JARSS 2021;29(2):119-24
doi: 10.5222/jarss.2021.44366

Özgün Araştırma / *Original Article*

Estimation of Appropriate Endotracheal Tube Size in Pediatric Patients: Use of Epiphyseal Diameter of the Distal Radius and Subglottic Diameter

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Pediyatrik Hastalarda Uygun Endotrakeal Tüp Çapının Belirlenmesi: Distal Radius Epifiz Çapının ve Subglottik Çapın Kullanımı

ABSTRACT

Objective: *The aim of this study is to test the usefulness of epiphysis of distal radius measurement as a surrogate parameter for endotracheal tube (ETT) size prediction in children.*
Methods: *Seventy-three children were intubated with cuffed ETT selected according to age-based formula. Transvers diameter of epiphysis of distal radius and subglottic diameter of trachea were measured by ultrasound (USG). Correlation between the outer diameter of best-fit endotracheal tube and transvers diameter of both radius epiphysis and subglottic diameter were calculated. The need for tube exchange, time for USG measurements and the ease level of measurements were compared.*
Results: *First attempt success at intubation was 83.6%. The correlation of the epiphysis diameter of the distal radius and best-fit ETT was significant ($p<0.001$, $r=0.619$, $r^2=0.383$, 95% CI=0.419-0.838). Similarly the correlation of subglottic tracheal diameter and best-fit ETT was significant ($p<0.001$, $r=0.744$, $r^2=0.553$, 95% CI=0.678-825). Estimated ETT sizes according to radial epiphysis diameter and subglottic diameter were optimal in 82.2% and 94.5% respectively. Time for the USG measurements of radial epiphysis and subglottic area were 38.3±9.6 and 24.9±4.6 seconds respectively ($p<0.001$). The level of ease of USG measurements were rated for radial epiphysis as 6 (5-9) and for subglottic area as 8 (7-9) ($p<0.001$).*
Conclusion: *USG measured transverse diameter of distal radius epiphysis resulted in similar success rate to age-based formula in our child population. Subglottic diameter measured by USG estimates ETT size more accurately; it is also less time consuming and easier.*

Keywords: *Child, endotracheal tube size, measurement, ultrasound*

ÖZ

Amaç: *Bu çalışmanın amacı, çocuklarda endotrakeal tüp (ETT) çapının belirlenmesinde yedek parametre olarak distal radius epifiz ölçümünün yararlılığını test etmektir.*
Yöntem: *Yetmiş üç çocuk, yaşa dayalı formüle göre seçilen kafli ETT ile entübe edildi. Distal radius epifizinin transvers çapı ve trakeanın subglotik çapı ultrason (USG) ile ölçüldü. En uygun endotrakeal tüpün iç çapı ile hem radius epifizi hem de subglottik çapın transvers çapı arasındaki ilişki hesaplandı. Tüp değiştirme ihtiyacı, USG ölçümleri için zaman ve ölçümlerin kolaylık düzeyi karşılaştırıldı.*
Bulgular: *Entübasyonda ilk girişim başarısı %83.6 idi. Distal radiusun epifiz çapı ile en iyi uyan ETT arasındaki korelasyon anlamlıydı ($p<0.001$, $r=0.619$, $r^2=0.383$, 95% CI=0.419-0.838). Benzer şekilde, subglottik trakeal çap ile en iyi uygun ETT arasındaki korelasyon anlamlıydı ($p<0.001$, $r=0.744$, $r^2=0.553$, 95% CI=0.678-825). Radyal epifiz çapına ve subglottik çapa göre tahmini ETT çapları sırasıyla %82.2 ve %94.5. Radyal epifiz ve subglottik alanın ultrason ile ölçümleri için süre sırasıyla 38.3±9.6 ve 24.9±4.6 saniye idi ($p<0.001$). Ultrason ölçümlerinin kolaylık düzeyi radyal epifiz için 6 (5-9) ve subglottik alan için 8 (7-9) olarak derecelendirildi ($p<0.001$).*
Sonuç: *Ultrason ile ölçülen distal radius epifizinin transvers çapı, çocuk popülasyonumuzda yaşa dayalı formülle benzer başarı oranıyla sonuçlandı. USG ile ölçülen subglottik çap, ETT çapını daha doğru tahmin eder; aynı zamanda daha az zaman alır ve daha kolaydır.*

Anahtar kelimeler: *Çocuk, entübasyon tüp çapı, ölçüm, ultrasonografi*

Received/Geliş: 19 January 2021
Accepted/Kabul: 31 March 2021
Publication date: 28 April 2021

Cite as: Altun D, Doruk C, Dincer MB, Güler MM, Altun D, Çamcı E. Estimation of appropriate endotracheal tube size in pediatric patients: Use of epiphyseal diameter of the distal radius and subglottic diameter. JARSS 2021;29(2):119-24.

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INTRODUCTION

Endotracheal tube (ETT) size selection in children is important to avoid airway complications due to repeated intubation trials [1]. In daily practice correct size both for cuffed and uncuffed ETTs is usually determined by wide range of formula using demographic or physical properties of the pediatric patients [2]. Even the popular ones proposed by Cole [3], Khine [4] and Motoyama [5] are not fully successful for tube size prediction in all children [6-9]. These formulas calculate the internal diameter (ID) of ETT. However, outer diameter (OD) of the same ID sized ETT may differ between manufacturers. Therefore, the calculated ID may be misleading.

Airway size is a reflection of overall body growth. Therefore several body part measurements have been suggested as a surrogate for tracheal width for accurate ETT size prediction reported that epiphyseal transverse diameter of distal radius measured by ultrasonography (USG) could predict appropriate ETT size for uncuffed ETT [10-12]. The purpose of this current study is to test the usefulness of epiphysis of distal radius measurement as a surrogate parameter for endotracheal tube size prediction in Turkish children and compare it with USG measured subglottic tracheal diameter.

MATERIAL and METHODS

Ethics Committee Approval for this study was obtained from the Institutional Ethics Committee (2019/727) as well as written informed consent of the parents.

Children, aged between 1-8 years, who required endotracheal intubation under general anesthesia for adenotonsillectomy were included in the study. Exclusion criteria were American Society of Anesthesiologists (ASA) physical status higher than II, any accompanying airway conditions such as subglottic stenosis and skeletal system disorders.

Following premedication with oral midazolam of 0.5 mg kg^{-1}, standard monitoring consisting of ECG, SpO_2, and non-invasive arterial pressure were applied. General anesthesia was induced by inhalation of sevoflurane at 6-8% in 50% N_2O. Intravenous fentanyl 1 µg kg^{-1} and rocuronium 0.6 mg kg^{-1} were administered for muscle relaxation to facilitate mask ventilation and intubation. An experienced anesthesiologist blind to the patient's age performed the USG measurements (Figure 1). Subglottic diameter was measured and recorded using a linear probe (GE Healthcare LOGIQ e ultrasonography) by placing the probe in the middle of the anterior neck region. The probe was moved caudally to observe the cricoid cartilage following vocal cords visualization and the hyperechoic shadow of transverse air column diameter at the level of the cricoid cartilage was measured and recorded as the subglottic airway diameter [8]. Following USG measurement, orotracheal intubation was performed with cuffed ETT of the same brand (Chilecom Medical Devices, China) which was selected according to the age-based formula. Khine formula [4] was used for children <2 years and Motoyama formula [5] for children ≥2 years. The tube cuff was inflated by limiting the cuff pressure at 25 cm H_2O and mechanical ventilation was started with a 10 mL kg^{-1} tidal volume. Under this setting, if there was an audible leak at airway pressure <10 cm H_2O, or peak pressure exceeding 25 cm H_2O, to obtain the desired level of tidal volume or a need of cuff pressure exceeding 25 cm H_2O required to seal, the tube was considered small and changed to a 0.5 mm larger size. If there was no audible leakage at airway pressure exceeding 25 cm H_2O, the tube was considered large and changed to a 0.5 mm smaller size. The ETT size was accepted to be appropriate (best-fit ETT) when the leak occurred only between 10 to 25 cm H_20. The number of tube change needed for optimal fit was recorded. Following intubation, transverse diameter of the distal radius epiphysis was measured using USG with a linear

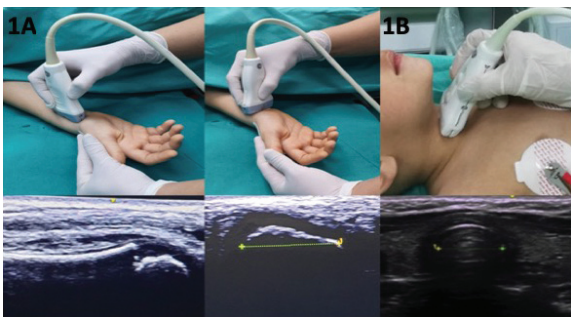

Figure 1. Ultrasonography measurement of epiphyseal diameter of distal radius and subglottic airway diameter. A. Epiphyseal transverse diameter of distal radius. B. Subglottic transverse airway diameter at cricoid cartilage level

(4-12 MHz) or hockey stick (5-18 MHz) probe. We used left wrist hand in all patients for standardizing the measurement method. USG probe was initially placed longitudinally at the wrist level over distal radius to identify the epiphysis. Than the probe was turned 90 degrees to see and measure the transverse diameter of the radius epiphysis [12]. The time from the first touch of the USG probe to the end of the measurement of the diameters was defined as measurement time and recorded. The investigator was also asked to rate the level of ease of ultrasound measurements by using an 11 point rating scale (0 represents the most difficult and 10 the easiest).

The primary outcome was to find out the correlation between USG measured diameters and the OD of best-fit ETT. We choose an effect size f^2=0.15, an alpha of 0.05 and beta of 0.1. We calculated the minimum required sample size to be 73 patients. Statistical analyses were performed with a statistical significance level of p<0.05 using Statistical Package for the Social Sciences version 20.0 (Chicago, USA). The Kolmogrov Smirnov test, Kurtuosis-Skewness and histograms were used to assess normality of the distribution. Correlations between the applied ETT size and two different USG measurements were tested using Pearson's correlation coefficient, with an r >0.70 being considered as a strong correlation [13]. Using linear regression analysis, 2 different numeric relations were created to predict the applied ETT using Epiphyseal diameter or Subglottic diameter. The concordance between tube sizes estimated by two different ultrasonic methods and applied ETT was also compared between groups as a contingency analysis by the chi-square test. Results are expressed as mean and standard deviation (SD) or median and 25-75 percentile for quantitative or number of cases and percentages for qualitative data.

RESULTS

Seventy-six pediatric patients were screened for the study. Due to lack of parenteral approval seventy-three cases enrolled to the study. The demographic data of the patients are given in detail in Table I.

Table I. Demographic data of the patients

Age (year)	5.7±2.0 (1-8)
Weight (kg)	22.2±6.8 (10-42)
Height (cm)	115.9±12.2 (75-138)

Data were given as mean + standard deviation (min-max)

After the first intubation attempt in 12 patients (16.4%) ETT, which was selected according to formula, needed to be changed; in eight of the children to one size smaller and in four to one size bigger. Pearson's correlation coefficient between USG measurement of epiphysis diameter of the distal radius and best-fit ETT was significant (p<0.001, r=0.619, r^2=0.383, 95% CI=0.419-0.838) (Figure 2A). Regression analysis between the applied ETT size and epiphyseal transverse diameter measurements of the distal radius showed the following relationship:

Applied ETT (OD) (cm)=2.911+(2.356×USG Epiphysis)

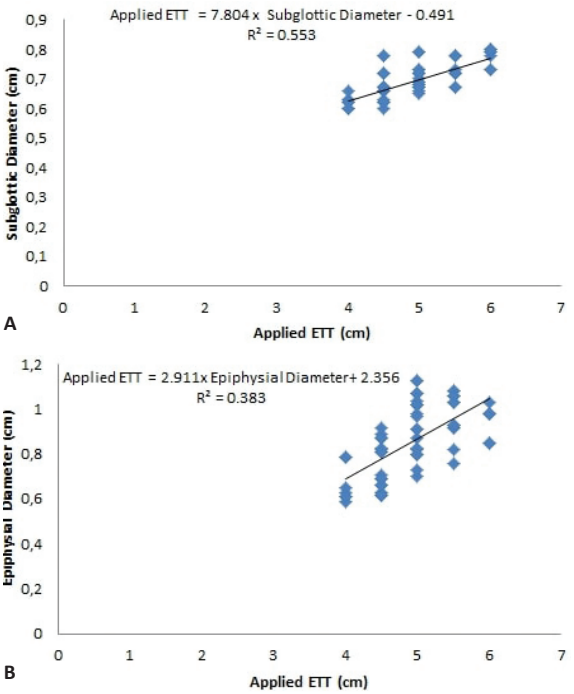

Figure 2. Scatter plot graphs of the relation between USG measurements and ETT size. A. Relation between subglottic transverse airway diameter and applied ETT size. B. Relation between epiphyseal transverse diameter of distal radius and applied ETT size

The radial epiphysis diameter to select to ETT size resulted optimal in 60 children (82.2%) which equals to a failure rate of 17.8%. The measurement was matched to one size bigger ETT OD, where as it was equal to two sizes bigger in three and two sizes bigger ETT OD in seven children. The correlation between US measurement of the subglottic tracheal diameter and best-fit ETT were found statistically

significant ($p<0.001$, $r=0.744$, $r^2=0.553$, 95% CI=0.678-825) (Figure 2B). Regression analysis between the applied ETT size and subglottic transverse diameter measurements showed the following relationship:

Applied ETT (OD) (cm) = (7.804 x USG Subglottic) - 0.491

The subglottic diameter measurement to select to ETT size resulted optimal in 69 children (94.5%) indicating a failure rate of 5.5%. The measurement was matched to one size bigger ETT OD in one of the cases, where it was equal to one size smaller in three children. Chi-squared test results showed that subglottic diameter measurements were significantly more accurate than radial epiphyseal measurements ($p=0.02$). Time for the USG measurements of epiphysis of the radius and subglottic diameter was 38.3±9.6 and 24.9±4.6 seconds respectively ($p<0.001$). The median values and 25-75 percentile of the level of ease were 6 [5-9] for the radial epiphysis measurement whereas it was 8 [7-9] for subglottic diameter measurement ($p<0.001$).

DISCUSSION

In this current study, a moderately strong correlation was found for prediction between appropriate ETT size and transverse diameter of distal radial epiphysis measured by USG. The failure rates were similar for ETT estimation between age-based formula (16.4%) and radial epiphysis diameter (17.8%). Interestingly, in 15% of the cases, the calculated ETT size according to transverse diameter of radial epiphysis overestimates tracheal diameter for more than one size. In contrast, USG measured subglottic diameter allows the estimation of optimal ETT in 94.5% of the cases. The USG measurement of subglottic diameter was faster and easier compared to radial epiphysis measurement.

In clinical practice, anesthesiologists often choose ETT size using age-or length-based formula. In this study, ETT sizes were primarily determined by using the age-based formula of Khine [4] and Motoyama [5]. Depending on the different growth rates of children, these formulas have limited first attempt success between 32-75.4% (Zhang, Shibasaki, Stugatti) [6,7,14]. Although we had higher first attempt success with age-based formula, it is logical to assume that a method related to the growth rate rather than chronological age would perform better in ETT size selection.

Laryngeal growth is expected to be parallel to the growth rate of cartilages of the body. Kim et al. [12] hypothesized that, transverse diameter of radial epiphysis, of which the ossification center begins to appear from seventh month after birth, would be correlated with tracheal diameter as bone and cartilage growth of the body are related to each other. Such a measurement as a surrogate parameter would be advantageous as it can be easily performed preoperatively in an awake child. In Korean population, these researchers found a correlation coefficient of 0.814 between radial epiphysis measurements and the uncuffed ETT size. Another study tested this relationship in Indian pediatric population and found a slightly higher correlation coefficient (0.8878) with a failure rate of 10% for similarly uncuffed ETT [15]. Their failure rate albeit small can be explained by individual variability of the cartilage growth and ossification of the hand depending on hormonal, nutritional, environmental and socioeconomic factors [16]. Indeed, wide spectrum of measurements resulting in different ETT sizes in children with similar age is exampled by Kim et al [12]. However, the difference between success rates of these two studies and our results may depend on the interracial difference of growth rate between Asian and Caucasian races. Unfortunately, we could not compare our overestimation of ETT size while using transverse diameter of radial epiphysis as neither Kim [12] nor Rajanalini et al. [15] have specified the difference between calculated and selected ETT ODs' in terms of under or overestimation rates.

Taking into account that outer diameter (OD) is decisive for optimal fit of ETTs, direct measurement of trachea should be more informative. Direct measurement of tracheal width by different methods can be used for estimation [17-19]. USG, as an option in these methods, provide a bedside tool to measure subglottic diameter to obtain reliable and consistent values among patients. Several studies found up to 90% high rates of agreement with best fit ETT and USG measured subglottic diameter [6-8,20]. Specifically, in patients with unbalanced growth and tracheal abnormalities, it is important to measure subglottic

diameter to choose right ETT size [14,21-23].

Our findings indicate that measurement of radial epiphyseal diameter required a longer time compared to subglottic diameter and rated as more difficult. This depends on the technique which needs two consecutive placement of USG probe. To visualize distal radial epiphysis, USG probe should be held longitudinally over distal end of the radius and then turned at 90 degrees angle to obtain transverse image of the epiphysis. This rotation leads to displacement and reposition of the probe to obtain the optimal image. Another reason may be that the anesthetist who performed the USG measurements is more familiar with sono-anatomy of the airway.

Another issue in the measurement method was the use of the left hand wrist. No difference was found between right and left wrist in determining bone age in studies evaluating bone differences between both sides [24-25]. In the literature review, in the evaluation of the wrist bones for determination of bone age, Greulich-Pyle [26], reported difference with no significance between right and left hand. Moreover, they suggested to use the left hand because it is usually less used and traumatized. According to these findings, we used left wrist in ultrasonographic measurements in our study.

Our findings are limited to cuffed ETTs and Turkish population. Furthermore, USG measurement requires of knowledge about the ETT ODs with which the anesthetists are unfamiliar. It should also be considered that correct tracheal diameter measurement by USG needs correct angulation as a strong angulation may lead to overestimation. Another point to be taken into account is that we measured radial epiphysis while the children were immobile under anesthesia, which may not reflect the primary advantage of this technique. Indeed, in obese children with short neck, the measurement of radial epiphysis may be useful technique for ETT size selection as it can also be performed in awake situation.

In conclusion, direct measurement of subglottic diameter results more accurate ETT size. USG measurement of transverse diameter of radial epiphysis is an option to select cuffed ETTs that yields results similar to age-based formula.

Ethics Committee Approval: The study was registered at University of İstanbul (28.05.2019, Sayı 746)
Conflict of Interest: None
Funding: None
Informed Consent: A written informed consent was obtained prior to surgery from the parent(s) or legal guardian(s) of the patients

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