The role of ultrasound in appropriate endotracheal tube size selection in pediatric patients

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Section Editor: Britta von Ungern-Sternberg

Summary

Background: The aim of this prospective study was to investigate the success of ultrasound in pediatric patients in determining the appropriate sized cuffed endotracheal tube and to compare the results with conventional height-based (Broselow) tape and age-based formula tube size.

Methods: One hundred and fifty-two children of 1-10 years of age, who received general anesthesia for adenotonsillectomy were enrolled to the study. In all participants, the transverse diameter of the subglottis was measured with ultrasound during apnea. An endotracheal tube was chosen with the outer diameter matched to the measured subglottic airway diameter. An age-based (Motoyama-Khine) and height-based (Broselow) endotracheal tube size was calculated. If there was resistance to passage of the tube into the trachea or an airway pressure >25 cmH₂O was required to detect an audible leak, the endotracheal tube was replaced with internal diameter of 0.5 mm smaller. If there was an audible leak at airway pressure <10 cmH₂O, or peak pressure >25 cmH₂O or a cuff pressure > 25 cmH₂O was required to seal, the tube was changed to the 0.5 mm larger internal diameter. Best-fit tube internal diameter was the resultant tube internal diameter that met the previously stated conditions. The need for endotracheal tube replacement and peak airway pressure were recorded.

Results: The internal diameter of ultrasound determined tube was the same as best-fit tube in 88% of children. Endotracheal tube was replaced in 15 patients with a one size larger, and in three patients with one size smaller tube. Using Bland-Altman analysis, a better agreement was observed with ultrasound measurement rather than height-based estimation and age-based formulas.

Conclusion: Our findings show that subglottic diameter measured by ultrasound appears to be a reliable predictor for the assessment of the subglottic diameter of the airway in estimating appropriate size pediatric endotracheal tube.

KEYWORDS
child<age, endotracheal tube, measurement, tube size, ultrasound
1 | INTRODUCTION

Choosing the "best-fit" endotracheal tube is crucial in pediatric patients to provide optimum ventilation without any laryngotraheal damage. For this purpose, various formulas based on the demographic characteristics (weight, age, height, and finger size) have been developed, but none has been fully successful in predicting the optimum endotracheal tube (ETT) diameter. As these formulas do not reflect individual variations in internal organ growth, determining appropriate ETT diameter is still a challenge for anesthesiologists and may result in several intubation attempts and unnecessary tube changes.

The aim of this prospective clinical study was to investigate the success of ultrasound in pediatric patients in determining the appropriate size of cuffed ETT and to compare the results with estimated conventional height-based (Broselow) tape and age-based formula tube size.

2 | MATERIALS AND METHODS

After obtaining Ethics Committee approval (No: 1854276) and written informed consent of parents, children (ASA I-II) aged between 1-10 years who received general anesthesia for adenotonsillectomy were enrolled in this study. Exclusion criteria were previous history of tracheostomy, tracheal and laryngeal pathologies, pulmonary disease including airway hyperreactivity or bronchial asthma, anticipated difficult airway, and with body mass index above the 85th percentile (overweight) and less than the 5th percentile (underweight).

After premedication with oral midazolam of 0.5 mg kg\(^{-1}\), the child was taken to the operating room and standard monitoring (EKG, SPO\(_2\), noninvasive arterial pressure) was applied. General anesthesia was induced by inhalation of sevoflurane at 6%-8% in O\(_2\)/N\(_2\)O (50/50%) mixture. Intravenous fentanyl 1 μg kg\(^{-1}\) and mivacurium 0.2 mg kg\(^{-1}\) was administered to facilitate mask ventilation and intubation.

One anesthesiologist was dedicated to patient care, whereas another anesthesiologist blind to exact demographic data and experienced in airway ultrasound (DA) measured the transverse diameter of the subglottic airway in brightness (B) mode using a 12 MHz linear probe (GE Healthcare LOGIQ e ultrasound) with patients supine and the head in neutral position. During mask ventilation, the probe was placed in the middle of the anterior neck region and moved caudally to observe the cricoid cartilage and vocal cords visualization. Subglottic airway diameter, defined as the hyperechoic shadow of transverse air column diameter at the level of the cricoid cartilage, was measured during apnea (Figure 1). Tracheal intubation was performed with the same brand of cuffed ETT (Rüsch Super Safety Clear, Teleflex Medical, Kernen, Germany), the outer diameter (OD) of which was matched as the closest size to the measured subglottic airway diameter. If there was a resistance to passage of the tube into the trachea or an airway pressure >25 cmH\(_2\)O was required to detect an audible leak, the tube was replaced with internal diameter (ID) 0.5 mm smaller one prior to inflation of the cuff. Cuff inflation was measured (Shiley™ Pressure Control, Covidien, Germany) and limited to 25 cmH\(_2\)O. Mechanical ventilation was initiated with 10 mL/kg tidal volume and a frequency to keep ETCO\(_2\) between 34 and 38 mm Hg. Peak airway pressure was recorded and the tube was changed to the nearest larger size (0.5 mm larger ID), if there was an audible leak at airway pressure <10 cmH\(_2\)O, or peak pressure >25 cmH\(_2\)O or a cuff pressure >25 cmH\(_2\)O was required to seal. Best-fit tube ID was defined as the tube ID that fulfilled all aforementioned criteria. The need for ETT replacement was recorded. Height-based ID according to modified Broselow tape as well as age-based ID according to Khine formula in children <2 years old and Motoyama formula in children ≥2 years old was calculated in all participants.

2.1 | Statistical analysis

Quantitative data were expressed as mean±standard deviation (SD). The qualitative data were presented as the number of cases and

What is already known

- Clinicians have used various formulas depending on demographic measurements, such as weight, age, height, and finger size, for choosing the "best-fit" endotracheal tube in pediatric patients. But none has been fully successful in predicting the optimum diameter.

What this article adds

- Ultrasound-measured subglottic airway diameter when matched to outer diameter of the cuffed tube provides a better fit than age- and height-based formulas.
percentage. Linear regression was used to test the association between ultrasound, age-, and height-based methods in pairs. Bland-Altman analysis was used to further assess the similarity of methods, and range of agreement was defined as mean bias ±2 SD.

### 2.2 Sample size calculation

Bland and Altman recommend at least 100 patients to be included in the analysis so as to calculate 95% confidence interval (CI)±0.34 s where s is the SD of the differences between measurements by the two methods. After taking into account our clinic’s number of expected adenotonsillectomy operations per month, we decided to include at least a 6-month period (September 2015 and March 2016) to recruit the minimum number of patients.

## 3 RESULTS

One hundred and seventy-one patients were screened. Parents refused consent in nine children. Previous airway surgery or laryngotracheal pathologies in eight children and airway hyperreactivity in two children resulted in the analysis of 152 patients.

Demographic data of the patients and peak airway pressures are presented in Table 1. The internal diameter of ultrasound determined tube (US ID) was the same as best-fit tube in 88% of children. Originally inserted tube size was elevated to one size larger in 14 patients and decreased one size smaller in 4 patients.

The agreement between different methods is shown in Figure 2. Best-fit tube ID and ultrasound estimated ID were correlated (R²=0.926) with the formula best-fit ID=0.225×(0.96×US ID). In Bland-Altman analysis, the 95% limits of agreement between best-fit ID and US ID ranged from −0.29 to 0.37 mm with a bias of 0.04 mm (Figure 2A). The calculation for the association between best-fit tube ID and Broselow tape estimated tube ID (B.T. ID) revealed the formula best-fit ID=0.911×(0.781×B.T. ID) with R²=0.793. For these two variables, Bland-Altman analysis with the 95% limits of agreement ranged from −0.79 to 0.46 mm and a bias of −0.16 mm (Figure 2B). Lastly, best-fit tube ID and age estimated ID (Age ID) were correlated (R²=0.695) and the formula was best-fit ID=0.655×(0.827×Age ID). Bland-Altman analysis revealed 95% limits of agreement between −0.9-0.5 mm and a bias of −0.2 mm (Figure 2C). The best-fit ID is plotted against other methods in Figure 3 to demonstrate the frequency of tube exchange requirements.

### TABLE 1 Demographic data of the patients and peak airway pressures

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean ± SD (min-max)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (year)</td>
<td>5.5±2.3 (1-10)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>20.7±6.1 (9-34)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>116±14.1 (75-137)</td>
</tr>
<tr>
<td>PAP (cmH2O)</td>
<td>17.8±2.7 (13-25)</td>
</tr>
</tbody>
</table>

PAP, peak airway pressure. Data were given as mean±SD (min-max).

### 4 DISCUSSION

Clinicians have used various formulas depending on demographic measurements such as age and height for pediatric endotracheal tube size selection, but these methods are not accurate and may produce conflicting results. Recently, ultrasound has been shown as a reliable, noninvasive method to evaluate the airway diameter, and several studies have investigated the role of ultrasound to guide ETT size selection in pediatric population (Table 2). Our study differs from aforementioned studies, as we directly converted measured subglottic airway diameter to appropriate cuffed tube ID, rather than calculating a bulky formula and compared the best-fit ID with age- and height-based estimations.

Ultrasound measurements reveal airway diameter and hence tube ODs and need to be converted to tube IDs. It should be kept in mind that tube OD for a given ID differs among individual brands.

There are two possible pitfalls while using direct ultrasound measurement of subglottic airway for cuffed tube size selection, ie, under or overestimation of tracheal diameter. In children, the subglottic anteroposterior (AP) diameter is slightly larger than the transverse diameter. As air shadow limits the assessment of AP diameter by ultrasound, measurement of transverse diameter at this level may explain why ultrasound underestimates actual tracheal diameter. Underestimation would lead to placement of a smaller ETT, resulting in higher resistance to airflow and higher peak pressures. However, underestimation may also offer a clinical advantage in cuffed ETT size selection. Because, although printed OD of cuffed and uncuffed ETT by the manufacturer are same, effective OD of cuffed tubes include an additional element, ie, the deflated cuff bulk.

In our study, we needed to replace the tube by a larger one in a small number of patients with 88% first attempt success. In contrast, Bae et al used a formula-derived tube ID from ultrasound-measured subglottic diameter with presence of air leak and showed that it was superior to age-based formula with 60% success in selection of correct uncuffed ETT size. Interestingly, in 40 patients where ultrasound method was unsuccessful, ultrasound frequently underestimated ETT size (31 patients out of 40). Schramm et al also studied uncuffed ETT and showed a lower success rate with ultrasound (48%) in a younger population. Kim et al also concluded that ultrasound measurement was helpful in choosing actual ETT size, although they did not pursue a “best-fit” sized tube and therefore did not give a success rate. In this study, the authors observed that in a small portion of patients, ultrasound underestimated ETT size. Shibasaki et al reported a high success rate (98%) using a regression equation of “ETT outer diameter (OD)=0.46×subglottic diameter+1.56”. Overestimation of tracheal diameter, hence overestimation of the maximum allowable ETT OD, may result in laryngotracheal damage. But, as ultrasound measurements are performed at a relatively narrow segment of the pediatric airway, such a complication would be less likely. We only needed to change the endotracheal tube to one size smaller in four of our patients.
In this study, ultrasound measurement guided ETT size selection resulted in generally smaller diameter tubes when compared to age-based formulas. Similarly, Shibasaki et al who also used Khine and Motoyoma formula demonstrated that age-based formulas computed larger ETT sizes than clinically appropriate.\(^{14}\) This is not surprising as age-based formulas may be limited in reflecting internal organ development variations. Another possible explanation for smaller tubes with ultrasound measurement is the previously discussed underestimation of tracheal diameter by ultrasound.

The Broselow tape has been developed for pediatric emergencies to predict body weight in order to estimate drug dosage as well as equipment sizes including ETT. This height-based ETT determination has been shown to be superior when compared to age-based calculations in uncuffed tubes.\(^{7,20}\) Interestingly, although recent modifications of the tape also notes sizes for cuffed tubes,\(^{4}\) no study has yet compared these recommended sizes with clinically appropriate tube sizes. Our results show that the Broselow tape was in better agreement with ultrasound measurements than age-based calculations. Hofer et al also reported a better match with the Broselow method than age-based calculations in uncuffed ETT selection.\(^{20}\)

Our study can be criticized for reporting a higher tube exchange rate than by some reported previously in literature.\(^{1,21,22}\) One explanation for this can be the possible underestimation of airway diameter by ultrasound measurements. Another explanation is the use of different settings to determine the appropriateness of tube size and different tube design,\(^{21,22}\) heterogeneous tube use,\(^{1}\) different population age,\(^{1,21,22}\) acceptance of leakage, and the use of throat packs.\(^{21}\) Interestingly, Azarfarin et al\(^{23}\) reported a higher tube exchange rate than ours in noncardiac surgical children again with different settings.
It can be argued that ultrasound measurements are operator dependent. However, ultrasound is documented to be an easily learned technique. Indeed, Lakhal et al have shown that 15 laryngeal ultrasound examinations are needed for reliable and reproducible measurements.

Our results cannot be extrapolated to uncuffed tubes. Cuffed endotracheal tubes are preferred in our institution for adenotonsillectomy operations to reduce the risk of aspiration and to prevent contamination of the atmosphere by volatile anesthetics.

One limitation of our study is that we did not investigate the incidence of respiratory complications such as postextubation stridor and laryngospasm. However, reported incidence of respiratory complications in adenotonsillectomy is relatively high and it would be difficult to differentiate if the complication was a result of mismatched ETT size or surgery itself. Another limitation of our study is the age range of children included in the study. We did not include children younger than 12 months as Kim et al had already observed a poor correlation between demographic parameters and ultrasound measurements at this age population. As ossification and calcification of laryngeal cartilages may hinder ultrasound measurements, we did not include children older than 10 years. We also did not include children with a history of difficult intubation or existing anatomical malformations.

In conclusion, our findings show that ultrasound appears to be a reliable predictor for the assessment of the subglottic diameter of the airway in children to estimate the appropriate size ETT for intubation. Ultrasound use in pediatric airway has promising clinical applications such as evaluation of subglottic airway narrowing, vocal cord movement, or prediction of difficult airway. Further studies would be needed to evaluate the usefulness of ultrasound in such settings.

CONFLICT OF INTEREST

No conflicts of interest declared. Institutional Ethics Committee Approval: 2015/1854276; Government Ethics Committee Chair: Dr. Arslan Kağan Arslan.

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