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Original Article

Normative data for trachea and main bronchi dimensions on computed tomography in children and adolescents

Emine Caliskan[1], Ozan Berk Gul[2], Mehmet Ozturk[3]

[1]Clinic of Pediatric Radiology, Dr. Lutfi Kirdar Kartal Education and Research Hospital, Istanbul, Turkey
[2]Department of Radiology, Faculty of Medicine, Selcuk University, Konya, Turkey
[3]Department of Pediatric Radiology, Faculty of Medicine, Selcuk University, Konya, Turkey

Abstract

Aim: To determine the reference values for trachea and main bronchi dimensions in children and adolescents using CT and to evaluate correlations with age and sex.

Material and Methods: This retrospective study evaluated 150 cases (75 males, 75 females) with the median age of 9 (6-14) years. Cases were divided into three groups according to age of 4-7 years (n=50, preschool), 8-12 years (n=50, school), and 13-17 years (n=50, adolescent). The dimensions of trachea segments (proximal, middle, distal parts), and right and left bronchi were measured on coronal CT images. Comparisons were made between age groups and sex in terms of these variables.

Results: The proximal, middle and distal sections of the trachea had median dimensions of 0.91 (0.79-1.08)cm, 1.08 (0.96-1.22) cm and 1.17 (1.06-1.32)cm, respectively. The order from statistically largest to smallest was distal, middle and proximal levels ($p<0.001$). The dimension of the right main bronchus was significantly larger than the left one ($p<0.001$) (median dimension for right 1.11 [0.96-1.30]cm, for left 1.04 [0.91-1.22]cm). There were no significant differences between the genders for main bronchi and trachea proximal and middle sections in terms of size. The trachea distal dimension was significantly larger in males compared to females ($p=0.036$). There were significant differences for all airways dimensions between the age groups ($p<0.001$) (from largest to smallest; adolescents, children, preschoolers).

Conclusion: Quantitative normative data were determined for the central airways of children and adolescents using coronal CT. These values may be used for diagnosis and management of medical procedures in routine practice.

Keywords: Adolescents; bronchus; children; computed tomography; trachea, reference values

INTRODUCTION

The trachea extends from the lower part of the cricoid cartilage to the carina and is divided into two main bronchi. The right main bronchus is shorter, has a more vertical course, and originates more superiorly than the left main bronchus. In children, many diseases like cystic fibrosis, bronchiolitis, bronchiolitis obliterans, asthma and hypersensitivity pneumonitis affect the small airways (1,2). However, a variety of congenital and acquired abnormalities like tracheobronchomegaly, tracheobronchomalasia, congenital or acquired stenosis, mediastinal mass, foreign object aspiration, and extrinsic compression by vascular anomalies may change the dimensions of the trachea and bronchi (3-5). Abnormalities may either diffusely or focally involve the central airways. Death and morbidity may be caused linked to severe and chronic respiratory problems.

Computed tomography (CT) of the chest is a cross-sectional evaluation of the central airways. Different to bronchoscopy, chest CT scanning is a noninvasive, fast and painless radiologic method that provides objective measurements of central airway dimensions. Since multislice images can be obtained from two-and three-dimensional reformatting, chest CT scan is more useful than X-ray for demonstrating the intrathoracic vessels, lungs and the tracheobronchial tree (6,7). Due to technological advances in recent years and dose reduction techniques in children, the use of CT in daily practice has become widespread. In recent years, advanced imaging techniques like MR imaging have attracted attention due to capability to assess lungs and airways (8,9). Though CT, accepted as the gold standard imaging method, ensures perfect resolution of the anatomic structures of the lungs and respiratory tracts, high ionizing-radiation exposure is still the major limitation in children.

“Normality” cannot be easily defined other than by statistical assessment of distributions of population data. Due to the harmful effects of ionizing radiation in

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Corresponding Author: Emine Caliskan, Clinic of Pediatric Radiology, Dr. Lutfi Kirdar Kartal Education and Research Hospital, Istanbul, Turkey **E-mail:** eminecaliskanrad@gmail.com

the pediatric period, the CT is used less compared to adults. Many radiologists and clinicians develop mental templates for normal CT appearance of trachea and main bronchi. However, it can be said that the normal values are a gray area in reality. As a result, it will be more objective and beneficial to determine the normal values numerically. Accurate information about tracheobronchial anatomy is important for performing a variety of airway maneuvers during surgical approaches to the thoracic cavity, endotracheal intubation in anesthesiology and bronchoscopic removal during foreign object aspiration. Additionally, knowing the normal measurements may be a road marker for radiologic diagnosis of congenital and acquired diseases in the pediatric period. The aim of this study was to determine the reference normal values for trachea and main bronchi dimensions in children and adolescents using CT and to evaluate correlations with age and sex.

MATERIAL and METHODS

This study received local ethics committee permission (2018/271). The study was completed in accordance with the principles of the Helsinki Declaration. As the study was retrospective, 'informed consent' was not obtained from parents. No personal information belonging to cases is given. Radiologic images given as examples are presented without names. Using thorax CT for prospective and systematic evaluation of central airways in growing children involves exposure to ionizing radiation. As a result, it is not accepted as ethical. This single-center study overcame this limitation to obtain pediatric CT reference values by using retrospective thorax CT taken for a variety of clinical indications.

This study investigated a total of 150 cases, 75 males and 75 females, with ages ranging from 4-17 years (median age: 9 [6-14] years), with thorax CT taken between January 2016 and November 2019. All CT images were selected from the hospital automation and archive system (PACS). CTs with any pathologic findings like chest trauma (contusions, rib fractures and pneumothorax), aortic pathologies (dissection, transection), pneumonic infiltrations, diffuse and focal air trapping, foreign body aspiration, peribronchial thickening, bronchiectasis, pleural collections, nodules, hilar, or mediastinal masses, metastasis, congenital anomalies of the thoracic great vessels, and visible endotracheal tube were excluded. Cases with no known chronic disease, normal blood values (patient history such as blood values, consultation notes and surgery notes were reached through the hospital automation system), sufficient image quality (sufficient inspirium, no motion artifacts or mild artifacts present with minimal effect on visualization) and normal thorax CTs were included in the study.

Cases were divided into three groups according to age of 4-7 years (n=50, preschool), 8-12 years (n=50, school) and 13-17 years (n=50, adolescent). The dimensions of trachea segments (proximal, middle and distal parts), and right and left bronchi were measured on coronal CT images. Comparisons were made between age groups and sex in terms of these variables.

CT Scanning

Thorax CT examinations were performed in supine position in a multi-slice CT scanner with or without contrast material (SOMATOM Definition Flash CT 256-slice scanner, Siemens Medical Solutions, Erlangen, Germany). The imaging data for enhanced CT were acquired during intravenous injection of 1.5 to 2 mL/kg of contrast agent at a rate of 1 to 3 mL/s. Saline solution of 5 to 20 mL followed the contrast material. The scanning parameters for both enhanced and non-enhanced CT were 25-30 mA, 80-90 kV, and depending on age and weight, section thickness of 1 mm and reconstruction interval of 0.5 mm. The coronal reformat images were analyzed for each case.

CT image analysis

Investigations were performed by a pediatric radiologist with more than 8 years of pediatric thorax CT experience. CTs were evaluated with a medical monitor used in routine clinical practice and integrated with the hospital automation and archive system. Images were not transferred to a separate work station. Firstly, basal images in the axial plane were visually assessed for normal and abnormal features. If necessary, sagittal, coronal and/or maximum intensity projection (MIP) images obtained from postprocessing reformat images were used. Patients determined to have normal CT had normality confirmed by accessing patient information in the clinical information system. For easier holistic evaluation of the craniocaudal anatomy of the central airways, measurements used coronal images and transverse dimensions. The trachea was separated into proximal, middle and distal parts. The trachea proximal segment was measured transversely at the thyroid gland level, the middle segment was measured at the thoracic entry level and the distal segment was measured immediately above the carina (Figure 1). The right and left main bronchi diameters were measured obliquely in the section equivalent to the center (Figure 2).

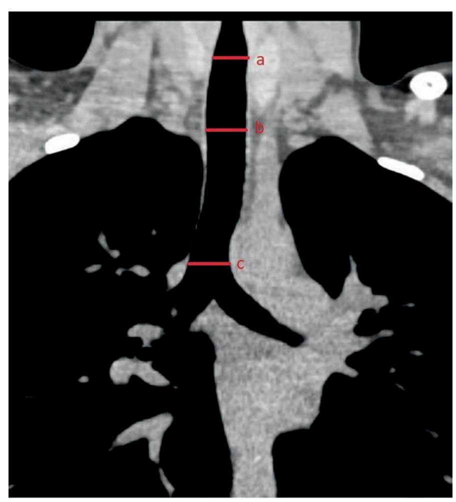

Figure 1. An example of transverse measurements of the proximal ([a] thyroid gland level), middle ([b] thoracic entry level) and distal ([c] just above carina) dimensions of the trachea on coronal CT

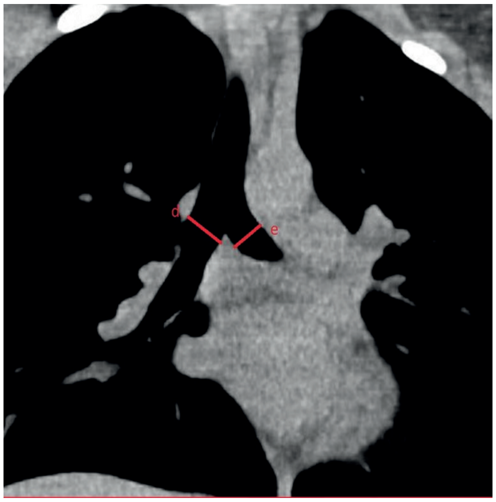

Figure 2. Figure shows how right and left main bronchial dimensions were measured on coronal CT ('d' for right, 'e' for left)

Statistical analysis

Analyses in the study used the SPSS Statistics 22.0 software (IBM Corp., NY, USA) program. Quantitative variables had normal distribution investigated with the Kolmogorov-Smirnov test. Variables with normal distribution in the groups were analyzed with the independent samples t test or one-way ANOVA methods, while variables without normal distribution were analyzed with the Mann Whitney U test. Multiple comparisons used the Tukey or Tamhane's T2 test. Dependent samples were compared with the Wilcoxon T or Friedman test. Spearman correlation analysis was used to investigate whether there were correlations between quantitative variables. Descriptive statistics for quantitative variables with normal distribution are given as mean ± standard deviation, while descriptive statistics for quantitative variables without normal distribution are stated as median (25%-75% percentile). Descriptive statistics for qualitative variables are stated as frequency (%). P values <0.05 were accepted as statistically significant.

RESULTS

Descriptive statistics for gender, age group, age (years), trachea proximal, middle and distal sections, right and left main bronchi dimensions (cm) are given in Table 1. According to Table 2, there were no significant differences between the genders in terms of age, right and left main bronchi dimensions, trachea proximal and middle section dimensions (p>0.05). The distal trachea dimension was significantly larger in boys compared to girls (p=0.036).

Table 1. Descriptive Statistics for Variables

Variable		Descriptive statistic
Gender	Male	75 (50)
	Female	75 (50)
Age group	4-7	50 (33.3)
	8-12	50 (33.3)
	13-17	50 (33.3)
Age (years)	9 (6-14)	
Proximal dimension of trachea (cm)	0.91 (0.79-1.08)	
Middle dimension of trachea (cm)	1.08 (0.96-1.22)	
Distal dimension of trachea (cm)	1.17 (1.06-1.32)	
Left main bronchus dimension (cm)	1.04 (0.91-1.22)	
Right main bronchus dimension (cm)	1.11 (0.96-1.30)	

Qualitative variables given as n(%), quantitative variables given as median (25%-75% percentile)

Table 3 compares the trachea proximal, middle and distal sections and right and left main bronchi dimensions between the age groups. Accordingly, all variables were found to have statistical differences at significant level between the age groups (p<0.001). The mean of all variables is in the order from largest to smallest of adolescents, school and preschool age groups. It was concluded that as age increases, the mean values for trachea proximal, middle and distal sections, right and left main bronchi dimensions increase. According to Table 4, the right and left main bronchi dimensions were found to be significantly different from each other. Accordingly, the right bronchus dimension was larger than the left bronchus dimension (p<0.001).

Table 2. Descriptive statistics and comparison according to group of quantitative variables

Variable	Groups		U	t	p
	Male	Female			
Age	9 (6-13)	9 (6-14)	2762	-	0.849
Left main bronchus dimension	1.04 (0.91-1.30)	1.03 (0.91-1.15)	2497.50	-	0.236
Right main bronchus dimension	1.09 (0.96-1.35)	1.11 (0.95-1.27)	2675	-	0.605
Proximal dimension of trachea	0.96±0.20	0.91±0.17	-	1.715	0.088
Middle dimension of trachea	1.13±0.23	1.08±0.18	-	1.584	0.115
Distal dimension of trachea	1.23±0.21	1.16±0.17	-	2.118	0.036

U: Mann Whitney U test, t: t test

Table 3. Descriptive statistics and comparison according to group of quantitative variables

Variable	Age Groups			F	p
	4-7 Years	8-12 Years	13-17 Years		
Proximal dimension of trachea	0.78±0.12 [a]	0.88±0.09 [b]	1.13±0.13 [c]	123.620	<0.001
Middle dimension of trachea	0.93±0.10 [a]	1.06±0.10 [b]	1.33±0.15 [c]	146.994	<0.001
Distal dimension of trachea	1.03±0.10 [a]	1.17±0.10 [b]	1.39±0.16 [c]	115.436	<0.001
Left main bronchus dimension	0.88±0.09 [a]	1.03±0.10 [b]	1.30±0.16 [c]	155.639	<0.001
Right main bronchus dimension	0.91±0.10 [a]	1.10±0.10 [b]	1.41±0.16 [c]	223.152	<0.001

Similarities between groups shown by letters in same row, differences shown by different letters
F: One-way ANOVA

Table 4. Descriptive statistics and comparison of dependent measurements

Variable	Left	Right	Z	p
Main bronchi	1.04 (0.91-1.22)	1.11 (0.96-1.30)	-7.289	<0.001

Z: Wilcoxon T test

According to Table 5, the dimensions of the trachea proximal, middle and distal sections were found to be significantly different. Accordingly, in the order from largest to smallest, the dimensions are distal, middle and proximal (p<0.001). According to Table 6, there were strong, positive and linear correlations between age with trachea proximal, middle and distal sections and right and left main bronchi dimensions (r=0.808; 0.863; 0.827; 0.841; 0.898, respectively and p<0.001). Accordingly, as age increases, the dimensions of the proximal, middle and distal sections of the trachea and of the right and left main bronchi increase.

Table 5. Descriptive statistics and comparison of dependent measurements

Variable	Proximal dimension	Middle dimension	Istal dimension	χ^2	p
Trachea	0.91 (0.79-1.08) [a]	1.08 (0.96-1.22) [b]	1.17 (1.06-1.32) [c]	239.801	<0.001

Similarities between groups shown by letters in same row, differences shown by different letters
χ^2 : Chi-square test

Table 6. Correlation table for age with trachea and bronchus dimensions

		Proximal dimension of trachea	Middle dimension of trachea	Distal dimension of trachea	Left main bronchus dimension	Right main bronchus dimension
Age	r=	0.808	0.863	0.827	0.841	0.898
	p=	<0.001	<0.001	<0.001	<0.001	<0.001

r: Correlation Coefficient

DISCUSSION

In this study, the normal diameters of central airways in the pediatric cases were assessed using coronal CT. As there are limited numbers of studies about this topic in relation to children in the literature, this study will significantly contribute to the literature.

The epithelium and glands of the trachea and pulmonary epithelium are derived from the endodermal lining of the laryngotracheal tube. The laryngotracheal tube and surrounding splanchnic mesenchyme are the origin for the larynx, the trachea, the bronchi, and the lungs (10). Congenital malformations of the trachea include a variety of conditions that cause respiratory distress in neonates and infants. The most frequent congenital tracheal malformations are: tracheomalacia, congenital tracheal stenosis, laryngotracheal cleft and tracheal agenesis. These diseases and some acquired situations (e.g., stenosis, mediastinal masses, foreign object aspiration, extrinsic compression by vascular anomalies) may change the dimensions of the central airways. In children, airway obstruction and endotracheal tube dimension selection may be important for ear nose throat experts, anesthesiologist and pediatric clinicians (11). Airway problems are observed more frequently in children compared to adults. Children with airway obstruction have structural characteristics making them more defenseless against airway blockage due to even small amounts of edema or mucus causing clear narrowing of the airway. In parallel with technological developments, the entry into routine use of radiologic tests like CT have made diagnosis of these diseases easier. As a result, it will be beneficial to quantitatively know the normal dimensions before stating they are abnormal.

In this study, the distal trachea was found to be wider than the proximal or middle sections. Distal anatomic widening immediately before splitting in two at the carina and bifurcation is plausible. Similarly, Kuo et al. stated in a study of children with CT that the mixed-effects model showed that the distal section was significantly larger than the middle and proximal sections of the trachea (12).

In this study, the proximal and middle sections of the trachea and both main bronchi dimensions were not found to be significantly different between the genders. Distal dimensions were significantly larger in males. Kuo et al. stated that there was no difference in dimensions before the age of 13-14 years (12). They stated that after this boundary, the dimensions were wider in boys than girls after puberty. In the right and left anteroposterior diameter, left transverse diameter, and left and right distance between posterior ends of the first bronchial cartilage in main bronchi, men had longer or wider values than women. A study of adult cadavers found that men had longer or wider values than women for the right and left anteroposterior diameter, left transverse diameter, and left and right distance between posterior ends of the first bronchial cartilage in main bronchi (13). Though there may be small changes due to age groups and ethnic differences, we think this is a similar result. In males, factors like height, weight, BMI and body mass may affect the dimensions of the central airways. This variation becomes more pronounced after the hormonally-activated period of puberty.

According to this study, as age and age group increased, the mean dimensions of the trachea segments and right and left main bronchi increased. The means for all variables can be listed from large to small as 13-17 years, 8-12 years and 4-7 years. Changes in the tracheal dimensions with age in this study are in agreement with those in studies by Griscom and Wohl, Rao L et al., Li H et al. and Seo JH et al. (14-17).

According to the study, the right main bronchus dimension is larger than the left main bronchus dimension. We think this outcome is associated with the excess of lobes and segments in the right lung. Though this knowledge is traditional, the numerical confirmation with normal data in our study makes our study valuable. Some studies in the literature have performed tracheobronchial angle measurements in children with CT (18,19). As ethnicity was proposed to cause some anatomic differences, a similar study involving expanded population or different ethnicities may be a subject for future studies (20).

There are some limitations to our study. The first is the low number of patients. Studies related to this topic may use larger study populations. Secondly, the study did not include children younger than 4 years of age. The third is that it was a retrospective study and we did not collect data about patient height, weight, body mass index or ethnicity. Fourthly, clinical and laboratory data used to support the reality that these subjects were healthy were obtained only from the electronic archive system. We cannot fully exclude potential underlying pathologic changes involving central airways to a degree. Fifthly, measurements were performed by a single radiologist and reliability between measurements could not be assessed.

CONCLUSION

Quantitative evaluation of the central airways by CT provided normative data based on age and gender groups. There were no significant differences between the genders in terms of right and left main bronchi dimensions and tracheal proximal and middle section dimensions. The distal dimension of the trachea was significantly larger in boys compared to girls. As age increased, the dimensions of the three segments of the trachea and both main bronchi increased. This information may be helpful for distinguishing congenital and acquired diseases of central airways in the pediatric age group.

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