Predicting Tracheal Airway Size in Adolescent Patients

Jia Ying Zheng, BS[1†], Vincent M. Desiato, MD[2], Shweta S. Kumar, MD[2], Aileen Wertz, MD[2], and Evan B. Young, MD[2]
[1]Geisinger Commonwealth School of Medicine, Scranton, PA 18509
[2]Geisinger Medical Center, Danville, PA 17822
[†]Doctor of Medicine Program
Correspondence: jzheng@som.geisinger.edu

Abstract

Background: The relationship between tracheal airway size and BMI has not been investigated in the adolescent population. Currently in pediatric patients, tracheal tube size is selected according to patient age. We aimed to determine if there is a relationship between patient characteristics including age, height, weight, and body mass index (BMI) and tracheal airway dimensions in adolescent patients.

Methods: Retrospective case series of patients aged 13 to 18 years old who underwent head and neck computed tomography (CT) at our institution from Jan. 1, 2009, to Dec. 31, 2019. Measurements were taken at the level of cricoid (subglottis) and narrowest anterior-posterior (A-P) diameter of the trachea. AP diameter, lateral diameter, and cross-sectional airway area were measured. Data analysis was done using bivariate analysis followed by linear regression to determine patient characteristics independently associated with tracheal airway size.

Results: 156 neck CTs were eligible. Height and age were significantly associated with tracheal airway dimensions for both female and male patients (F: $p < 0.001$; M: $p < 0.02$). Weight and BMI were not associated with tracheal airway size (F: $p > 0.1$; M: $p > 0.1$). Linear regression modeling for both genders has a positive association with height at all airway levels, including at the narrowest A-P diameter and narrowest lateral diameter, which was always at the subglottis.

Conclusion: Our results show estimating endotracheal tube size should consider height and patient's age, but not weight or BMI.

Introduction

Estimating tracheal airway size for endotracheal tube (ETT) placement is challenging. A too-narrow tube provides inadequate airflow and ventilation (1). Using a larger-than-necessary tube is associated with increased morbidity due to laryngeal and tracheal trauma (2). Complications can include sore throat, hoarseness, vocal cord injury, acute laryngeal injury, granulomas, and laryngotracheal stenosis (3, 4). In adult populations, there are conflicting methods and no widely accepted guidelines for determining ETT size. Health staff often rely on clinical judgment (5, 6). A retrospective study found that larger endotracheal or tracheostomy tubes are often used in patients with a higher BMI, but that increases in body mass are not associated with increased tracheal size in adult patients; in fact, often the opposite is true (7).

Currently, in pediatric patients, tracheal tube size is selected according to patient age (Cole formula: ID [inner diameter] = 4 + age/4 for uncuffed tube; Motoyama formula: ID = 3.5 + 4/age for cuffed tube in children aged 2 or more years; Khine formula: ID = 3.0 + 4/age for cuffed tube in children under 2 years of age) (8). Pediatric patients not only have a diverse range of body dimensions, but selection may be influenced by factors such as patient gender and body habitus. Studies have investigated the viability of using other methods besides the traditional age-based formulas to predict ETT size. In limited studies, ultrasonography was used to measure the subglottic upper airway (9) and, in another, diameter measurements of the epiphysis of the radius (10) were found to be correlated with ETT size.

The relationship between tracheal airway size and BMI has not been investigated in the adolescent population. The adolescent population contains a diverse range of body dimensions. There is an additional challenge in that pediatric age-based formulas may not be accurate, and yet adult guidelines do not apply either. Multiple intubation attempts lead to greater risk of injury. A study found that the cross-sectional size of the trachea was 25% (218± 44 vs. 163±24 mm^2, P<0.01) larger in males vs. females among ages 13–17 years (11). In this project, we aimed to determine the relationship between patient characteristics including age, height, weight, and BMI and tracheal airway dimensions in the population of adolescent patients.

Methods

This is a retrospective case series of patients aged 13 to 18 years old who underwent head and neck computed tomography (CT) at our institution from Jan. 1, 2009, to Dec. 31, 2019. Exclusion criteria were history of craniofacial or musculoskeletal abnormalities, tracheotomy/airway surgery prior to CT, head and neck malignancy, premature birth (<34 weeks) Variables gathered were age, gender, height, weight, and BMI.

A single investigator collected measurement data using dedicated medical imaging software Aquarius TeraRecon version 4.4.14.P1 (52), which provides a 3D reconstruction of the airway. Measurements were taken at the level of cricoid which is synonymous with subglottis/narrowest lateral measurement (1–2 cm below glottis using visual exam and confirmation with TeraRecon) and narrowest anterior-posterior (A-P) diameter of the trachea. These measurements included A-P diameter, lateral diameter, and cross-sectional airway area.

Data analysis was performed using Graphpad Prism. Bivariate analysis followed by linear regression was used to determine patient characteristics independently associated with airway size. Measurements of airway size that were included in data analysis included narrowest A-P and lateral diameter, as well as A-P and lateral cross-sectional area. Comparison across gender was accomplished using independent t test.

This study received IRB approval (#2020-1090).

Results

In this investigation,156 patients were included in which 73 (47%) were female. Three hundred twenty-five CT scans were initially identified as performed during the study period on patients in the proposed age range. There were 169 patients who were excluded due to history of craniofacial or musculoskeletal abnormalities, tracheotomy/airway surgery prior to CT or MRI, head and neck malignancy, premature birth (<34 weeks), and repeated CTs (in which the earliest CT in date range was used). The BMI range for males was 17.5 to 47.9 and was 15.8 to 43.1 for females. See Table 1 for demographic information and clinical characteristics.

	Entire Sample (n=156)	Female (n=73)	Male (n=83)	P value
Age (Y)	16.41 (1.68)	16.34 (1.73)	16.5 (1.65)	0.6522
BMI (kg m^{-2})	25.67 (6.74)	25.17 (5.87)	26.1 (7.46)	0.3875
AP (mm)	12.9 (2.45)	13.23 (2.61)	12.6 (2.28)	0.1085
Lateral (mm)	8.89 (1.55)	8.76 (1.6)	9.0 (1.47)	0.3577
AP Cross Sectional Area (mm^2)	151.55 (46.75)	152.9 (52.91)	150.3 (42.99)	0.7343
Cricoid Cross Sectional Area (mm^2)	112.4 (35.08)	108.2 (35.87)	116.2 (34.14)	0.2322

Table 1. Descriptive statistics for entire sample and stratified by gender, data obtained from CT head and neck done at Geisinger Commonwealth Medical Center from Jan. 1, 2009, to Dec. 31, 2019. Values are the mean (SD). P-values are for independent t-test result between male and female. BMI, body mass index; AP, anteroposterior measurement at narrowest point in trachea; lateral, lateral measurement at cricoid.

	AP (Trachea)		Lateral (Cricoid)		Airway Area (Trachea)		Airway Area (Cricoid)	
	Estimate (SE)	P-Value	Estimate (SE)	P-Value	Estimate (SE)	P-Value	Estimate (SE)	P-Value
Male								
BMI(kg m^{-2})	-0.0172 (0.0338)	0.6111	-0.0178 (0.0218)	0.4168	-0.464 (0.638)	0.4687	-0.312 (0.507)	0.5402
Age (yr)	0.271 (0.151)	0.07641	0.122 (0.098)	0.2191	6.87 (2.80)	0.01626**	4.50 (2.25)	0.04869**
Weight (kg)	0.0161 (0.0117)	0.1729	0.00388 (0.00765)	0.6132	0.356 (0.220)	0.1090	0.210 (0.176)	0.2360
Height (cm)	0.107 (0.0208)	1.752E-06**	0.0525 (0.0144)	0.0004545**	2.38 (0.367)	6.675E-09**	1.61 (0.312)	1.6286E-06**
Female								
BMI (kg m^{-2})	-0.0216 (0.0527)	0.6830	0.0081 (0.033)	0.8069	-1.45 (1.06)	0.1739	0.315 (0.724)	0.6654
Age (yr)	0.257 (0.165)	0.000848**	0.297 (0.120)	0.01600**	13.4 (3.26)	0.0001**	6.29 (2.34)	0.0090**
Weight (kg)	0.0029766 (0.016411)	0.07393	0.0199 (0.0103)	0.05627	0.529 (0.335)	0.1186	0.594 (0.220)	0.008602**
Height (cm)	0.0999 (0.0216)	1.68E-05**	0.0499 (0.0143)	0.00084**	2.53 (0.401)	2.17E-08**	1.34 (0.300)	2.82E-05**

Table 2. Bivariate Analysis. All airway lateral measurements in mm and area in mm^2. ** Statistically significant correlations. Data obtained from CT head and neck done at Geisinger Medical Center from Jan. 1, 2009, to Dec. 31, 2019.

The narrowest A-P diameter was found to always be the trachea. Narrowest lateral diameter was always at subglottis, synonymous with cricoid. These measurements were included in data analysis. Height and age were found to be correlated with CT A-P/lateral diameters and A-P/lateral cross-sectional airway area, as shown in Table 2. Height and age were significantly associated with tracheal airway dimensions for both female and male patients (F: $p=2.17E-08$, $p=0.0001$; M: $p=6.675E-09$, $p=0.01626$). Weight and BMI were not found to be significant predictors (F: $p=1186$, $p=0.1739$; M: $p=0.1090$, $p=0.4687$).

Linear regression modelling (Figure 1) showed significant associations for females with height and age on both tracheal A-P and cricoid lateral diameters and A-P and cricoid cross-sectional airway area. Age was a significant predictor of airway dimensions, including narrowest A-P ($p= 0.0001$), A-P cross-sectional area ($p=0.0008$), cricoid lateral ($p=0.0021$), and cricoid cross-sectional area ($p= 0.0160$). Females also demonstrated an increased cricoid cross-sectional area with increased weight, but this relationship is not consistent with BMI trends or repeated in other airway measurements or in males.

Although BMI and weight did not show statistical significance, Figure 2 shows the trend for smaller airway size when plotted against BMI. The male patient with a BMI of 17.5 had an A-P tracheal airway measurement of 14.6 mm and a subglottis of 9.8 mm. The male patient with a BMI of 47.9 had an A-P tracheal airway measurement of 9.8 mm and a subglottis of 8.67 mm in comparison. There was no statistically significant difference in height vs airway size between sexes (Table 1). There appears to be a larger A-P diameter measurement in females compared with males, but this was not shown to be significant ($P= 0.1085$). However, males had larger lateral diameter compared to females. Again, this was not found to be significant ($P=0.3577$).

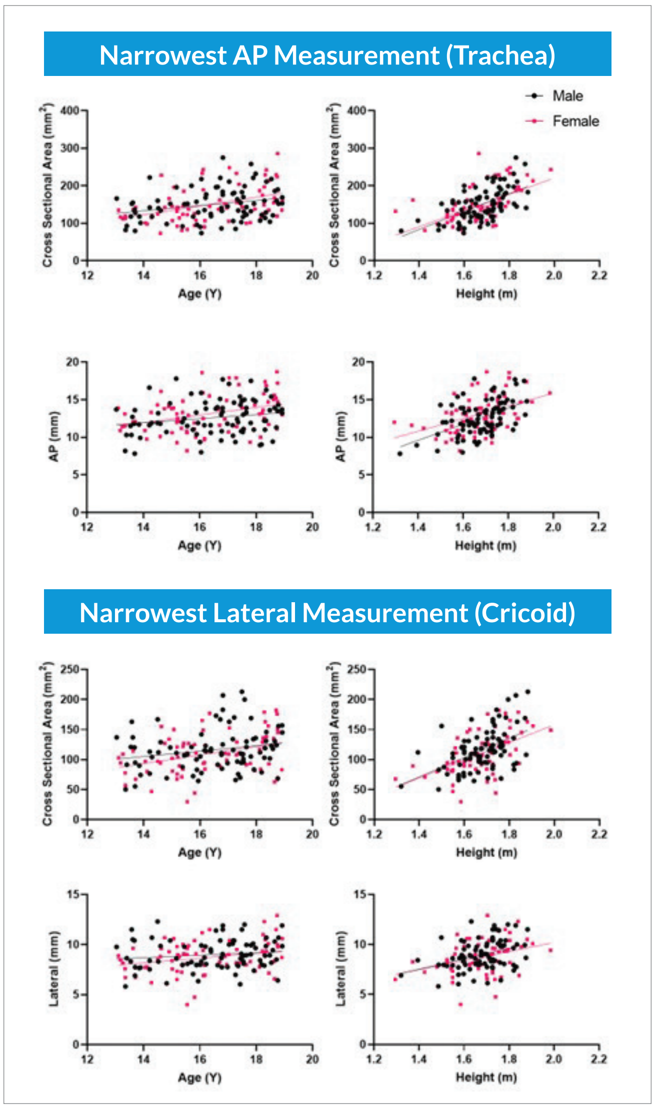

Figure 1. Linear regression modelling of cross-sectional area and diameter at the narrowest AP and lateral airway measurements. Figures on the left show effect of age and on the right shows effect of height. None are significantly different between sexes.

Discussion

The most important finding of this investigation is that height was most strongly positively correlated with cricoid area and narrowest tracheal area. An important secondary finding was weight and BMI were not associated with airway size, which differed from previous findings in adults that suggested they do (7). Current studies support that boys and girls have similar dimensions of the airways from birth until approximately age 14 (11). After this age, there is a difference between sexes, with significantly larger tracheal dimensions being found in boys than in girls (11). This difference is likely because of puberty (9), when growth of the central airways continues in boys and starts to decline in girls. Our results did not show a significant difference between sexes, and we did not further analyze the different in growth after age 14 but age itself was a predictor of airway size in both sexes. Age was a significant predictor of A-P and airway area, cricoid and airway area in female patients. Age was also a significant predictor in male patients, but only for cricoid and A-P airway area (Table 2).

Another report showed that patients with elevated BMI may have smaller tracheal sizes in various dimensions than normal or low weight patients (12). However, the categorization for adolescent BMI is different from categorization for adults and

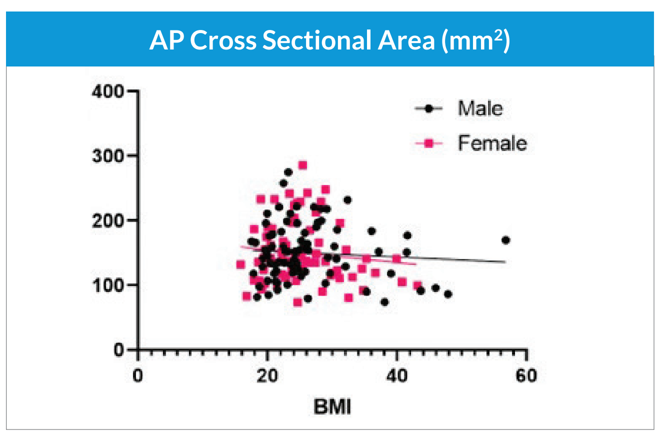

Figure 2. BMI vs AP Cross-Sectional Area. Not statistically significant but suggests trend of smaller airway measurements with increasing BMI. Male: slope=-0.4643 $R^2=0.0065$, $p=0.4688$; Female: slope= -0.9919, $R^2=0.01516$ and $p=0.3029$.

varies by age percentile and gender (13), so this should be a consideration.

It would be of interest to see how this study can be applied to a more diverse patient population. One hundred thirty-nine patients (89%) in this study were White, which may affect the applicability of this information in practice. Of the estimated 4,424 pediatric tracheostomies that occurred in 2012, 51% were ≤3 years old, and 62% were male. Nearly half (48%) were White, followed by Black (21%), Hispanic (20%), and Asian (3%) (14). There are preliminary studies suggesting that among pediatric Chinese populations, endotracheal tube size should be smaller (15), but this has not been extensively studied. A study with a population that includes patients of various heights, weights, body mass indexes, and ethnicities may be beneficial and more applicable to other adolescent populations.

A limitation of this study is that it was a retrospective chart review of a limited population. CT images obtained were not all conducted with the same protocol or have the same image quality. There are cross-section changes during breathing which could potentially affect airway dimensions. Another limitation of this study is the inability to completely exclude the potential of some degree of underlying pathologic airway disease that could lead to airway changes, despite adherence to the exclusion criteria.

Conclusion

Our results show estimating endotracheal or tracheostomy tube size should consider height and the patient's age. We may also consider in the future whether race and gender have any effect. A study with a population that includes patients of various heights, weights, body mass indexes, and ethnicities may be beneficial and more generalizable to other pediatric/adolescent populations.

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Disclosures

The authors have nothing to disclose.

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