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Prediction of endotracheal tube size using airway ultrasonography and correlation with traditional formulas in pediatric patients undergoing cardiac surgery

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Abstract

Accurate endotracheal tube (ETT) size selection is essential in pediatric patients undergoing cardiac surgery to minimize airway trauma and post-extubation complications. Traditional weight- and height-based formulas often fail to provide reliable predictions, necessitating the use of alternative methods, such as airway ultrasonography (USG). This study aims to assess the predictive effectiveness of USG in determining ETT size compared to conventional formulas. This prospective, single-center study included 20 pediatric patients younger than one year of age undergoing cardiac surgery. Preoperative ETT size predictions were obtained using USG, weight-based, and height-based formulas. The clinically applied ETT size was recorded, and statistical analyses, including correlation analysis, multivariate logistic regression, and Bland-Altman analysis, were performed to compare predictive accuracy. USG-predicted ETT sizes showed complete agreement with the clinically used ETT in all cases (100%), demonstrating a perfect correlation ($r=1.00$, $p<0.001$). The weight-based formula correctly predicted the clinical ETT size in 50% of cases ($r=0.48$, $p=0.03$), while the height-based formula had the lowest accuracy, with a match rate of 40% ($r=0.38$, $p=0.08$). Bland-Altman analysis confirmed that USG measurements exhibited the minimal bias and the tightest limits of agreement in comparison to conventional formulas. Airway ultrasonography is a superior and highly accurate method for predicting optimal ETT size in pediatric cardiac surgery patients, outperforming traditional weight- and height-based formulas. USG should be considered a standard tool in pediatric anesthesia to enhance airway management and reduce complications associated with incorrect ETT sizing.

Keywords: Airway ultrasonography, pediatric anesthesia, endotracheal tube size, cardiac surgery, predictive accuracy

Introduction

Selecting the optimal endotracheal tube (ETT) size in pediatric patients is significantly more critical than in adults. An oversized ETT can cause airway trauma, increasing the risk of post-extubation stridor and subglottic stenosis. Conversely, an undersized ETT may increase airway resistance, elevate aspiration risk, lead to inadequate ventilation, impair end-tidal gas monitoring, and necessitate reintubation with a different tube size [1]. In pediatric patients undergoing cardiac surgery, where prolonged postoperative intubation is common, accurate ETT size selection becomes even more crucial.

Age-based formulas do not accurately reflect true tracheal diameter and often necessitate repeated laryngoscopies to identify the correct ETT size. To minimize unnecessary airway instrumentation and reduce trauma risk, pre-anesthetic tracheal diameter assessment is essential. A high rate of tube exchange and prolonged intubation may further increase the risk of hypoxia and aspiration [2]. In infants and neonates, age-based tube sizing formulas are unreliable, and alternative weight- and height-based formulas may be required.

Airway ultrasonography provides detailed imaging of the upper airway, including the thyroid cartilage, vocal cords, and

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trachea. Ultrasonography (USG) is a trustworthy, effective, non-invasive, and painless imaging method that enables real-time assessment of the narrowest transverse diameter of the subglottic airway, assisting in the determination of the optimal ETT size. Additionally, USG has been shown to accurately confirm ETT placement and depth [3,4].

The accuracy and reliability of ultrasound measurements may depend on the experience of the operator. However, studies have demonstrated that with proper training and experience, anesthesiologists can obtain accurate airway ultrasonographic measurements and reliable tracheal inner diameter assessments [5,6].

Although USG provides potential advantages, its exact accuracy in predicting the optimal ETT size for pediatric cardiac surgery patients remains to be fully confirmed. Given the challenges of mechanical ventilation during the perioperative period and the risks of post-extubation complications, accurate ETT size selection is of utmost importance in pediatric cardiac patients. Hence, this study seeks to assess the predictive efficacy of airway ultrasonography in determining ETT size in pediatric cardiac surgery and to compare USG measurements with ETT sizes determined using weight- and height-based formulas in infants and neonates.

Material and Methods

This single-center, prospective study was conducted between February 1, 2024, and February 1, 2025, in the Departments of Anesthesiology and Reanimation, Pediatric Cardiac Surgery, and Pediatric Cardiology at our hospital. The study included all pediatric patients younger than one year of age undergoing cardiac surgery due to congenital heart disease, regardless of sex.

Exclusion criteria:

- Patients with any respiratory condition that may lead to airway constriction,
- Patients with pre-existing laryngeal or tracheal abnormalities or fibrosis that may impact airway structure,
- Patients with anticipated difficult airways,
- Syndromic patients,
- Patients undergoing emergency surgery.

After obtaining written informed consent, a routine pre-anesthetic evaluation was performed, and a total of 20 patients (male and female) with normal airway anatomy were included in the study.

Upon arrival in the operating room, patients underwent regular monitoring with electrocardiography (ECG), non-invasive blood pressure, and pulse oximetry prior to the administration of induction agents. The anesthetic induction protocol included:

- Midazolam (0.1 mg/kg)
- Fentanyl (1 µg/kg)
- Ketamine (1 mg/kg)
- Rocuronium bromide (0.6 mg/kg)

Additionally, cefazolin (30 mg/kg, IV) and methylprednisolone (3 mg/kg, IV) were administered as standard prophylactic medications.

Following induction, an experienced anesthesiologist performed airway ultrasonography on each patient while they were positioned on the operating table. The anesthesiologist conducting the ultrasound assessments had undergone prior training in infant airway ultrasonography before the study, ensuring consistency in measurement accuracy.The learning curve for USG-guided tracheal diameter measurement from the previous studies is about 12–15 [7]. We did 20 cases before the start of the study.

After muscle relaxation and manual mask ventilation, a linear hockey-stick ultrasound probe was placed transversely below the larynx to measure the transverse air column diameter at the lower border of the cricoid cartilage, which was recorded as the tracheal diameter [8]. The air shadow created by the tracheal inner walls was used to determine the appropriate tracheal diameter (Figure 1).

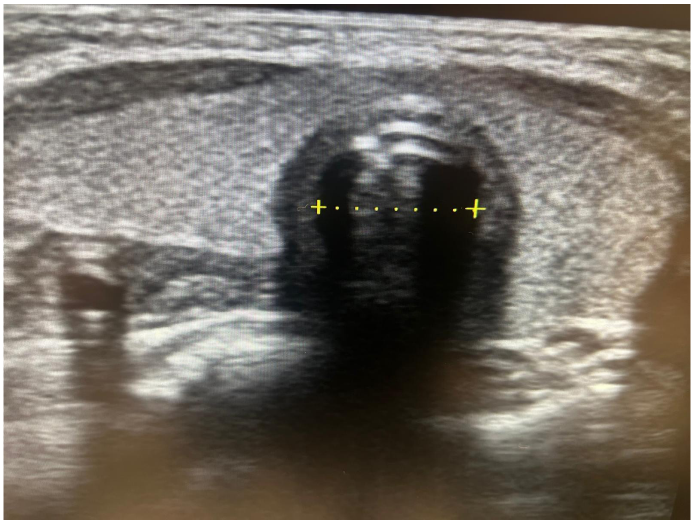

Figure 1. Ultrasonographic measurement of the transverse subglottic diameter of the cricoid cartilage

Following ultrasound assessment, patients underwent laryngoscopy and were intubated with an uncuffed ETT. The measured tracheal diameters and the actual ETT sizes used in clinical practice were recorded. Additionally, ETT sizes were estimated preoperatively using the following formulas [2,9,10];

- **Weight-based formula:** ETT internal diameter (mm) = 4+(Weight (kg)×0.1)
- **Height-based formula:** ETT internal diameter (mm) = 2+(Height (cm)/30)

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All demographic data, recorded ETT sizes, and tracheal diameter measurements were documented in a standardized tracking form. Correlations between the measured and estimated values were then analyzed.

This study was carried out in accordance with the Declaration of Helsinki and received approval from the University of Health Sciences Türkiye, Başakşehir Çam and Sakura City Hospital Local Ethics Committee (Approval Number: 24.04.2024.269, Date: 24.04.2024).

Statistical Analysis

The statistical analysis was conducted using NCSS (Number Cruncher Statistical System) 2007 software. Descriptive statistics, such as mean, standard deviation, and median, were applied to summarize the data. The Pearson correlation coefficient was utilized to evaluate the association between the clinically applied ETT size and the predicted sizes from various methods. Correlation strength was categorized as follows: weak (0.00–0.30), moderate (0.30–0.70), and strong (0.70–1.00). A p-value of <0.05 was considered statistically significant.

Multivariate logistic regression analysis was performed to assess the predictive accuracy of different estimation approaches. Odds ratios (OR) and 95% confidence intervals (CI) were calculated to determine the strength of the relationship between each method and the clinical ETT size.

A Bland-Altman analysis was applied to evaluate the agreement between the predicted and actual ETT sizes. This method illustrated bias and the limits of agreement for each approach, providing insight into variations in predictive accuracy.

These statistical techniques facilitated an objective comparison of airway ultrasonography, weight-based, and height-based formulas in determining the most appropriate ETT size for pediatric patients undergoing cardiac surgery.

Results

A total of 20 infant patients undergoing cardiac surgery were enrolled in this study. The demographic and clinical characteristics of the study population are summarized in Table 1. The mean age of the patients was 6.55±3.79 months, with an average weight of 6.92±1.56 kg and a height of 68.10±9.25 cm. The median cardiopulmonary bypass (CPB) duration was 112.10 minutes (range: 48–221 minutes).

The predicted uncuffed ETT sizes using airway USG, weight-based, and height-based formulas were compared with the clinically used ETT sizes (Table 2). USG-based predictions showed complete agreement with the ETT sizes used in clinical practice in all cases (100%). In contrast, the weight-based formula correctly predicted the clinical ETT size in 50% of cases, whereas the height-based formula matched in 40% of cases.

The statistical analysis revealed a strong correlation between USG-predicted ETT sizes and the clinically applied ETT sizes (r=1.00, p<0.001). In comparison, the weight-based formula exhibited a weaker correlation (r=0.48, p=0.03), and the height-based formula showed the lowest correlation (r=0.38, p=0.08), indicating poor predictive performance.

Multivariate logistic regression analysis further confirmed these findings (Table 3). USG measurement showed a perfect fit with clinical ETT sizes. The weight-based formula had an OR of 1.02 (95% CI: 0.85-1.21, p=0.58), while the height-based formula had an OR of 0.94 (95% CI: 0.78-1.12, p=0.26), both demonstrating no statistically significant predictive ability.

Bland-Altman analysis revealed that USG-based predictions exhibited minimal bias and the tightest limits of agreement with clinical ETT sizes. The weight-based and height-based formulas showed wider variability and larger biases, further supporting the superiority of USG in accurately determining ETT size.

These findings indicate that airway ultrasonography is the most dependable approach for determining the optimal ETT size in pediatric cardiac surgery patients, surpassing conventional weight- and height-based formulas.

Table 1. Demographic and clinical variables for patients

	Mean±SD	Median (Min-Max)
Age (months)	6.55±3.79	5.75 (1.5-12)
Weight (kg)	6.92±1.56	6.5 (4.5-9)
Height (cm)	68.10±9.25	67.5 (53-80)
CPB time (min)	112.10±52.71	101 (48-221)
Procedure	**n**	**%**
VSD/AVSD repair	7	35
Total repair of TOF	5	25
Glenn shunt	5	25
Valve repair	3	15

CPB: cardiopulmonary bypass, VSD: ventricular septal defect, AVSD: atrioventricular septal defect, TOF: tetralogy of Fallot, SD: standard deviation

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Table 2. Predicted and clinically used ETT sizes for each case

Case	Predicted ETT size by USG measurementm il	Predicted ETT size by weight-based formula	Predicted ETT size by height-based formula	ETT size used in clinical practice an ETT no
Case 1	4.5	4.5	4	4.5
Case 2	4.5	4.5	4.5	4.5
Case 3	4	4.5	4	4
Case 4	5	4.5	4.5	5
Case 5	4.5	5	4	4.5
Case 6	4.5	4.5	4	4.5
Case 7	4.5	4.5	4	4.5
Case 8	5	4.5	4.5	5
Case 9	5	5	5	5
Case 10	4.5	5	4.5	4.5
Case 11	4.5	4.5	4.5	4.5
Case 12	4.5	4.5	4	4.5
Case 13	5	4.5	4.5	5
Case 14	4	4.5	4	4
Case 15	4.5	4.5	4	4.5
Case 16	5	5	5	5
Case 17	4.5	5	4	4.5
Case 18	4.5	5	4.5	4.5
Case 19	5	4.5	4.5	5
Case 20	4.5	4.5	4	4.5

ETT: endotracheal tube; *Values that do not match the clinical ETT number are marked in red

Table 3. Multivariate logistic regression analysis of the agreement between predicted and clinical ETT sizes

Variables	p	Odds ratio	95% confidence interval
USG measurement	**<0.000**	Perfect Fit	-
Weight-based formula	0.58	1.02	0.85-1.21
Height-based formula	0.26	0.94	0.78-1.12

USG: ultrasonography, ETT: endotracheal tube

Discussion

The accurate selection of ETT size is critical in pediatric patients, especially those undergoing cardiac surgery, as it is associated with the risk of prolonged intubation and airway complications. This study demonstrated that airway USG provides a highly accurate method for predicting ETT size, showing complete agreement with the clinically applied ETT in all cases. In contrast, traditional weight-based and height-based formulas exhibited limited predictive accuracy, confirming findings from previous studies [11-13].

Our results align with those of Shibasaki et al., who demonstrated that USG could reliably measure the subglottic tracheal diameter and improve ETT selection accuracy [2]. Similarly, Bharathi et al. reported that USG-based ETT predictions were superior to age-based formulas in pediatric patients [1]. The strong correlation between USG-measured diameters and the actual clinical ETT sizes in our study further supports the notion that direct anatomical measurement is superior to estimations based on demographic parameters [14,15].

Conversely, our findings indicate that weight- and height-based formulas, while commonly used, may not provide sufficiently accurate ETT size predictions. The weight-based formula correctly predicted clinical ETT size in only 50% of cases, and the height-based formula was even less accurate, aligning with prior research highlighting the limitations of these methods [16]. Factors such as variations in tracheal diameter, individual growth patterns, and ethnic differences may contribute to these inconsistencies [11].

Bland-Altman analysis confirmed the superior agreement of USG-based predictions with clinical ETT sizes, showing the least bias and narrowest limits of agreement compared to weight- and height-based formulas. These findings are consistent with reports by Lakhal et al., who found that USG estimates had higher precision compared to formula-based methods [7]. Additionally,

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studies by Kim et al., Su et al. and Altun et al. emphasize the advantages of USG over conventional estimation formulas in pediatric anesthesia [8,11,16].

Limitations

Although this study has notable strengths, certain limitations should be acknowledged. First, the study was carried out at a single center with a relatively small sample of 20 patients, which may restrict the generalizability of the results. Secondly, all measurements were carried out by a single experienced anesthesiologist, which might have minimized interobserver variability but also restricted the applicability of the findings to wider clinical settings. Future research should focus on validating these results through multicenter studies with larger sample sizes and assessing interobserver variability in USG-based airway evaluations.

Conclusion

Given its high accuracy, non-invasive nature, and ease of real-time application, airway ultrasonography should be considered a standard tool for ETT size prediction in pediatric patients, particularly those undergoing cardiac surgery. Future research should also explore whether incorporating USG measurements into predictive models alongside demographic factors could further refine ETT size selection.

Conflict of Interests
The authors declare that there is no conflict of interest in the study.

Financial Disclosure
The authors declare that they have received no financial support for the study.

Ethical Approval
This study was carried out in accordance with the Declaration of Helsinki and received approval from the University of Health Sciences Türkiye, Başakşehir Çam and Sakura City Hospital Local Ethics Committee (Approval Number: 24.04.2024.269 Date: 24.04.2024).

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