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Pediatric Laryngeal Measurements Based on Computed Tomography Images

ABSTRACT

Background: This study aimed to establish average laryngeal measurements in the Turkish pediatric population and measure the narrowest portion of the pediatric airway.

Methods: The laryngeal measurements of 88 pediatric patients between the ages 0 and 17 were retrospectively obtained from neck computed tomography scans performed between January 2018 and May 2021. Subjects were divided into 6 age groups. Four following measurements were made: cricoid anteroposterior, cricoid transverse, subglottic anteroposterior, and subglottic transverse. Cross-sectional areas were calculated using these dimensions. Subglottic cross-sectional area/cricoid cross-sectional area ratio for each subject was calculated and patients were divided into 2 groups: group 1, subjects with ratio < 1; group 2, subjects with ratio ≥ 1.

Results: Mean age was 8.97 ± 5.7. Mean anteroposterior diameters at subglottis and cricoid ring levels were 13.74 ± 4.45 mm and 13.26 ± 4.39 mm; mean transverse diameters were 7.88 ± 2.62 mm and 9.06 ± 3.12 mm, respectively. The subglottic anteroposterior diameter was greater than cricoid ($P < .001$), but the transverse diameter was smaller than cricoid ($P < .001$). Subglottic cross-sectional area was 93.24 ± 59.20 mm^2 and cricoid cross-sectional area was 103.61 ± 69.15 mm^2. Subglottic cross-sectional area/cricoid cross-sectional area ratio was smaller than 1 in 69 subjects (group 1; mean = 0.85) and equal to or greater than 1 in 19 subjects (group 2; mean = 1.33).

Conclusion: The narrowest portion of the airway was subglottis immediately below the vocal cords, in contrast to the common belief as to the cricoid ring. Subglottic cross-sectional area/cricoid cross-sectional area ratios showed that the pediatric airway was larger at cricoid (69 subjects, 78.4%), and this ratio does not differ based on age.

Key words: Pediatric airway, laryngeal diameters, cricoid

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INTRODUCTION

The determination of age-dependent pediatric laryngeal dimensions (LD) is important for the application of appropriate airway equipment, prevention of laryngeal stenosis, and assessment of the pathologic airway in pediatric patients.[1] A norm of age, gender, and ethnicity-based pediatric LD would aid in the determination and use of correct endotracheal tube sizes and therefore lead to a decrease in complications related to intubation. The vast majority of laryngeal stenosis at pediatric age is acquired due to endotracheal intubation.[2] Apart from preventive measures, LD are also important for the diagnosis and outcome assessment of surgical treatment of laryngeal stenosis.

Pediatric airway dimensions vary depending on the age of the patient. As expected, several studies of different populations have found an increase in LD and volume with increasing age.[3-6] Some of these studies have also shown larger LD in pediatric males compared to females in the same age group.[3] Differences in measurements among studies point to possible laryngeal dimension differences among different ethnicities and highlight the importance of determining LD for different populations. To our knowledge, no research was conducted in Turkey to make an estimation of LD in the pediatric population. Therefore, this study aimed to establish average laryngeal measurements for the Turkish pediatric population through the evaluation of the neck computed tomography (CT) images of children.

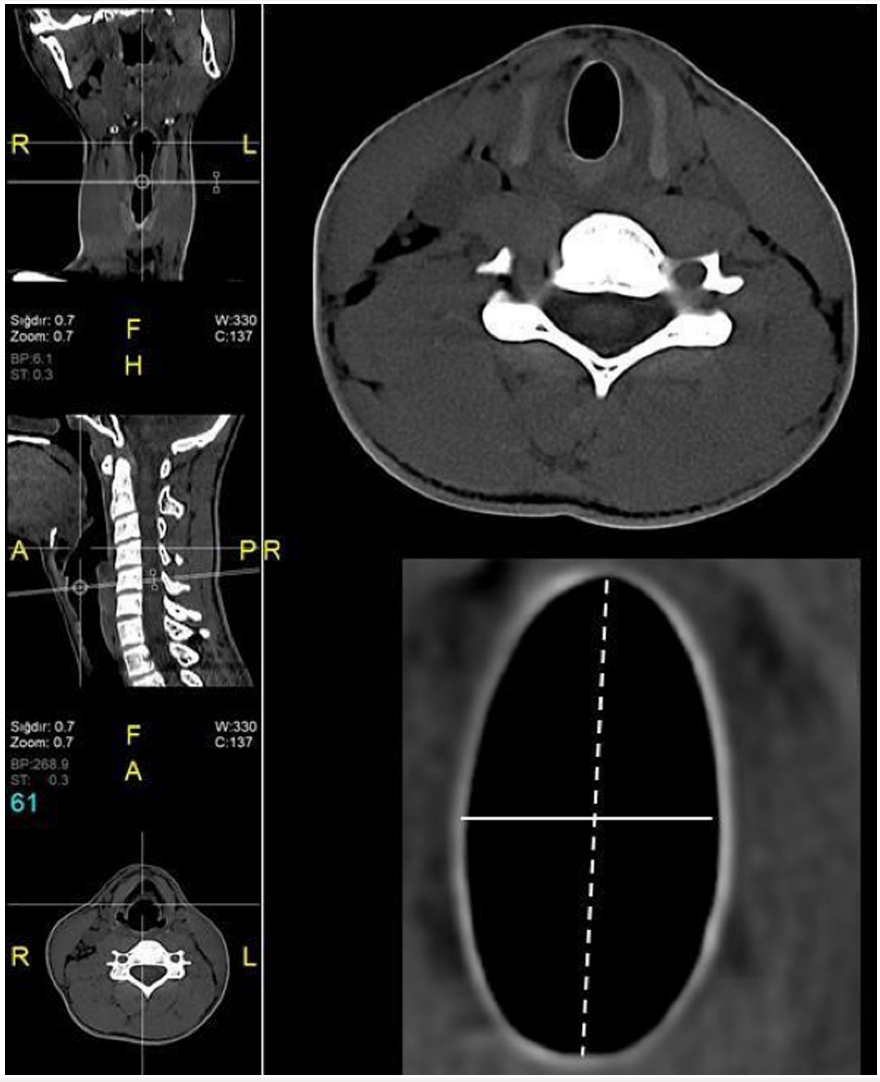

Figure 1. Cricoid measurements of a 14-year-old boy are given as an example. Dashed line: anteroposterior diameter, straight line: transverse diameter.

MATERIAL AND METHODS

Subjects

The medical data of 202 patients aged between 0 and 17 and had undergone a CT scan of the neck in a single tertiary university hospital from January 2018 to May 2021 were retrospectively reviewed. This study was approved by the Ethical Committees of Koç University (2020.035.IRB2.016). The reason for the retrospective structure of the study was to avoid unnecessary radiation exposure. Subjects with prior airway surgery and subjects who had identifiable deformities in their airways on the CT scan were excluded. Finally, 88 subjects were included in the study and they were divided into 6 age groups as follows: 0-11 months; 1 year (12-23 months); 2-3 years; 4-5 years; 6-7 years; 8-9 years; 10-11 years; 12-13 years; 14-15 years; 16-17 years.

MAIN POINTS

- The narrowest portion of the pediatric airway is the subglottis in most subjects.
- The inner transverse diameter of the larynx enlarges in the cranial to caudal direction.
- The intralaryngeal proportions do not depend on age.
- The region most susceptible to intubation trauma is the subglottic region.

Imaging

All patients underwent 256 sliced CT detector (Siemens SOMATOM Definition, Siemens Healthineers, Erlangen, Germany) with a slice thickness of 0.6 mm, and a total of 4 measurements were made: cricoid anteroposterior (AP), cricoid transverse, subglottic AP, and subglottic transverse. Volume rendering images were used for the accurate measurement at the optimal slice position (Figure 1). No sedation or anesthesia was used on patients during imaging. True axial plane images were obtained using the multiplanar reformatted

imaging technique, and all measurements were done on magnified images.

Statistical Analysis

The statistical analysis was performed with the Statistical Package for the Social Sciences for Mac version 26.0 (IBM SPSS Corp.; Armonk, NY, USA). The cross-sectional areas (CSA) were calculated using cricoid diameters and subglottic diameters. The normality tests were conducted, and skewness and kurtosis values were referred for the decision of normally distributed data. Paired samples *t*-test was used for the comparison of the measurements obtained at the level of the subglottis and the cricoid ring. Pearson correlation test was performed to assess the correlation of the increase in LD at the levels of subglottis and cricoid ring with age. The ratio of subglottic CSA/cricoid CSA for each subject was also calculated. According to this ratio, the subjects were divided into 2 groups: group 1, subjects with ratio < 1; group 2, subjects with ratio ≥ 1. The age of the 2 groups was compared using Mann–Whitney *U* test.

RESULTS

A total of 88 subjects aged between 0 and 17 were included in the study with a mean age of 8.97 ± 5.7 years. The number of subjects and mean ages in each age group are shown in Table 1. The relationship of LD with the age showed a strong correlation demonstrating *r* values that ranged between 0.875 and 0.911, so all measurements were found to increase with respect to age; the *r* value for the AP diameters was greater than that of the transverse group. The mean AP diameters at the level of subglottis below the vocal cords and at the cricoid ring were 13.74 ± 4.45 mm and 13.26 ± 4.39 mm; the mean transverse diameters were 7.88 ± 2.62 mm and 9.06 ± 3.12 mm, respectively. The subglottic AP diameter was found to be greater than that of the cricoid ($P < .001$), but the subglottic transverse diameter was found to be smaller than that of the cricoid ring ($P < .001$). It was noted that the AP diameter slightly differs in the axial plane from cranial to caudal direction, in contrast to the transverse diameter, which increases significantly at the cricoid level. Average measurements for each age group are shown in Table 2. Figure 2 demonstrates the 4 measurements and their changes within the age groups, and cross-sectional areas for different age groups are given in Figure 3.

Mean subglottic CSA was 93.24 ± 59.20 mm^2 and mean cricoid CSA was 103.61 ± 69.15 mm^2. The ratio of subglottic/cricoid CSA was less than 1 in 69 of the subjects (group 1; mean value = 0.85) and equal to or greater than 1 in 19 of the subjects (group 2; mean = 1.33). There was no statistically significant

Table 1. Four Laryngeal Measurements of Different Age Groups; Mean Subglottic Anteroposterior (AP), Subglottic Transverse, Cricoid AP, and Cricoid Transverse Diameters in Millimeters

Age Group (years)	N	Subglottic AP (mm)	Subglottic Transverse (mm)	Cricoid AP (mm)	Cricoid Transverse (mm)
0	4	7.40 ± 1.47	3.82 ± 0.54	7.60 ± 1.01	4.85 ±0.52
1	6	8.40 ± 0.32	4.87 ± 0.77	7.90 ± 0.58	5.78 ± 0.51
2-3	6	9.87 ± 1.05	5.18 ± 0.75	9.21 ± 1.09	6.65±0.69
4-5	13	11.38 ± 1.31	6.38 ± 1.15	10.64 ± 1.15	7.09 ± 0.79
6-7	17	11.41 ±0.75	6.89 ± 0.89	10.90 ± 1.05	7.80 ± 0.89
8-9	5	11.40 ± 1.10	7.58 ± 1.82	11.16 ± 1.10	8.62 ± 1.64
10-11	1	12.10	8.40	11.60	8.10
12-13	9	15.44 ± 2.44	9.20 ± 1.77	15.52 ± 2.27	9.93 ± 1.7
14-15	11	18.49 ± 2.10	9.93 ± 0.99	17.94 ± 2.19	11.52 ± 1.65
16-17	16	19.83 ± 2.66	11.27 ± 1.87	19.12 ± 2.49	13.51 ± 2.29
Total	88	13.75 ± 4.46	7.89 ± 2.61	13.26 ± 4.39	9.12 ± 3.04

AP, anteroposterior.

Table 2. Mean Subglottic CSA and Cricoid CSA Measurements of Different Age Groups in mm^2

Age Group	N	Subglottic Cross-Sectional Area (Mean, mm^2)	Cricoid Cross-Sectional Area (Mean, mm^2)
0	4	22.51 ± 7.25	28.87 ± 4.17
1	6	32.05 ± 4.82	35.66 ± 3.17
2-3	6	40.56 ± 8.91	48.60 ± 10.43
4-5	13	57.68 ± 15.32	59.75 ± 12.47
6-7	17	61.74 ± 8.91	66.88 ± 9.56
8-9	5	67.95 ± 16.92	76.35 ± 20.34
10-11	1	79.83	73.79
12-13	9	114.26 ± 39.40	123.60 ± 39.02
14-15	11	145.05 ± 28.40	163.07 ± 35.46
16-17	16	177.84 ± 48.12	205.57 ± 55.64
Total	88	93.34 ± 59.20	104.38 ± 68.35

N, number of patients in each age group; CSA, cross-sectional area.

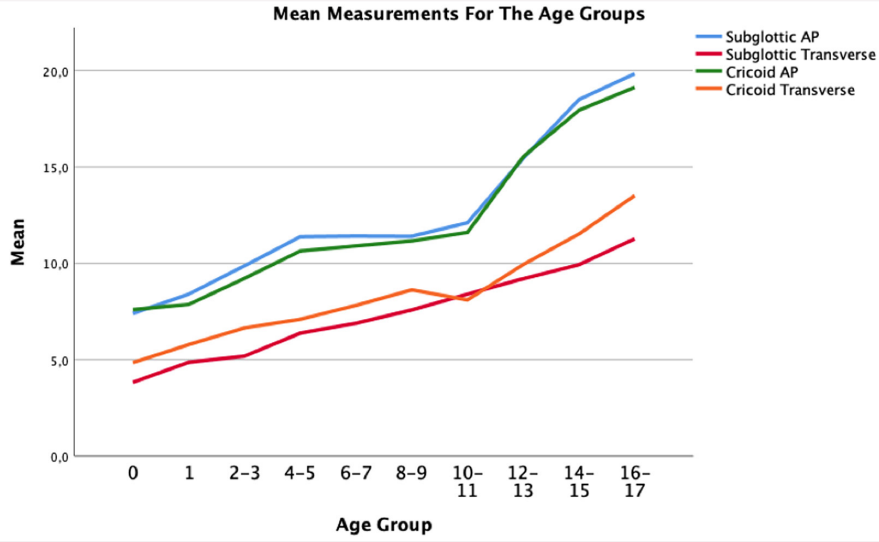

Figure 2. Mean measurements of different age groups. Subglottic AP, subglottic transverse, cricoid AP, cricoid transverse diameters were measured in mm. AP, anteroposterior.

difference between the 2 groups regarding age ($P = .43$). Hence, this ratio was not found to be related to age.

DISCUSSION

The pediatric larynx was believed to be conical or funnel-shaped with the narrowest area at the cricoid ring.[7] This information was adapted from the cadaveric study by Bayeux,[8] in which the measurements were made by preparing a moulage of the cadaveric larynges of 15 subjects. However, this technique might have caused some inaccurate results, as the procedure of moulage could have caused the laryngeal soft tissues of the subglottis to stretch in contrast to the rigid cartilage of the cricoid ring, as Motoyama[9] mentioned. Litman et al[10] published a study on the LD after making measurements on magnetic resonance imaging (MRI) scans of 99 subjects (neonates to 14-year-old) and found the shape of the pediatric larynx to be conical in the transverse dimension with the apex of the cone at the level of the vocal cord, in contrast to the findings of Bayeux[8], and cylindrical in the AP dimension. Dalal et al.[11] reported similar results with their study based on videobronchoscopic images of 128 subjects aged from 6 months to 13 years old. Recent studies based on CT scans have suggested the narrowest area of the pediatric airway to be the subglottic region immediately below the vocal cords.[12,13] As 3-dimensional (3D) imaging techniques advance, our knowledge on the exact shape, narrowest area, and elasticity of the pediatric airway has evolved. Computed tomography scan, compared to MRI, continues to be the better choice for 3D laryngeal imaging and measurements, as it provides a better image quality with better delineation between the air-tissue interface.[14]

Figure 3. Cross-sectional areas of different age groups. Subglottic CSA and cricoid CSA were measured in mm^2. CSA, cross-sectional area.

Table 3. The Number of Patients, Mean Age, Age Ranges, Mean CSAs for Subglottic, and Subglottic Regions in Group 1 and Group 2

	Group 1	Group 2
Number of patients	69	19
Age, mean (years)	9.1	8.2
Age, range (years)	0-18	0-17
CSA, mean subglottic (mm^2)	93.8	91.4
CSA, mean cricoid (mm^2)	109.8	84.4
CSA ratio, mean	0.85	1.08

In our study, CT scan images of pediatric patients which were previously performed for reasons other than airway pathologies constituted the data. The shape of the pediatric larynx was found to be cylindrical when the AP diameters from subglottis to cricoid were analyzed, in contrast to the transverse diameters, which formed a conical shape enlarging from subglottis to cricoid ring in 76 subjects (86.3%). So, the transverse diameter at the level of the subglottis below the vocal cords was the narrowest diameter in most of the subjects in this study group. The CSAs were elliptic both at the level of subglottis below the vocal cords and the cricoid ring, with the longer axis of the ellipse being the AP diameter at both levels. However, the enlargement of the transverse diameter from cranial to caudal provides the airway to be larger at the level of the cricoid when we analyze it according to the subglottic CSA/cricoid CSA ratio, as can be seen in Table 3 (group 1, 69 subjects, 78.4%). Only 21.6% of the subjects (group 2) had subglottic CSA/cricoid CSA ratio of greater than 1 and there was no difference between the 2 groups regarding the age. Hence, it can be suggested that the intralaryngeal proportions do not depend on age but differ among the individuals themselves. The data of group 1 demonstrate that the majority of the pediatric subjects in our study group, regardless of age, have narrower CSA at the level of the subglottic region compared to that of the cricoid region.

As the study findings support that subglottis below the vocal cords is usually the narrowest portion of the pediatric airway, it can be speculated that this level is the most vulnerable region to intubation trauma and should be considered as a reference level for the determination of tube size. Any difficulty in inserting the tube through the vocal cords should warrant downsizing of the tube. When we evaluate the pediatric subglottic airway pathologies, subglottic cysts in children are being diagnosed at an increasing rate in parallel to the increasing rates of neonatal intubation.[15] Considering the relevant anatomy demonstrated in our study, intubation is most likely to traumatize the subglottis immediately below the vocal cords, which is the exact region the subglottic cysts are usually located.

This study aimed to establish average laryngeal measurements in the pediatric population and measure the narrowest portion of the pediatric airway. The research is conducted in a Turkish tertiary center, where the racial background is caucasian. The results of this study can be considered not only valuable for the turkish pediatric population but also for the pediatric population with the caucasian background. Small sample size due to the limited number of CT imaging in the pediatric age group decreases the certainty of these results overall. Nevertheless, our results would be expected to provide a general reference to physicians on pediatric upper airway measurements.

CONCLUSION

This study demonstrated that the narrowest portion of the airway in pediatric subjects was mostly the subglottis immediately below the vocal cords, in contrast to the commonly accepted cricoid ring, and this ratio does not differ based on age, which challenges the longstanding view on the narrowest site of the pediatric airway. These findings may provide useful guide for the performance of more accurate invasive procedures on the pediatric airway.

Ethics Committee Approval: Ethics committee approval was received from the Ethical Committees of Koç University (Approval no: 2020.035. IRB2.016)

Informed Consent: This study was retrospective in nature, hence, written informed consent was not needed to be obtained.

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Declaration of Interests: The authors have no conflict of interest to declare.

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