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Original Article / Özgün Araştırma

Ultrasonographic Measurement of Subglottic Diameter for Paediatric Cuffed Endotracheal Tube Size Selection: Feasibility Report

Pediatrik Kaflı Endotrakeal Tüp Büyüklüğünün Seçiminde Subglottik Çapın Ultrasonografik Ölçümü: Fizibilite Raporu

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Abstract / Öz

Objective: The aim of this feasibility study was to investigate the first attempt success of ultrasonography (USG) in paediatric patients in predicting an appropriate cuffed endotracheal tube (ETT) size.

Methods: Fifty children who were 1-10 years of age and who received general anaesthesia with endotracheal intubation for adenoidectomy or adenotonsillectomy were enrolled in the study. In all participants, the transverse diameter of the subglottic airway was measured with USG at the cricoid level without ventilation. The outer diameter (OD) of the maximum allowable ETT was chosen according to the measured subglottic airway diameter. In the presence of resistance to passage of the tube into the trachea or in the absence of an audible leak at airway pressure of >25 cm H_2O, the ETT was replaced with a tube whose internal diameter (ID) was 0.5 mm smaller. If a leak was audible at airway pressures of <10 cm H_2O, if a seal could not be achieved with a cuff pressure of >25 cm H_2O or if a peak airway pressure of >25 cm H_2O was observed during ventilation, the tube was changed to a tube one size larger. The OD of the best-fit ETT was converted to the ID. The best-fit ID, the requirement for ETT replacement, the duration of airway diameter measurement by USG and the peak airway pressure were recorded.

Results: The success rate of the first attempt with USG was 86%; the ETT was replaced in five patients with a tube one size larger and in two patients with a tube one size smaller.

Conclusion: Our findings show the subglottic diameter measured by USG to be a reliable predictor in estimating the appropriate paediatric ETT size.

Keywords: Paediatric endotracheal tube, subglottic diameter, ultrasonography

Amaç: Bu fizibiliti çalışmasının amacı pediyatrik hastalarda uygun büyüklükte kaflı endotrakeal tüpün (ETT) öngörülmesinde ultrasonografinin (USG) ilk girişim başarısını araştırmaktır.

Yöntemler: Çalışmaya 1-10 yaş arası adenoidektomi veya adenotonsillektomi için endotrakeal entübasyon ile genel anestezi alan 50 çocuk dahil edilmiştir. Bütün katılımcılarda subglottik havayolunun transvers çapı krikoid kartilaj seviyesinden ventilasyon yapılmadan ultrasonografi ile ölçülmüştür. izin verilen maksimum ETT dış çapı (DÇ) ölçülen sublottik havayolu çapına göre seçilmiştir. Tüpün trakeadan geçişi sırasında dirençle karşılaşılması halinde veya havayolu basıncı >25 cm H_2O'da duyulabilen kaçak varlığında ETT iç çapı (iÇ) 0,5 mm olan bir başkasıyla değiştirilmiştir. Eğer havayolu basıncı <10 cm H_2O'da duyulabilen kaçak varsa veya kaf basıncı >25 cm H_2O'ya ulaşmıyorsa veya tepe havayolu basıncı ventilasyon sırasında >25 cm H_2O ise tüp bir büyük çapla değiştirilmiştir. En iyi uyan ETT DÇ'ı iÇ'a dönüştürülmüştür. En uygun iÇ, ETT değiştirme ihtiyacı, ultrasonografi ile havayolu çapı ölçüm süresi, ve tepe havayolu basınçları kaydedilmiştir.

Bulgular: Ultrosonografi ile ilk deneme başarı oranı %86, ETT 5 hastada bir numara büyük olan, 2 hastada bir numara küçükle değiştirilmiştir.

Sonuç: Bulgularımız USG ile ölçülen subglottic çapın uygun pediyatrik ETT çapının belirlenmesinde daha güvenilir bir belirleyici olduğunu göstermiştir.

Anahtar kelimeler: Pediatrik endotrakeal tüp, subglottik çap, ultrasonografi

Introduction

Cuffed endotracheal tubes (ETTs) are preferred for pharyngolaryngeal surgery in paediatric patients as they decrease the risk of blood aspiration (1, 2). Furthermore, ETTs can provide efficient ventilation with better end-tidal gas monitoring and can reduce environmental pollution due to the sealing of the trachea (3, 4). In clinical practice, several formulas based on characteristics such as weight, age, height and finger size have been developed to select the ideal ETT size to avoid damage to the airway mucosa (5). Visualisation of the paediatric subglottic airway diameter by ultrasonography (USG) can enable a practitioner to better predict ETT size, preventing unnecessary tube changes and airway trauma. Several studies have investigated ideal cuffed tube size selection in paediatric patients; however, all these studies, including those where ultrasonographic measurements were performed (6-9), selected the initial ETT size according to age-based formulas. However, other than Bae et al. (6), who investigated uncuffed tube size, none of these studies actually involved initial placement of an ETT according to ultrasonographic measurements. Therefore, the aim of this feasibility study was to investigate the first attempt success of ultrasound in choosing the right ETT size.

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Methods

Approval from the Istanbul University Ethics Committee and written informed consent of the parents were obtained. The first 50 children who were between 1 and 10 years of age and who received general anaesthesia with endotracheal intubation for adenoidectomy or adenotonsillectomy between July and August 2015 were chosen as subjects in this study.

Children with previous histories of tracheal and laryngeal pathologies, such as tracheostomy, pharyngeal surgery with anatomical airway abnormalities and anticipated difficult airway, were excluded from the study; American Society of Anesthesiologists III-IV patients with unstable cardiopulmonary conditions and patients with body mass indices above the 85th percentile (overweight) and below the 5th percentile (underweight) were also excluded. Children were premedicated with 0.5 mg kg^{-1} oral midazolam. Following routine monitoring (ECG (Electrocardiography), SpO_2, and non-invasive arterial pressure), general anaesthesia was induced and maintained with sevoflurane in an O_2/N_2O (50/50%) mixture. After establishing an intravenous (IV) route, 1 µg kg^{-1} fentanyl and 0.2 mg kg^{-1} mivacurium were administered. One of the investigators (DA) measured the subglottic airway transverse diameter in the brightness (B) mode using the linear probe (range, 4.5-13 MHz) of the USG device (GE Healthcare LOGIQ e) while the children were placed in the supine and neutral head positions. The children were ventilated via a facemask during the measurement. The probe was placed on the anterior neck; then, proceeding in the caudal direction, the cricoid cartilage and vocal cords were visualised. The subglottic airway diameter during apnoea was measured at the cricoid cartilage level as the hyperechoic air column diameter (Figure 1), as described by Kim et al. (9)

The same brand of cuffed ETT (Rüsch Safety Clear, Teleflex Medical, Kernen, Germany) was used for all children. The manufacturer-provided ETT outer diameter (Table 1) was used to convert the measured subglottic airway diameter to the ETT internal diameter (ID) with which the trachea was intubated (USG-ID). Resistance to tube advancement or absence of an audible leak at an airway pressure of >25 cm H_2O prompted the replacement of the original tube with another tube with an ID 0.5 mm smaller. Conversely, if a leak was audible at an airway pressure of <10 cm H_2O or if a cuff pressure of >25 cm H_2O was not enough to achieve a seal, the tube was changed to a tube one size larger. The tube that satisfied the aforementioned conditions was accepted as the best-fit tube, and its ID was recorded as the best-fit ID. The ETT cuff pressure was monitored and maintained below 25 cm H_2O using an automatic manometer (Shiley™ Pressure Control, Covidien, Germany). First attempt success was defined as the concurrence of USG ID and best-fit ID.

The USG ID and best-fit ID, the need for ETT replacement, the duration of airway diameter measurement by USG (time between the placement of the USG probe and completion of the measurement) and the peak airway pressure were recorded.

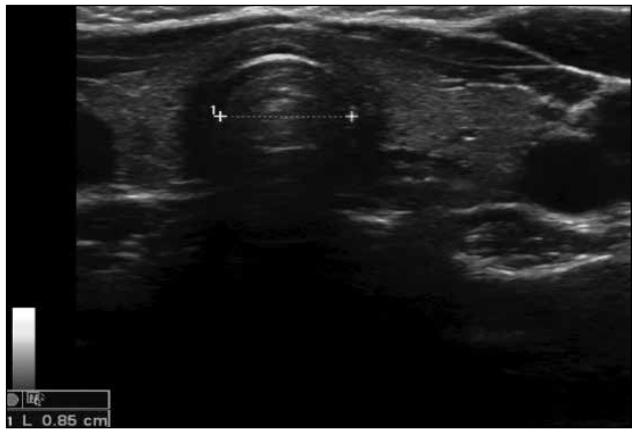

Figure 1. Ultrasonographic measurement of the subglottic airway diameter at the cricoid cartilage level. The dotted lines show the USG-OD (8.5 mm).
USG: ultrasonography; OD: outer diameter

Table 1. Outer and inner diameters of cuffed endotracheal tubes of the used brand*

OD (mm)	3.3	4.0	4.8	5.3	6.0	6.7	7.3	8.0	8.8
ID (mm)	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5

*Rusch Safety Clear, Teleflex Medical, Kernen, Germany

OD: outer diameter; ID: inner diameter

Statistical analysis

Feasibility studies aim to estimate important parameters before planning the main study (10). This feasibility report is for a larger comparative study to estimate the first attempt success rate in young Turkish children when the ETT size is selected according to the subglottic diameter measured with USG (our primary outcome). To obtain a more precise result (for the necessary degree of precision) for sample size calculation, we included 50 children in the study. Quantitative data were provided as mean±SD (minimum-maximum). Qualitative data were presented as the number and percentage of cases.

Results

The age of the study population was 5.3±1.6 (2-8) years with a weight of 21±5.3 (13-34) kg and a height of 117.4±9.9 cm (93-133). The durations of measurement using USG, the measured USG-IDs, the best-fit IDs and the peak airway pressures of the 50 included paediatric patients are given in Table 2. The success rate at the first attempt with USG was 86%; the ETT was changed in five patients to a tube one size larger and in two patients to a tube one size smaller.

Discussion

Estimating tracheal tube size in children is crucial; ideally, the maximum allowable tube size would be estimated with simple measurements rather than using cumbersome formulas derived from measurements or demographic data. In this novel feasibility study, we used direct ultrasound measurement of the subglottic diameter to identify cuffed tube size with a first attempt success rate of 86%.

The use of USG to predict appropriate ETT size in children has been previously studied (6-9). These studies differ from each other, as shown in Table 3. In two of these studies (7, 8), after a traditional method (i.e. age based formulas) of initial tube size selection, a best-fit tube size within predefined leak thresholds was identified by repetitive changes. These authors then correlated this best-fit tube size with ultrasonographic measurements and devised formulas rather than directly applying the measured subglottic diameter. Kim et al. (9) also used an age-based formula for initial size selection and reported a good correlation between measured subglottic diameter and actual ETT OD. However, they did not calculate a formula depending on ultrasonographic measurement; instead, they calculated one with demographic variables. To our knowledge, there is only one study of uncuffed tubes that compares the success of an age-based formula with ultrasonographic measurement-dependent tube size selection (6); however, this study also identified a linear regression formula from 41 children to compute ultrasonographic measurement-predicted tube size (correctly sized tracheal tube ID (mm)=0.705xsubglottic diameter (mm)-0.091). In this study, unlike others, we selected the initial tube size diameter on the basis of subglottic measurements rather than age-based formulas.

Our first attempt success rate with direct measurement is higher than that of two previous studies (6, 8), yet lower than that of one study (7). Bae et al. (6) reported 60% success in the selection of correct uncuffed ETT size. Schramm et al. (8) also studied uncuffed ETT and showed a lower success rate (48%) in a younger population. Shibasaki et al. (7) attained higher success (98%) for cuffed tubes when a regression equation was applied to directly measured subglottic diameters. Kim et al. (9) also concluded that ultrasonographic measurement was useful in choosing actual ETT size, although they did not attempt to determine 'best-fit' sized tubes and therefore did not provide a success rate. The difference between our results and those of other studies can be explained by several factors, such as measurement location, precision and predetermined air leak test limits.

In terms of location, in previous studies, the probe was positioned at the cricoid cartilage level, either at mid-cricoid level (6) or at the lower end of the cricoid ring (7). However, contrary to previous teachings, the narrowest portion of the airway is not at the cricoid level (11). Litman et al. (12) reported the vocal cord level as the narrowest portion of the paediatric larynx, followed by the sub-vocal cord level and the cricoid level, in sedated, unparalysed children using magnetic resonance imaging. The ratio of the transverse to the anteroposterior diameter of the trachea was found to be around 0.4 at the vocal cord level, 0.5 at the sub-vocal cord

Table 2. The duration of measurement, measured (USG-ID) and inserted tube ID and peak airway pressure during ventilation

	Mean±SD (min-max)
USG duration (s)	37.8±9.1 (25-55)
USG-ID (mm)	4.7±0.6 (3-6)
Best-fit ID (mm)	4.8±0.6 (3.5-6.5)
PAP (cm H_2O)	17.1±2.1 (13-22)

Data are provided as mean±standard deviation (SD).

PAP: peak airway pressure; USG: ultrasonography; ID: inner diameter

Table 3. Studies examining the appropriate paediatric ETT with ultrasonographic measurements

Author, year	Population	Initial tube size selection	Tube type	Condition	Allowed leak pressure	Measurement level
Shibasaki et al. (7)	n=192	1 month-6 years	Age- and height-based formulas	Cuffed and uncuffed	Apnoea with no CPAP 10-20 cm H_2O for uncuffed ETT 20-30 cm H_2O for cuffed ETT	At the lower edge of the cricoid cartilage
Bae et al. (6)	n=141 <8 years	Age-based formulas	Uncuffed	10 cm H_2O CPAP	15-30 cm H_2O	At the mid cricoid cartilage level
Schramm et al. (8)	n=50 <5 years	Age-based formulas	Uncuffed	Apnoea with no CPAP	15.3-25.5 cm H_2O	At the narrowest portionof the subglottic airway (MTDSA)
Kim et al. (9)	n=215 1-72 months	Age-based recommendation	Cuffed	Apnoea	No air leak test	At the mid cricoid cartilage level

ETT: endotracheal tube; CPAP: continuous positive airway pressure

level and 0.8 at the cricoid level. Thus, as an ultrasound probe can only provide blurred images of vocal cords, ultrasound imaging may in fact omit the narrowest portion of the trachea. Indeed, Shibasaki et al. (7) used this fact to explain their conversion of the measured diameter to a relatively smaller ETT OD using a coefficient of 0.46 and a constant of 1.56 in cuffed ETT. However, if the vocal cords are paralyzed, the narrowest point of the larynx should move more caudally, and the transverse to anteroposterior diameter ratio should be closer to 0.8. This is supported by Schramm et al. (8), who described the minimal transverse diameter of the subglottic airway (MTDSA) as the narrowest part of the subglottis and found that the MTDSA was closely related with uncuffed ETT OD. Their ETT OD was calculated from the MTDSA using a coefficient of 0.877 and a constant of 0.798 for uncuffed tubes. Our measurement for probe positioning was similar to that of Schramm et al. (8).

For measurement precision, we attempted to correctly identify the air-mucosa interface at the cricoid level; however, we did not include the bilateral margins of the cricoid cartilage, as criticised in the Shibasaki study by Kim et al. (9)

It should be noted that ultrasound can accurately measure airway diameter in the transverse, but not in the anteroposterior, direction. This is because the posterior portion of the trachea is not clearly visualised by the acoustic shadow of air. Therefore, because the anteroposterior diameter of the trachea is larger than its transverse diameter, this results in underestimation of the actual tracheal diameter and the selection of a smaller ETT. Interestingly, in the study by Bae et al. (6), USG frequently underestimated ETT size in patients where the ultrasonographic method was unsuccessful (31 out of 40 patients). In fact, this underestimation can be advantageous for cuffed ETTs when one considers that the bulk of the deflated cuff is not included in the OD (13-15). However, underestimation may have disadvantages of high airway resistance and increased airway pressures, whereas overestimation is also dangerous as it may cause the selection of a larger ETT, resulting in airway trauma and laryngotracheal damage. We believe that we avoided both underestimation and overestimation in our study by monitoring leak pressure thresholds and peak airway pressures. Further, in this study, we only used one brand of ETT, as the wall thickness of the ETT may affect the tube size ID for a given OD and hence may affect the peak airway pressure.

The accuracy of measurement with USG depends on the experience of the operator and may include bias. However, all measurements were performed by the same experienced anaesthetist in this study.

Last but not the least, when considering differences in success, it should be recalled that in any study involving best fit, the clinically selected 'best-fit' ETT may not be the only size that fits the criteria.

Ultrasonographic measurement for ETT selection can be seen as time consuming. In our study, the measurement took 37.8±9.1 (25-55) s. As this study did not compare the ultrasonographic method with another method for ETT selection, we cannot speculate about the total intubation time.

Our results in this adenotonsillectomy study population cannot be extrapolated to uncuffed tubes. One limitation of our study is that we did not investigate the incidence of respiratory complications such as post-extubation stridor and laryngospasm. However, the reported incidence of respiratory complications in adenotonsillectomy is relatively high (16), and it would be impossible to differentiate whether the complication was a result of mismatched ETT size or due to the surgery itself. Another weakness of our study is the limited age range of the included children, which was dependent on our adenotonsillectomy population during the study period. We also did not include children with histories of difficult intubation or existing anatomical malformations.

Conclusion

Our findings show that USG appears to be a reliable predictor for the assessment of the subglottic diameter of the airway in children to estimate the appropriate ETT size for intubation.

Ethics Committee Approval: Ethics committee approval was received for this study from the ethics committee of İstanbul University İstanbul School of Medicine.

Informed Consent: Written informed consent was obtained from parents of the children who participated in this case.

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