±0.4 | 6.4±0.4 | 6.9 | 7.2±0.3 |
| US-measured subglottic diameter (mm) | 7.5±0.4 | 7.9±0.5 | 8.2±0.2 | 8.5±0.2 |
| Age-based formula 1 ETT OD (mm) | 6.2 | 6.9 | 6.9 | 7.5 |
| Age-based formula 2 ETT OD (mm) | 5.9±0.4 | 6.7±0.4 | 6.9 | 7.5 |

ETT – Endotracheal tube; OD – Outer diameter; US – Ultrasound. All values are as numbers or mean±SD

**Table 2: Correlation between age-based ETT (formula 1, 2) OD and US-measured subglottic diameter with final ETT OD**

| Parameter | $R^2$ | $P$ |
|---|---|---|
| Formula-1-based OD | 0.6 | <0.001 |
| Formula-2-based OD | 0.7 | <0.001 |
| US-measured-subglottic diameter-based OD | 0.7 | <0.001 |
| Age | 0.7 | <0.001 |
| Height | 0.3 | <0.001 |
| Weight | 0.4 | <0.001 |

ETT – Endotracheal tube; OD – Outer diameter; US – Ultrasound

**Table 3: Predicted tube size from mean ultrasound-measured diameters using the derived formulae**

| Age (years) | Mean US-measured diameter (mm) | Tube size predicted from US diameter (ID/OD, mm) |
|---|---|---|
| 2-3 | 7.5 | 4.5/6.1 |
| >3-4 | 7.9 | 4.5/6.4 |
| >4-5 | 8.2 | 5.0/6.7 |
| >5-6 | 8.5 | 5.0/6.9 |

ID – Inner diameter; OD – Outer diameter; US – Ultrasound

**Table 4: Estimation of tube size using 3 different formulae**

| | Correctly predicted ETT size | Overestimated ETT size | Underestimated ETT size |
|---|---|---|---|
| US-measured diameter[1] | 29 (70.7%) | 4 (9.7%) | 8 (19.5%) |
| Age-based formula 1[2] | 27 (65.8%) | 13 (31.7%) | 1 (2.4%) |
| Age-based formula 2[3] | 30 (73.2%) | 5 (12.19%) | 6 (14.6%) |

[1]: (0.87×U/S measured diameter) - 0.47; [2]: (age/4) + 4; [3]: (age/3) + 3.5. *P* value between US-measured diameter and formula 1 is 0.6, and between US-measured diameter and Formula 2 is 0.8. ETT – Endotracheal tube; US – Ultrasound

vary depending on the manufacturer. All the formulae currently used for predicting ETT size provide only the inner diameter. The advantages of using US for measuring airway diameters are the following: it is a minimally invasive technique, is easily available at the bedside, and has proven value for assessing airway anatomy. In addition, it can also assess the airway for any other abnormality before attempting intubation. A study done by Kim *et al*. verified that US-measured subglottic diameter can be applied for selecting an appropriate size ETT.[7]

The correlation between the ultrasound-measured subglottic diameter and the size of actual ETT placed was very good. Regression analysis was used to derived a formula to obtain the outer diameter of the ETT, namely, ETT OD = 0.87×USD in mm-0.47. Shibasaki *et al*. developed a formula (ETT OD = 0.55×USD+1.16 [*R*0.9]) for uncuffed ETTs after studying the ultrasound diameter of 48 patients. Bland Altman analysis showed a bias of 3.3 mm with a range of 1.9 to 4.6 mm.[4] The bias, in our study, was 1.45 mm. They further went on to validate their formula in another group of patients and demonstrated a 96% agreement. Schramm *et al*. in their study on 50 children found the minimal transverse diameter of the subglottic airway (MTDSA) to correlate well with the size of the ETT actually placed. Bland Altman analysis showed a bias of -0.02 mm (range of -1.12 to 1.08). However, they did not derive any formula for predicting the outer diameter of the tube and estimated that if they had used the MTDSA for choosing the ETT, it would be successful in obtaining the correct size in 48% of children.[8] In our study, we found that US-derived measurement could predict the correct size of tube in 70.7% of children. Hence, probably, a formula needs to be established since the MTDSA cannot be directly extrapolated as the outer diameter of ETT. Kim *et al*. found a bias in the range of 0.71 to -1.03 mm. However, they used only cuffed ETTs and also included children less than 2 years of age. They did not perform or quantify any test like the leak test that we used to identify the appropriateness of the selected tube.[7]

We noted a rate of agreement of 65.8% when we used Cole's formula for estimating the size of the ETT to be placed. Our findings are similar to the study by Shibasaki *et al*. that reported a success rate of 60%.[4] Other studies have also noted a similar rate of 47–77%.[3,9] The mean bias was 0.2 with a range of 0.089 to 0.3. In contrast, Schramm *et al*. demonstrated that Cole's formula tended to underestimate the tube size (mean bias, -0.34).[8] A study by Bae *et al*. also revealed that Cole's formula underestimated the size of uncuffed ETT in a similar-sized population, with only 31% of the patients being intubated with a correct-sized tube. Bae *et al*. demonstrated a 60% agreement between the correct-sized tube and US-measured diameter.[3]

Our institutional age-based formula (formula 2) had better correlation than Cole's formula with a 73% agreement with the correct ETT sized tube. The bias too was lower at – 0.02. We also derived a formula based on age using regression analysis and found that ETT ID is 3.75 + age/4 and OD of 0.34 × age in years+5.17. Shibasaki *et al*. had derived an age-based formula as OD = 0.03 × age in months+5.4. age in months+5.4.[4] This finding perhaps indicates that locally derived formulae may be more dependable than one universal rule, and underlines the importance of ethnic and geographic differences in predicting airway size.

We also found height and weight correlate poorly with the actual ETT size placed. This was similar to the findings of Shibasaki *et al*.[4] Singh *et al*. found that subglottic measurement done with ultrasound as well as diameter of right little finger had a very high rate of prediction and correlation with correct ETT size in Indian children.[10] Another study done on Indian children between the ages of 1 and 8 years by Kumar *et al*. found a high correlation between length of the child and the correct ETT chosen while there was poor correlation with age of the child.[11] Gupta *et al*. found a higher correlation between ultrasound-derived subglottic diameter than age based-formula in predicting the correct size of ETT among Indian children.[12] Subramanian *et al*. found age to correlate well with clinically optimum ETT placed. Age-based formula (age/3 + 3.5) predicted correct ET size in 59% of patients. They also opined that age-based formula differs based on ethnicity of the child; therefore, ETT size for Indian children needs to be on locally developed formulae.[13]

Ultrasound can only aid in measuring the transverse diameter of the subglottic region. The anteroposterior (AP) diameter cannot be measured as the air in the trachea prevents the visualisation of the posterior tracheal wall. Lakhal *et al*. assessed the AP and transverse diameter of the cricoid region by using MRI in 19 healthy adult volunteers and found that the mean transverse diameter (15 ± 2 mm) is narrower than the mean anteroposterior diameter (19 ± 3 mm) at the cricoid region. He also demonstrated good correlation between ultrasound measurements and MRI measurements of cricoid region. Thus, the transverse diameter of the cricoid region represents the narrowest measure of the trachea and is adequate for selecting the outer diameter of appropriate ETT.[6]

The disadvantage of using US is that it is operator dependent. However, we feel that this limitation can be overcome by practice. The learning curve for airway assessment by ultrasound is very short, and plateaus by 15–20 examinations. It also provides accurate measurements in a very short time. In our study, we took less than 1 min (data not presented) to perform each assessment. Hyoid is the only calcified bone in a child's larynx.[14] As the child grows older, cartilaginous structures like thyroid, cricoid and trachea undergo calcification resulting in acoustic shadowing and interference with image acquisition.[15] Hence, ultrasonographic assessment is more valuable in the younger age group (<8 years). This is the age group wherein selection of ETT size is difficult.

The limitation of our study was that we have not tested the formula what we have derived in paediatric population and we have used the ETT provided by a single company.

## CONCLUSION

In conclusion, US-measured subglottic diameter correlates with the actual tracheal tube used and may be useful in choosing the appropriate size ETT. Locally derived age-based formulae are more reliable than the standard Cole's formulae. We found that the ETT size predicted by age-based formula that was derived in this study (age/4 + 3.75), the formula used in our institution (Age/3 + 3.5) as well as US derived measurements for outer diameter (0.87 × U/S measured diameter) – 0.47 were similar. Therefore, it is our opinion that there is no advantage in ultrasound measurement.

### Declaration of parent consent

The authors certify that they have obtained all appropriate parent consent forms. In the form, the parent/s have given their consent for their child's images and other clinical information to be reported in the journal. The parents understand that their child's names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Nil.

### Conflicts of interest

There are no conflicts of interest.

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