Original Article

Usefulness of Ultrasound-guided Measurement of Minimal Transverse Diameter of Subglottic Airway in Determining the Endotracheal Tube Size in Children with Congenital Heart Disease: A Prospective Observational Study

Abstract

Introduction: The search for an accurate and predictable method to estimate the endotracheal tube (ETT) size in pediatric population had led to derivation of many formulae. Of this, age-based formulae are the most commonly used. Studies have shown that minimal transverse diameter of subglottic airway (MTDSA) measurements using a high-frequency probe improves the success rate of predicting the airway diameter to about 90%. We did a prospective observational study using MTDSA as the criteria to select the size of ETT in children with congenital heart disease. **Methods:** In this prospective observational study, 51 children aged from 1 day to 5 years, scheduled for cardiac surgery, were enrolled for this study. The ETT size was guided solely based on the MTDSA. Leak test was used to determine the best-fit ETT size. **Results:** Data from 49 patients were analyzed. Agreement between the ETT determined by MTDSA and that predicted by Cole's age-based formulas with the best-fit ETT size was analyzed using a Bland–Altman plot. **Conclusion:** Age-based formula showed poor correlation (27.5%) compared to MTDSA (87.8%) in predicting the best-fit ETT. We observed that pediatric patients with congenital heart disease need a larger sized ETT as compared to what was predicted by age-based formula. Using ultrasound MTDSA measurements to guide selection of ETT size is a safe and accurate method in pediatric cardiac population.

Keywords: *Endotracheal tube, minimal transverse diameter of subglottic airway, ultrasound*

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Introduction

Predicting the correct size of endotracheal tube (ETT) is often difficult in the pediatric population.[1] Various formulae and anthropological measurements using age, crown-heel length, height, and width of fifth fingernail have been used.[2] Age-based formulae are most commonly used and show a variable success rate ranging from 47% to 77%.[3,4] An undersized ETT results in insufficient ventilation, unreliable end-tidal gas monitoring, operating room pollution, and increased medical gas cost and presents a potential risk for aspiration. Conversely, a larger tube can cause trauma and postoperative stridor and may result in subglottic granulomas and stenosis. Ultrasound (USG) measurement of minimal transverse diameter of subglottic airway (MTDSA) is a relatively recent modality used for predicting the size of ETT.[5] Despite a success rate of about 90%, MTDSA has not been used as a primary criterion for ETT selection.[6] Patients with congenital heart disease coming for palliative or corrective surgery present a few unique problems including an increased incidence of airway anomalies (3%),[7] prolonged postoperative ventilation, and poor lung compliance requiring higher inspiratory pressures. Transesophageal echocardiography probe insertion has been known to cause airway obstruction[8-10] and leak, especially with an undersized ETT. Multiple laryngoscopic attempts to change to an appropriately sized tube can compromise patient's hemodynamic status and precipitate pulmonary hypertensive crisis and cyanotic spells. To the best of our knowledge, it is the first study to use USG-derived MTDSA for selection of ETT size in pediatric cardiac population.

Methods

This prospective observational study was approved by the Institutional Review

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Board and Ethics Committee. Inclusion criteria were children <5 years of age with congenital heart defects coming for cardiac surgery. Children with anticipated difficult airway and parental refusal were excluded from the study. Fifty-one children were included in the study. Written informed consent was obtained from the parent or legal guardian.

Method of image acquisition and endotracheal tube size prediction

Linear array high-frequency transducer (GE L8-18i) with a 25 mm hockey stick footprint was used for image acquisition in all cases. The probe was initially placed longitudinally [Figure 1a] to identify cricoid cartilage [Figure 1b]. The probe was then turned transversely [Figure 2] and the MTDSA measured at the level of lower border of cricoid cartilage at end inspiration (10 cm H_2O airway pressure). The outer diameters (ODs) of various sizes cuffed and uncuffed ETT (Portex) are shown in Table 1. We selected the ETT based on the OD closest to MTDSA and not more than the MTDSA. To eliminate bias, the person measuring the MTDSA was blinded to the age of the child.

All the children were induced with sevoflurane; fentanyl and rocuronium were used for neuromuscular paralysis. Measurements of MTDSA were taken at end-inspiratory phase by an independent anesthesiologist experienced in airway USG. The measured value was communicated to the attending consultant anesthetist, who selected the ETT based on MTDSA measurement. If there was resistance to pass the ETT through vocal cords, then 0.5 mm smaller size ETT was placed.[6,7] Uncuffed Portex tube was used in all cases except where prolonged ventilation (>24 h) was anticipated. In those cases, a microcuff ETT (Kimberly Clark) was used. Air leak following intubation was assessed (with head in neutral position) by the investigator blinded to both age and measured MTDSA. Tube size was considered best fit when a minimal tracheal leak was detected at an inflation pressure of 20 cmH_2O with either uncuffed tube or Kimberly Clark tube with the cuff deflated. If there was an audible leak at 10 cmH_2O, a larger size tube was inserted. No or minimal leak at 30 cm H_2O mandated downsizing as per the protocol.[1,2,6] Time taken for MTDSA measurement (i.e., from placement of probe to MTDSA is measured) and the number of attempts of intubation were also noted. Patient characteristics (age, gender, and weight) and other parameters were tabulated, compared, and statistically analyzed.

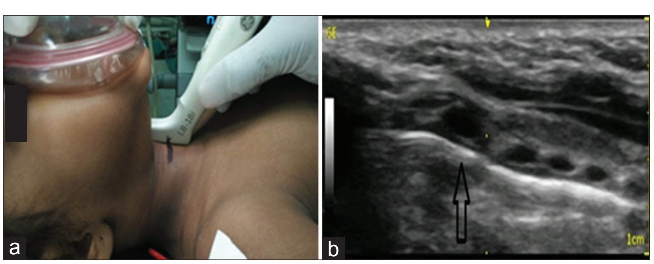

Figure 1: (a) Initial probe position to identify cricoid cartilage and (b) the arrow indicates cricoid cartilage

For each patient, the tube size was calculated according to Cole's formula[11] [Table 2]) and documented along with MTDSA and final ETT size.

Statistical analysis

Sample size

It was estimated that USG has a reliability of 96% as compared to age-based formula.[6] However, expecting an agreement of 80% which should significantly greater than

Table 1: External diameter of cuffed (Kimberly Clark) and uncuffed endotracheal tube (Portex)

Inner diameter (mm)	Uncuffed ETT	Cuffed ETT (outer diameter)
	Outer diameter (mm)	Cuff deflated (mm)
2.5	3.5	
3.0	4.2	4.3
3.5	4.8	5.0
4.0	5.5	5.6
4.5	6.2	6.3
5.0	6.9	
5.5	7.6	
6.0	8.2	
6.5	8.7	

ETT: Endotracheal tube

Table 2: Recommended internal diameter of tracheal tube

Tracheal tube size for infants and children according to age	Values are in mm
Neonate to 3 months	3.0
3-9 months	3.5
9-21 months	4.0
>21 months	Age (years)/4+4

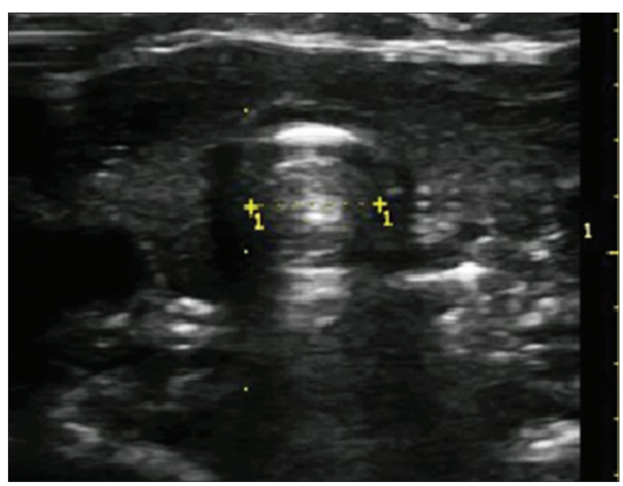

Figure 2: Minimal transverse diameter of subglottic airway measurement

the chance agreement of 50% with alpha and beta errors at 5% and 10%, respectively, we need to study about 36 children. Expecting 5% failure, we need to study about 50 children.

The scatter plot between predicted ETT size based on age and the best-fit ETT size was done. Similarly, the scatter plot between the ETT size based on MTDSA and the clinically best-fit ETT was also done. Bland–Altman plot of the difference between the predicted ETT size by age-based formula and best-fit ETT (final ETT) was drawn, and the bias index was computed. A similar graph was drawn based on the predicted ETT size based on USG and best-fit ETT. The intraclass correlations (ICC) between predicted ETT size by MTDSA and best-fit and predicted ETT size by age and best fit were computed. The percentage of error and bias index were calculated. The SPSS. IBM Corp. Released 2013. IBM SPSS Statistics for Windows, version 22.0. (Armonk, NY: IBM Corp.) and R software. R Core Team (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Learning curve

The learning curve for USG-guided MTDSA measurement from the previous studies is about 12–15.[5] We did 15 cases as pilot under radiologist's supervision before the start of the study.

Results

A total of 51 patients were enrolled for the study. Two patients were excluded during the study; one developed severe cyanotic spell and needed tracheal intubation before MTDSA measurement could be taken and the other child was found to have redundant subglottic tissue causing airway narrowing. Data from 49 patients were analyzed, of which 31 were males (63.3%) and 18 were females (36.7%). There were 28 infants, six were in the 1–2 years age group, and 15 were in the 2–5 years age group. Mean age and weight of the children were 19.43 ± 16.79 months and 8.08 ± 3.91 kg, respectively [Table 3]. Uncuffed ETTs were used in 90% of patients.

Table 3: Accuracy of ultrasound in different age groups

Age (years)	Number of patients	Weight (kg)*	Cases where two intubations are done	Success rate of USG (%)
0-1	28	5.27±1.86	5	82.1
1-2	6	9.58±1.4	1	83.3
2-3	9	11.44±1.87	0	100
3-4	4	14.5±1.29	0	100
4-5	2	15±0.0	0	100
Total	49	8.08±3.9	6	87.8

*Weight in Kg±2 SD. USG: Ultrasound

Agreement between best-fit endotracheal tube and the age-based prediction endotracheal tube

The scatter plot of best-fit ETT and ETT predicted by the age-based formula is presented in Figure 3a. The correlation between the two methods was 0.756 ($P < 0.001$). However, when the internal diameter is <4 mm, there is variability in the scatter. The Bland and Altman graph of the above two methods of estimation is presented in Figure 3b. The bias was 0.375. The graph suggested that the observations were evenly scattered irrespective of the range of final ETT values. However, the age-based formula in general underestimated the diameter, and therefore, most of the observations were above the zero line. The ICC was 0.747 ($P < 0.001$). The percentage of error was 23.5%.

Agreement between best-fit endotracheal tube and the prediction based on the minimal transverse diameter of subglottic airway

The scatter plot of best-fit ETT and ETT predicted by the MTDSA is presented in Figure 4a. The correlation between the two methods was 0.98 ($P < 0.001$). This implied that there is almost perfect correlation between the two methods. The Bland and Altman graph of the above two methods of estimation is presented in Figure 4b. The bias was 0.041. The graph suggested that the observations were evenly scattered irrespective of the range of final ETT values. The ICC was 0.98 ($P < 0.001$). The percentage of error was 7.8%.

Highest level of linear correlation was observed between ETT size predicted by MTDSA and the best-fit (final) ETT with a regression equation of the ETT OD of 0.88 × MTDSA + 0.32, $r^2 = 0.932$. Age in months also correlated with optimal ETT size in millimeters, although the correlation was weaker than for subglottic diameter with the ETT OD of 0.88 × age + 0.85, $r^2 = 0.572$.

Comparison of prediction methods with the correctly sized endotracheal tube

The rate of irrelevant difference between the correctly sized ETT (best fit) and the age-based formula with a maximum allowed deviation of ≤ 0.3 mm was 38.8% (95% confidence interval [CI] 25.1%–52.4%), while the USG-guided measurements correctly predicted the optimum-sized ETT in 89.8% (95% CI 81.3%–98.3%). Choice of ETT was determined as adequate if deviations were <0.3 mm from the OD of the correct ETT.

Comparison of prediction methods with the endotracheal tube of the correct size

ETT size determined by MTDSA was successful in predicting the best-fit ETT in 43 out of 49 instances with a success rate of 87.8% (95% CI 75.2%–95.4%). Had we used age-based formulae, the success rate would have been 13 out of 49, which is 26.5% (95% CI 14.9%–41.1%).

Subgroup analysis shows that the accuracy of USG was lower in infants and in children <2 years. The accuracy

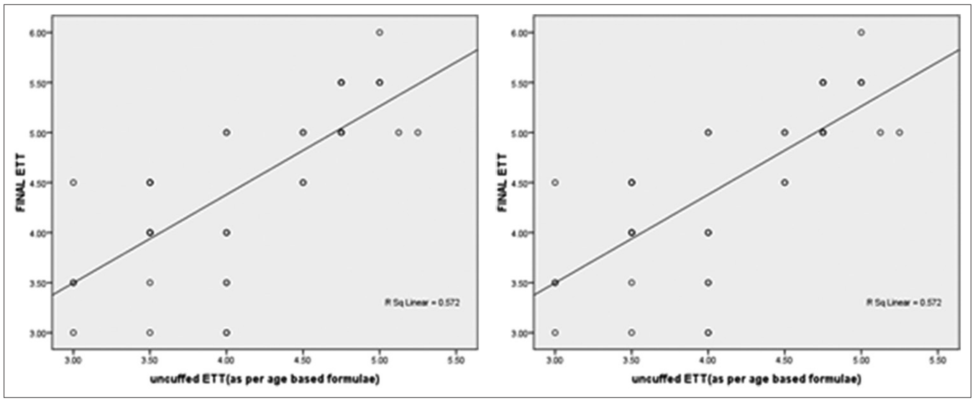

Figure 3: (a) The scatter plot of best fit ETT and ETT predicted by the age based formula. (b) Bland and Altman graph of best fit ETT and ETT predicted by the age based formula

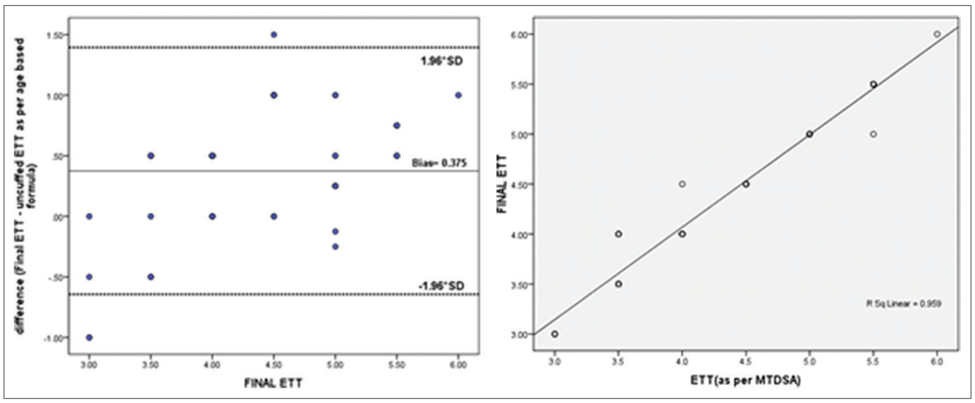

Figure 4: (a) The scatter plot of best fit ETT and ETT predicted by MTDSA. (b) Bland and Altman graph of best fit ETT and ETT predicted by MTDSA

was 100% in children between 2 and 5 years. However, the numbers are small to derive any meaningful interpretation.

The ICC for the best-fit ETT size and ETT predicted by MTDSA is 0.977, which is statistically significant ($P \leq 0.001$). This ICC indicates a substantial agreement between the final ETT size used and ETT predicted by MTDSA, while the ICC for the correct size ETT and ETT predicted by age-based formula is 0.747 which is statistically significant ($P \leq 0.001$). Correlation analysis showed a significant relationship between MTDSA and optimum-sized ETT, while age-based formula showed a particularly poor correlation in ETT <4.0 mm (1 year of age).

Discussion

Sonographic anatomy of the larynx and trachea in healthy children has been described in previous studies.[12] The sonographic appearance in children is characterized by a hyperechoic air mucosal interface and homogenous cartilage rings in the absence of calcification. These are surrounded by hypoechoic constrictor muscles and isoechoic thyroid tissue,[13] thus allowing transverse dimensions to be measured accurately using USG. Studies have identified the narrowest portion to be transverse diameter at the vocal cord in both spontaneously breathing and paralyzed pediatric airway.[14,15] The transverse diameters at both vocal cord and cricoid level are less than the corresponding anteroposterior diameter.[14] In paralyzed patients, the immobile vocal cords are difficult to image; moreover, angulation of the probe to improve resolution of the cords can introduce errors in accurate measurement of glottic transverse diameter. The cricoid being a relatively rigid, complete cartilaginous ring compared to the vocal cords should in practice be the limiting and hence predictive factor in selecting ETT size. In our study, none of the patients had resistance on passing ETT through vocal cords when measurements were based on MTDSA at the cricoid level. We surmise that in clinical practice, the triangular opening and pliability of the vocal cords and cricoarytenoid joints render the discrepancy between glottis and cricoid cross-sectional area insignificant.

Our study concurred with previous studies[1,2,6] in showing that MTDSA had significantly higher accuracy (87.8%) in predicting ETT size when compared to age-based formula (27.5%). Though the success of age-based formula in our study was comparable to Bae *et al*. and Schramm *et al*. (31% and 24%), our success rates were better when using MTDSA to predict the size of ET tubes.

MTDSA predicted the ETT size correctly in 100% of cases between 2 and 5 years, while age-based formula had a success of only 33%. In children between 1 and 2 years of age, MTDSA predicted the ETT correctly in 83.3% (6/7) as compared to 42.8% using age-based formula. The success rate of MTDSA was 82.1% in infants, while the age-based formulae had a success rate of 14.3% (4/28). A subgroup analysis of children <1 year showed that out of the five patients who needed upsizing of the ETT based on leak test, four had a MTDSA value which corresponded exactly to the OD of the upsized ETT. This revealed a procedural bias, as in whenever the MTDSA value was found to be exactly equal to the OD of an ETT on the chart, the intubating anesthetists tended to use the next smaller size to avoid introducing a snugly fitting tube. This happened in 5 of 28 infants where the upsized ETT OD was upsized to equal the initial MTDSA measurement. Choosing an ETT with the same OD as that of MTDSA would have significantly improved the success rate of MTDSA in this age group. In the 1–2 years of age group, there was one patient in which a similar bias led to undersizing the ETT. Subgroup analysis showed that predictability of ETT size using age-based formula was lowest in children <9 months of age. Age-based formula undersized the ETT in 80% cases (4/5) below 3 months of age and 93.74% (15/16) in children between 3 and 9 months. On the contrary in children between 9 and 12 months, it overpredicted the ETT size in five out of seven cases (71.4%). Compared to other age groups, MTDSA measurement was less accurate in children <2 years.

Interestingly, though 68% of children in our group were below the 5th percentile as per the WHO standard of weight for age,[16] 48% of them required a larger size tube compared to what was predicted using age-based formula. In this study, the predictive accuracy of age-based formula was lesser in children with congenital cardiac disease as compared to studies done in pediatric patients of similar age group. Azarfarin *et al*.[17] in a study using age-based formula found that children undergoing cardiac surgeries required a larger sized ETT compared to those of similar age coming for noncardiac surgeries. Chen *et al.* in a retrospective analysis of CT scan images of children with congenital heart disease found that height is most effective parameter determining tracheal diameter as compared to age weight and sex.[18]

The OD of the ETT may vary among the manufacturers.[19] To minimize this bias, we used uncuffed tubes (Portex) and Kimberly Clark cuffed ETTs. Unlike the previous investigators who studied the correlation between the MTDSA and OD of ETT, we allowed the consulting anesthetist to select an ETT with an OD closest to the MTDSA but never more. This takes away the problem of manufacturer variability in ETT sizes due to differences in wall thickness, thereby preventing airway trauma especially with the use of cuffed ETT.[20] The average time taken from USG marking of cricoid to selection of tube size was 43 s. Given the complex nature of the primary illness in these patients, we did not notice any desaturation episodes of hypotension, while MTDSA measurements were taken under 10 cm H_2O of end-inspiratory pressure.

None of the children in the study group developed postextubation stridor or subglottic stenosis during the study period and on their first follow-up evaluation at 4 weeks after discharge from the hospital.

Limitations of the study

In this study, best-fit ETT (final ETT) size used as the standard to validate the accuracy of MTDSA in guiding ETT size was based on detection of leak at 20 cm H_2O of pressure, which is an extrapolation from adult data. Given the immaturity of the pediatric airway, a lower pressure to estimate leak should be recommended.

The sample size was not equally distributed among all age groups.

There is a natural bias toward undersizing in clinical practice, rather than oversizing when choosing ETTs. This is reflected in the five patients below 1 year of age who needed upsizing as discussed above. The deflated Kimberly Clark tube has an OD which is 0.1 mm more than that of the uncuffed Portex tube. This could affect the outcome of leak test when the tube is a snug fit.

Conclusion

Ultrasonography is a safe and reproducible method for assessing subglottic diameter and prediction of appropriate size ETT. Measurements in small sick infants may need a larger learning curve. In our study population, cricoid diameter as measured by MTDSA showed poor correlation with anthropometric growth. MTDSA significantly improves accurate estimation of ETT size where age-based formula may have poor predictability. We compared the clinically best-fit ETT with the ETT size predicted by MTDSA. These fulfilled our study criteria for validating a method using direct measurement.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their 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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