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Araştırma/*Research Article*

Measurement of the Endotracheal Tube Diameter Using Computed Tomography Images for Pediatric Patients: Comparison with Classic Formulas

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Pediatrik Hastalarda Bilgisayarlı Tomografi Kullanılarak Endotrakeal Tüp Çapının Belirlenmesi: Klasik Formüllerle Karşılaştırma

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ABSTRACT

Objective: *In this retrospective study, we aimed to evaluate the compatibility of endotracheal tube (ETT) size used during surgery with tracheal diameter measured by computed tomography(CT) and classic formulas in children who underwent CT imaging preoperatively due to surgical indications.*
Methods: *The study included preoperatively CT scanned, 0-3 year-old patients who were operated due to congenital heart diseases between June 1-October 1, 2018.Using the CT scans, transverse and anteroposterior tracheal diameters were measured from the subglottic level. As these diameters reflect the external diameter of the ETT, the inner diameter-which corresponds the ETT size-was calculated using a correction formula. Besides, Cole's formula was used to calculate the ETT size for each child, and the tube sizes used during surgeries were obtained from anesthesia charts.ETT sizes were compared.*
Results: *43 patients (22 girls [51.2%],21 boys [48.8%]) were included.The mean age was 10.5±9.6 months. 18 patients (41.9%) had cyanotic, 25 patients (58.1%) had acyanotic heart disease.Mean corrected transverse and anteroposterior tracheal diameters at CT images were 4.35±0.69mm and 4.30±0.71 mm, respectively. The mean diameter calculated by Cole's formula was 4.22±0.20 mm. The mean tube size used during surgeries was 4.37±0.60 mm. There was no statistically significant difference between the tube sizes used during the surgeries and the corrected transverse tracheal diameters from CT measurements (p>0.05). But the tube sizes used during the surgeries found significantly larger than the diameters obtained by Cole's formula (p<0.05).*
Conclusion: *In 0-3 years of age pediatric patients who undergo a congenital heart surgery,corrected tracheal transverse diameter measured by CT is more effective,reliable and less invasive than classic formulas for determining appropriate ETT size.*

Keywords: *pediatric endotracheal tube size, subglottic diameter, computed tomography, Cole's formula*

ÖZ

Amaç: *Bu retrospektif çalışmada, ameliyat öncesi bilgisayarlı tomografi çekilmiş ve kalp cerrahisi yapılmış pediyatrik hastalarda, kullanılan tüp numarasının, ölçülen trakea çapı ile ve klasik formüllerle uygunluğu karşılaştırıldı.*
Yöntem: *1 Haziran 2018-1 Ekim 2018 tarihleri arasında, konjenital kalp hastalığı nedeniyle opere edilmiş ve ameliyat öncesinde trakea ölçümü yapılacak şekilde bilgisayarlı tomografi çekilmiş olan 0-3 yaş aralığındaki hastalar çalışmaya dâhil edildi. Trakeal BT'de subglottik seviyede transvers çap ve anteroposterior çap ölçüldü. Bu çaplar ETT dış çapını yansıtmaları nedeniyle bir düzeltme formülü kullanılarak ETT numarasına karşılık gelen iç çap hesaplandı. Ayrıca Cole formülüne göre, her çocuğa uygun ETT çapı hesaplandı ve anestezi dosya kayıtlarından cerrahide uygulanan ETT numaraları kaydedildi. Uygulanan tüp numaraları, Cole formülüyle hesaplanan tüp numaraları ve trakeal BT'deki ölçümle belirlenmiş olan ETT numaraları ile karşılaştırıldı.*
Bulgular: *Kırk üç olgu mevcuttu. Olguların %51.2'si (n=22) kız, %48.8'i (n=21) erkek ve yaş ortalaması 10,5±9.6 aydı. Hastaların %41.9'unda (n=18) siyanotik konjenital kalp hastalığı, %58.1'inde (n=25) asiyanotik konjenital kalp hastalığı vardı. Altı hasta (%14.0) Down Sendromlu, 4 hasta ise redo-olguydu (%9.3). Trakeal BT'de, trakea transvers çapı ölçümüne göre düzeltilmiş tüp çapı ortalaması 4.35±0.69 mm, trakea anteroposterior çapı ölçümüne göre düzeltilmiş tüp çapı ortalaması 4.30±0.71 mm, Cole formülü ile hesaplanan tüp çapı 4.22±0.20 mm ve klinikte uygulanan tüp çapı 4.37±0.60 mm idi. Ameliyatlarda uygulanan tüp çapları ile düzeltilmiş trakea transvers ölçüm çapları arasında istatistiksel olarak anlamlı fark yoktu (p>0.05). Fakat ameliyatlarda uygulanan tüp çapları, Cole formülü ile hesaplanan tüp çaplarına göre anlamlı oranda büyük bulundu (p=0.03).*
Sonuç: *Pediyatrik kalp cerrahisi geçiren 0-3 yaş arası çocuklarda endotrakeal tüp çapının belirlenmesinde bilgisayarlı tomografi ile ölçülen düzeltilmiş trakea transvers ölçüm çapları, klasik formüllere göre daha etkin, güvenilir ve non invaziv bir yöntemdir.*

Anahtar kelimeler: *pediatrik endotrakeal tüp numarası, subglottik çap, bilgisayarlı tomografi, Cole formülü*

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INTRODUCTION

The selection of an appropriate endotracheal tube is very important for the prevention of airway management complications in the pediatric patients with special anatomical features. An endotracheal tube, which is too small in diameter, can result in inadequate ventilation and end-tidal gas monitoring, anesthetic gas leakage, and an increased risk of aspiration, while a tube that is too large can cause potential subglottic stenosis or upper airway damage such as ischemia or ulceration [1,2].

There is no consensus on how the diameter of an endotracheal tube (ETT) for a pediatric patient should be determined. Various formulas have been developed to overcome these variations caused by anatomical, structural, and racial differences [3-4]. Different formulas are currently in use in order to make the selection of ETT size based on age, height, and weight possible. The most well-known formula for uncuffed ETTs is the Cole's formula: internal diameter (mm) = (age / 4) + 4. For the selection of cuffed endotracheal tubes, the Khine's formula (internal diameter [mm] = [age / 4] + 3) is recommended for patients younger than 2 years old, while the Motoyoma formula (internal diameter [mm] = [age / 4] + 3.5) is recommended for those older than 2 years [3].

The use of ETT's internal diameter in age-based formulas has some disadvantages; therefore, it has been suggested that measuring the outer diameter is a more reliable approach in choosing the appropriate ETT [6]. Recent advances in technology, which have led to an increased use of ultrasound (US), computed tomography (CT), and magnetic resonance imaging (MRI) in clinical practice, also allow those imaging techniques to be used for the measurement of the diameter of the subglottic region, which is considered to be the narrowest part of the trachea, particularly in children. This measurement corresponds to the outer diameter of the ETT. Compared to the conventional formulas, the most appropriate ETT can be selected more safely by various correction formulas [7,8].

In our hospital, preoperative CT scanning is performed to identify the surgical indications and to predict the potential intraoperative complications for most of the pediatric patients who are scheduled for open cardiac surgeries. As those CT scans also include the neck region, it is possible to measure the tracheal diameter and to estimate the ideal ETT size.

The aim of this study was to evaluate the compatibility of the ETT size used in clinical practice, by comparing it with the diameter calculated by conventional formulas and the tracheal diameter measured from the CT scans in the pediatric patients, who underwent preoperative CT imaging due to surgical indications and whose operations were completed.

MATERIAL and METHODS

This study was conducted in accordance with the principles of the Declaration of Helsinki after obtaining an approval from the Clinical Research Ethics Committee of Mehmet Akif Ersoy Thoracic and Cardiovascular Surgery Training and Research Hospital (date: 8/6/2018; decision no: 2018-19). The retrospective analysis included patients aged 0 to 3 years who underwent cardiac surgery due to congenital heart diseases between June 2018 and October 2018. All patients had been intubated with an uncuffed ETT and had undergone CT imaging preoperatively that allowed the measurement of the trachea. The patients, who had undergone tracheostomy, who had already been intubated when transferred to the operating room from the intensive care unit, and those whose data could not have been accessed retrospectively, were excluded from the study.

Computed tomography (CT angiography) was performed with a Toshiba Aquilon One 640/320 (Toshiba Medical Systems Corp, Tokyo, Japan) device. The anteroposterior (AP) (Figure 1) and the transverse (Figure 2) diameters of the trachea at the subglottic level were retrospectively measured and recorded by the same radiology specialist (N.K.Ş.) from the CT scans of 43 patients who met the aforementioned criteria.

A study form for each patient was developed by using data which were retrieved from the anesthesia charts, and which included the age, gender, the diagnosis of the congenital heart disease, and the ETT size used.

Figure 1. The anteroposterior diameter of the trachea.

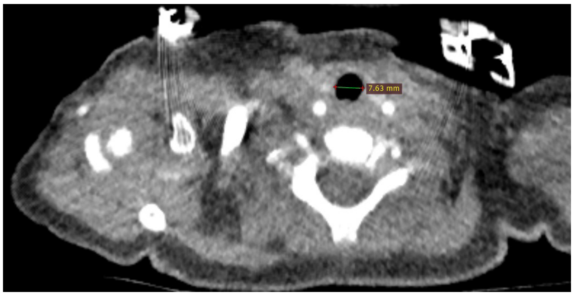

Figure 2. Transverse diameter of the trachea.

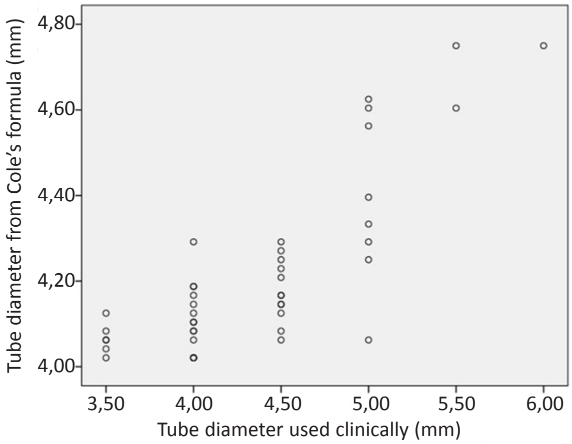

Figure 3. Scatter plot of the endotracheal tube diameters calculated with Cole's formula and those used clinically.
r=0.78, p<0.01

For each child, an ETT diameter was calculated according to the Cole's formula (internal diameter [mm] = [age / 4 + 4]). As the transverse and AP diameters measured from the tracheal CT scans were the outer diameters, the inner ETT diameter was calculated using the correction formula (0.705 x subglottic diameter – 0.091) [1]. Although this correction formula is used for US measurements, we accepted it as a reference because the same region was measured from the tracheal CT scan. The ETT sizes used during the intubations of the patients were also retrieved from the anesthesia forms.

Statistical analysis

The SPSS 21.0 (IBM) software package was used to analyze the data obtained in this study. The measures of central tendency and spread such as number, percentage, mean, median, and standard deviation were used to generate descriptive statistics. Numerical data were analyzed for normal distribution by using visual (histogram) and statistical methods (Shapiro-Wilk test). The Welch test was used to evaluate the differences between independent variables, and Pearson's correlation test and scatter plots were used to identify the correlations between numerical variables. The agreement between the measurements was assessed using the one-sample t-test, linear regression, and Bland–Altman plots. $p<0,05$ was accepted as indicating statistical significance.

RESULTS

The distribution of the demographic, physical, and clinical characteristics of the patients is shown in Table 1. Twenty-two out of the 43 patients were female (51.2%), and 21 were male (48.8%). The mean age was 10.5±9.6 months. Eighteen patients (41.9%) had cyanotic, and 25 patients (58.1%) had acyanotic heart disease.

A comparison of the ETT diameters based on different measurements is shown in Table 2.

There were no statistically significant differences

Table 1. Distribution of patients' demographic, physical, and clinical characteristics.

	n	%*
Sex		
Male	21	48,8
Female	22	51,2
Age (months)	Mean±SD: 10,5±9,6, Median: 7 Minimum: 1, Maximum: 36	
Weight (kg)	Mean±SD:: 7,3±3,4, Median: 6,9 Minimum: 3,0, Maximum: 19,5	
Height (cm)	Mean±SD: 69±13, Median: 66 Minimum: 52, Maximum: 109	
Redo case	4	9,3
Positive	39	90,7
Negative		
View	18	41,9
Cyanotic	25	58,1
Asyanotic		

** Column percentage, SD: standard deviation*

between the diameter of the ETT used in clinical practice and the diameters calculated according to Cole's formula or measured from the CT scans (p>0.05).

Figures 4-5 indicate the correlations between the ETT diameters calculated by different formulas and the tube diameter used in clinical practice. The diameter of the ETT used in clinical practice was significantly and strongly correlated with the diameters calculated by the Cole's formula, the corrected transverse tracheal measurement and the corrected AP tracheal measurement (r=0.78, p<0.01; r=0.72, p<0.01, respectively). Although the tube size used in clinical practice and the diameter calculated by Cole's formula had the highest correlation coefficient, the largest discrepancy in mean values was observed in those variables (Table 2). Correlation coefficients may be insufficient in determining the compatibility between different measurements. In these cases, Bland–Altman plots are recommended for determining the true compatibility. Figures 5 and 6 show the Bland–Altman plots, pertaining to the tube diameters used for intubation and the corrected transverse tracheal diameter and the Cole's formula diameters, respectively. Table 3 shows the evaluation of whether the mean difference between the ETT sizes used in clinical practice and the diameters obtained by Cole's formula and corrected transverse tracheal measurement differed from zero. While the mean difference between ETT size used in clinical practice and the diameter calculated by the corrected transverse tracheal measurement was statistically equal to zero (p>0.05), the difference between the tube size used in clinical practice and the diameter obtained by the Cole's formula differed significantly from zero (p=0.03) (Table 3).

Table 4 indicates the linear regression analysis of the averages of ETT diameters used in clinical practice and the diameters calculated by Cole's formula and the corrected transverse tracheal measurement, evaluating proportional bias. There was no proportional bias in terms of the compatibility between the tube diameter used for intubation and the tube diameter calculated by the corrected transverse tracheal measurement (p>0.05). However, proportional bias was detected between the tube diameter used for intubation and that calculated by Cole's formula (p<0.01). This supports the conclusion that the tube sizes used in clinical practice are more compatible with the corrected transverse tracheal diameters than those calculated by the Cole's formula in children aged 0-3 years.

Table 1. Distribution of patients' demographic, physical, and clinical characteristics.

Variable	Clinical Diameter (Mean±SD)	Cole's Formula Diameter (Mean±SD)	Corrected tracheal transverse tube diameter (Mean±SD)	Corrected tracheal AP tube diameter (Mean±SD)	Welch	p*
Measurement (mm)	4.37±0.60	4.22±0.20	**4.35±0.69**	4.30±0.71	1.31	0.27

**Welch test p-value*

Table 3. Test of difference from zero for mean differences between tube diameters used clinically and the diameters obtained using corrected transverse tracheal measurements and Cole's formula.

Measurement differences	(Mean±SD)	t*	p*
Clinical Diameter – Corrected transverse tracheal diameter measurement	0.02 ± 0.44	0.3	0.75
Clinical Diameter – Cole's Formula Diameter	0.15 ± 0.45	2.2	0.03

** One-sample t-test (ref=0)*

Table 4. Linear regression analysis of the averages of ETT diameter used clinically and the diameters derived from corrected tracheal transverse measurement and Cole's formula, with evaluation of proportional bias.

Variable		b	S(b)	T	p
Clinical diameter and the transverse measurement	**Constant**	0.73	0.49	1.5	0.14
	Average of clinical diameter and transverse measurement	-0.16	0.11	-1.5	0.15
Clinical diameter and Cole's formula diameter	**Constant**	-4.48	0.32	-13.9	<0.01
	Average of clinical diameter and Cole's formula diameter	1.08	0.08	14.4	<0.01

b: Regression coefficient, S(b): Standard error of the regression coefficient

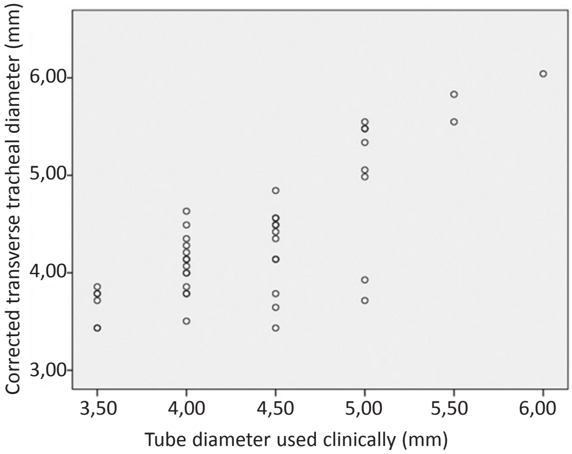

Figure 4. Scatter plot of the corrected transverse tracheal diameter measurement and the endotracheal tube diameter used clinically.
r=0.72, p<0.01

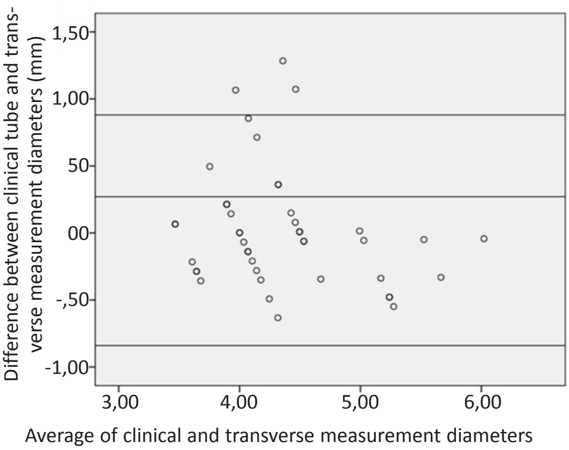

Figure 5. Bland-Altman plot for clinical diameter and corrected tracheal transverse measurement diameter differences and averages.

DISCUSSION

In this study, we retrospectively reviewed the files of the pediatric patients aged 0 to 3 years who underwent cardiac surgeries due to congenital heart disease following preoperative CT imaging that enabled tracheal measurements. We compared the ETT diameters used in clinical practice with diameters calculated by Cole's formula and the diameters measured at the subglottic transverse and AP levels from the patients' CT images. As those tracheal measurements from CT images corresponded to the outer diameter of an ETT, we used a correction formula to determine an inner diameter. The ETT number corresponding to the inner diameter was recorded. Our results demonstrated that ETT sizes used in clinical

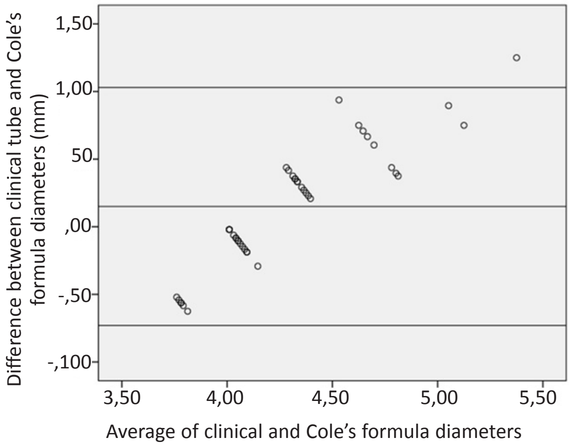

Figure 6. Bland-Altman plot for clinical diameter and Cole's formula diameter differences and averages.

practice were more compatible with the corrected transverse tracheal diameters compared to those calculated by Cole's formula.

Different studies have also shown that the conventional formulas used for determining ETT sizes were insufficient for pediatric patients. Since the human body has structural variations among various populations, the use of the same formulas to determine the most appropriate ETT size for children in different countries has yielded discrepant results. Wang et al. have reported that, unlike in Caucasian populations, the best correlation in determining ETT size for Chinese children was related to the height [9]. Similarly, Shima et al. have also reported a correlation with height in their study of Japanese children [10]. In contrast, Türkistani et al. have observed a correlation between an age-based formula and the fifth finger's diameter in determining the ETT diameter [11]. In a thesis study conducted by Onuk et al. to examine the suitability of conventional formulas for the Turkish population, the discrepancy between the calculated and the used ETT sizes were reported at a rate of 56.3%, and it was found that the Cole's formula yielded a larger ETT size [3].

Wani et al. have retrospectively analyzed the CT images of 220 children aged one month to 10 years who underwent radiological examination [8]. The CT scans were obtained during natural sleep or under sedoanalgesia. The AP and the transverse diameters were measured at the subglottic level and from the cricoid ring. The transverse diameter was narrower than the AP diameter, indicating that the airway was elliptical just below the vocal cords. Their study demonstrated that the airway between the subglottic region and the cricoid ring in children changed from an elliptical to a circular shape. A cone-shaped airway was not observed. The subglottic transverse diameter was the smallest size measured, and this region was most likely to be resistant to the ETT insertion. This study showed that the narrowest part of the airway in pediatric patients, especially in the transverse measurements, was the region just below the vocal cords, but not at the level of the cricoid ring [8].

In their study, Coordes et al. have made tracheal measurements on CT scans of the patients over 16 years of age [12]. They stated that although many intubations were performed each day, there was no evidence-based guideline on tube selection and placement and that manufacturers also failed to provide evidence-based recommendations. This was even more critical for children, especially those between 0-3 years of age with congenital heart disease, which was similar to our study group.

In their study of 141 pediatric patients under eight years old, Bae et al. have used a similar regression equation to demonstrate that the correct ETT size was chosen for 60% of the patients when USG was used whereas an age-based formula pointed the correct tube size only for 31% of the patients [1]. They concluded that although it was more useful than age-based formulas, even USG was not a completely reliable method for determining the appropriate tube size for children.

We also determined, based on our review of the literature, that both formulas and USG were insufficient for selecting the best tube size, especially in the age group of 0-3 years [1,2]. We believe that the subglottic tracheal diameters measured from preoperative CT scans may be useful in determining the appropriate ETT size, especially for this age group of children with congenital heart disease. Children in the 0–3 year age group were scanned preoperatively under sedation with spontaneous breathing. The measurements, corresponding to the outer diameter of the ETT, were made by a radiology specialist, and the inner diameter of the ETT was calculated using the correction formula specified by Bae et al [1].

Our findings suggest that the ETT sizes used in clinical practice for children aged 0-3 years are more compatible with the diameters obtained from the corrected transverse tracheal measurements on CT compared to those calculated by the Cole's formula. Further studies with larger sample sizes and different patient groups are needed.

Limitation: The major limitation of our study is the low number of patients, since it is conducted on children in 0-3 years of age who had thorax CT either for diagnosis or for treatment, before congenital cardiac surgery. More comparative studies are needed in different age groups who have thorax CT scans for different purposes before surgery.

CONCLUSION

We believe that the corrected transverse tracheal diameter measured from CT scan is more effective and accurate in determining the ETT size for the pediatric patients between 0-3 years of age when compared to the conventional formulas used in clinical practice to determine the tube size. However, this method is more appropriate if CT scans have already been obtained for the purpose of treatment and /or surgical planning or modification.

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