Pediatric Laryngeal Dimensions: An Age-Based Analysis

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BACKGROUND: In children, the cricoid is considered the narrowest portion of the "funnel-shaped" airway. Growth and development lead to a transition to the more cylindrical adult airway. A number of airway decisions in pediatric airway practice are based on this transition from the pediatric to the adult airway. Our primary aim in this study was to measure airway dimensions in children of various ages. The measures of the glottis and cricoid regions were used to determine whether a transition from the funnel-shaped pediatric airway to the cylindrical adult airway could be identified based on images obtained from video bronchoscopy.

METHODS: One hundred thirty-five children (ASA physical status 1 or 2) aged 6 mo to 13 yr were enrolled for measurement of laryngeal dimensions, including cross-sectional area (G-CSA), anteroposterior and transverse diameters at the level of the glottis and the cricoid (C-CSA), using the video bronchoscopic technique under general anesthesia.

RESULTS: Of the 135 children enrolled in the study, seven patients were excluded from the analysis mainly because of poor image quality. Of the 128 children studied (79 boys and 49 girls), mean values (±standard deviation) for the demographic data were age 5.9 (±3.3) yr, height 113.5 (±22.2) cm and weight 23.5 (±13) kg. Overall, the mean C-CSA was larger than the G-CSA (48.9 ± 15.5 mm^2 vs 30 ± 16.5 mm^2, respectively). This relationship was maintained throughout the study population starting from 6 mo of age ($P < 0.001$, $r = 0.45$, power = 1). The mean ratio for C-CSA: G-CSA was 2.1 ± 1.2. There was a positive correlation between G- and the C-CSA versus age ($r = 0.36$, $P < 0.001$; $r = 0.27$, $P = 0.001$, respectively), height ($r = 0.34$, $P < 0.001$; $r = 0.29$, $P < 0.001$, respectively), and weight ($r = 0.35$, $P < 0.001$; $r = 0.25$, $P = 0.003$, respectively). No significant gender differences in the mean values of the studied variables were observed.

CONCLUSION: In this study of infants and children, the glottis rather than cricoid was the narrowest portion of the pediatric airway. Similar to adults, the pediatric airway is more cylindrical than funnel shaped based on these video bronchoscopic images. Further studies are needed to determine whether these static airway measurements in anesthetized and paralyzed children reflect the dynamic characteristics of the glottis and cricoid in children.

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The pediatric laryngeal and cricoid relationship has been described as "funnel-shaped" with the apex of the funnel at the level of the cricoid.[1] This funnel-shaped airway description, based on a limited number of postmortem airway measurements, forms the anatomical basis for a number of pediatric airway management decisions.[1–3] Recent clinical studies conducted using different measurement techniques measured airway dimensions using two different techniques (magnetic resonance imaging and videobronchoscopy) and found that the glottis is narrower than the cricoid.[4,5] Anatomic airway dimensions in a range of pediatric age groups would help resolve the contrasting airway descriptions and determine whether, and when, a transition occurs from the funnel-shaped pediatric airway to the more cylindrical adult airway. In addition, a method to measure the airway might

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also be useful to evaluate the formulae used for endotracheal tube sizing (ETT) using age as a determinant for calculation of ETT size[6–9] and determine the utility of current recommendations for the transition from uncuffed to cuffed ETTs.[10–12]

In current pediatric practice, the advantages of cuffed ETTs,[13,14] improvements in cuff and tube design,[15,16] cuff pressure monitoring, and the absence of airway sequelae associated with using cuffed tubes have led to this trend in practice.[17,18] The majority of conclusions that support ETT sizes and cuffed tubes are based on observations of the cricoid ring (ellipsoidal versus circular) and an absence of ETT-related complications rather than direct measurements of the glottic and cricoid dimensions. Age-based anatomic changes in the larynx have several clinical implications, including the use of cuffed versus uncuffed ETTs in children.

The purpose of this study was 1) to measure pediatric airway dimensions of various ages to establish the relationship between the glottis and cricoid dimensions related to growth and development and 2) to determine when, and if, a transition occurs from the funnel-shaped airway observed in children to the more cylindrical adult airway. If a transition in airway dimensions, particularly the glottis and cricoid dimensions, could be defined, then advice about airway management, such as the use of cuffed versus uncuffed tubes, could be based on anatomic airway dimensions.

METHODS

After approval by the IRB at both the participating institutions and written informed parental consent, 135 children aged 6 mo to 13 yr were investigated for measurement of dimensions of the larynx at the level of the glottic opening and at the level of the superior aspect of the cricoid ring using the video bronchoscopic technique. All children were ASA physical status 1 or 2. Children with known abnormalities of the airway were excluded from the study. Midazolam, 0.5 mg/kg was administered orally as premedication at the discretion of the attending anesthesiologist. After application of standard monitoring (pulse oximeter, electrocardiogram, and noninvasive arterial blood pressure), all children were induced by an inhaled anesthetic induction technique using nitrous oxide-oxygen-sevoflurane followed by establishment of IV access. Rocuronium (0.5 mg/kg), IV, was administered to achieve neuromuscular blockade of the upper airway muscles. At the beginning of the procedure, in each patient, a size 5 French suction catheter was taped to a rigid telescope such that a fixed distance (1.5 cm or 2 cm) of the catheter protruded from the tip of the telescope. A video bronchoscopic image of a graph paper with a least count of 1 mm with the tip of the catheter touching the graph paper was first obtained. At induction, before bronchoscopy, the mode of ventilation of the patient was at the discretion of the anesthesiologist. After administration of the muscle relaxant, the patient's lungs were manually ventilated with oxygen: sevoflurane technique until the insertion of the laryngoscope followed by the bronchoscopic telescope by the otolaryngologist. After appropriate positioning (supine with extension of the head and neck using a shoulder roll), the video bronchoscopy was performed using the same telescope-suction catheter assembly and the Storz video endoscopy system (distributed by Karl Storz Endoscopy-America, Culver City, CA, Copyright Karl Storz GmbH & CO KG, Tuttlingen, Germany).

Upon insertion of the Hopkins telescope alone (size 4 mm), glottic views and transglottic views at the level of the cricoid cartilage were obtained. The laryngoscopy and bronchoscopy were thus performed using an "apneic" technique (i.e., no positive pressure ventilation). The patients were apneic when the video of the glottis and cricoid was obtained. Obtaining the airway images required less than 1 min (20–45 s). In all children, Sp_{O_2} was maintained >95% throughout the glottic and cricoid measurements. Tracheal measurements were not obtained primarily because of the desire to limit the duration of bronchoscopy.

With the catheter tip touching each of the two regions of interest under consideration, video telescopic movie clips of the glottis and the subglottis at the level of the superior aspect of the cricoid ring were obtained. Still image frames of the regions of interest were obtained and converted to JPEG format using either Windows media player classic or QuickTime player (QuickTime Player 7.0.3 Copyright 1991–2005, Apple Computer, Cupertino, CA) and the ACDSEEpro (version8.1 [Build 99] copyright 2005 ACD systems) computer software. Any distortion corrections of the images were made using the ACDSEEpro computer software. The cross-sectional areas (CSAs) and diameters (anteroposterior, AP and transverse, trans) of the images (glottis and the cricoid) were analyzed offline (Figs. 1a–c) by a blinded observer using the ImageJ (1.33u, Wayne Rasband WS, US National Institute of Health, NIH, Bethesda, MD, http://rsb.info.nih.gov/ij/) software.

In all study patients, the relationship between the cricoid CSA (C-CSA) and the glottis CSA (G-CSA) was also studied by analyzing the ratios between the two measurements (i.e., C-CSA:G-CSA).

Statistical Analysis

Statistical analysis was performed using the SIGMASTAT version 3.1, copyright SYSTAT software, San Jose, CA. For each of the variables in the three groups, the results are described as mean and standard deviation (SD). Linear regression analysis and Pearson product moment correlation were used for data on G-CSA and C-CSA, as well as trans and AP diameters of the glottis (G-trans, G-AP), and the cricoid (C-trans, C-AP) regions versus the three independent variables, i.e., age, height, and weight. For

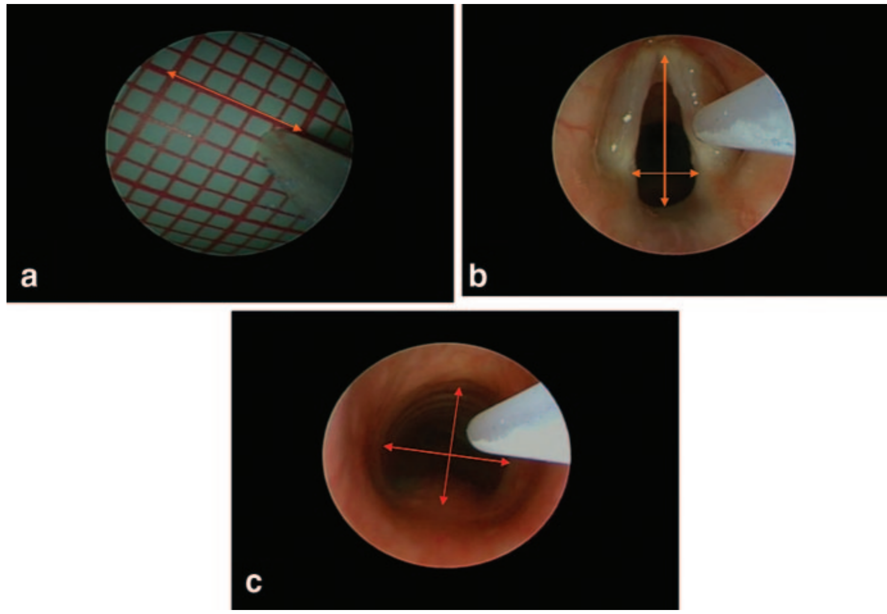

Figure 1. Measuring laryngeal dimensions. The catheter tip touching the graph paper (a), the glottis (b), and cricoid (c) regions.

Table 1. Results of the Linear Regression Analysis for Laryngeal Dimensions Versus Age, Height, and Weight, Respectively, in 128 Patients

	Age	Height	Weight
G-CSA	$r = 0.36$	$r = 0.34$	$r = 0.35$
	$P < 0.001$	$P < 0.001$	$P < 0.001$
G-AP	$r = 0.38$	$r = 0.36$	$r = 0.39$
	$P < 0.001$	$P < 0.001$	$P < 0.001$
G-trans	$r = 0.24$	$r = 0.22$	$r = 0.17$
	$P = 0.005$	$P = 0.009$	$P = 0.047$
C-CSA	$r = 0.27$	$r = 0.29$	$r = 0.25$
	$P = 0.001$	$P < 0.001$	$P = 0.003$
C-AP	$r = 0.13$	$r = 0.12$	$r = 0.12$
	$P = 0.129$	$P = 0.167$	$P = 0.14$
C-trans	$r = 0.13$	$r = 0.19$	$r = 0.12$
	$P = 0.117$	$P = 0.03$	$P = 0.18$
Cricoid:glottic CSA	$r = 0.18$	$r = 0.11$	$r = 0.14$
	$P = 0.04$	$P = 0.18$	$P = 0.11$

G-CSA = glottic cross-sectional area; G-AP = glottic anteroposterior diameter; G-trans = glottic transverse diameter; C-CSA = cricoid crosssectional area; C-AP = cricoid anteroposterior diameter; C-Trans = cricoid transverse diameter.

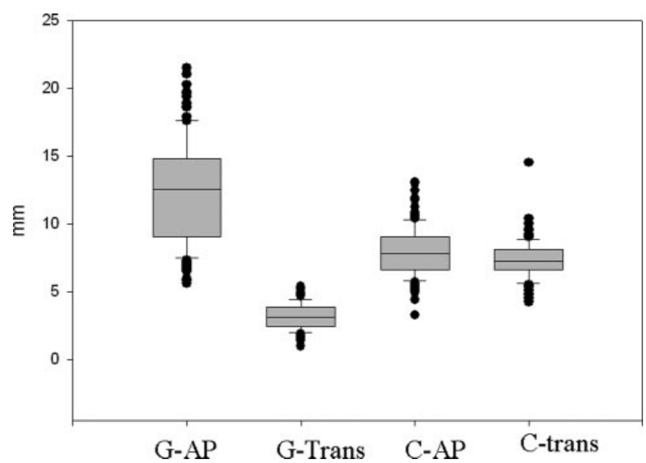

Figure 3. Box and whiskers plot for the diameter measurements in the study population, $n = 128$. G-AP = glottic anteroposterior diameter; G-trans = glottic transverse diameter; C-AP = cricoid anteroposterior diameter; C-Trans = cricoid transverse diameter.

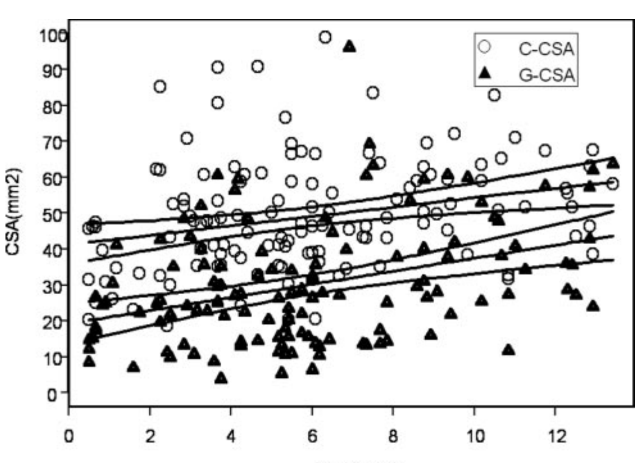

Figure 2. Scatterplot with regression line and confidence interval lines for the cross-sectional areas (CSA) versus age. C-CSA = cricoid cross-sectional area; G-CSA = glottic cross-sectional area.

gender differences analyses, the unpaired t-test (parametric data) and the Mann–Whitney Rank Sum test (nonparametric data) were applied to analyze the differences in values of each of the variables between male and female children. A P value <0.05 was considered as significant.

RESULTS

Overall, 135 patients were enrolled in the study. Of these, seven patients were excluded from the analysis mainly because of poor image quality. Of the 128 children studied (79 boys and 49 girls), mean values ($\pm$SD) for the demographic data were age 5.9 ($\pm$3.3) yr, height 113.5 ($\pm$22.2) cm, and weight 23.5 ($\pm$13) kg. The relationship between C-CSA and the G-CSA was given by the equation C-CSA = 36.157 + (0.426 $\times$ G-CSA), $r = 0.45$, $P < 0.001$, power = 1. The C-CSA

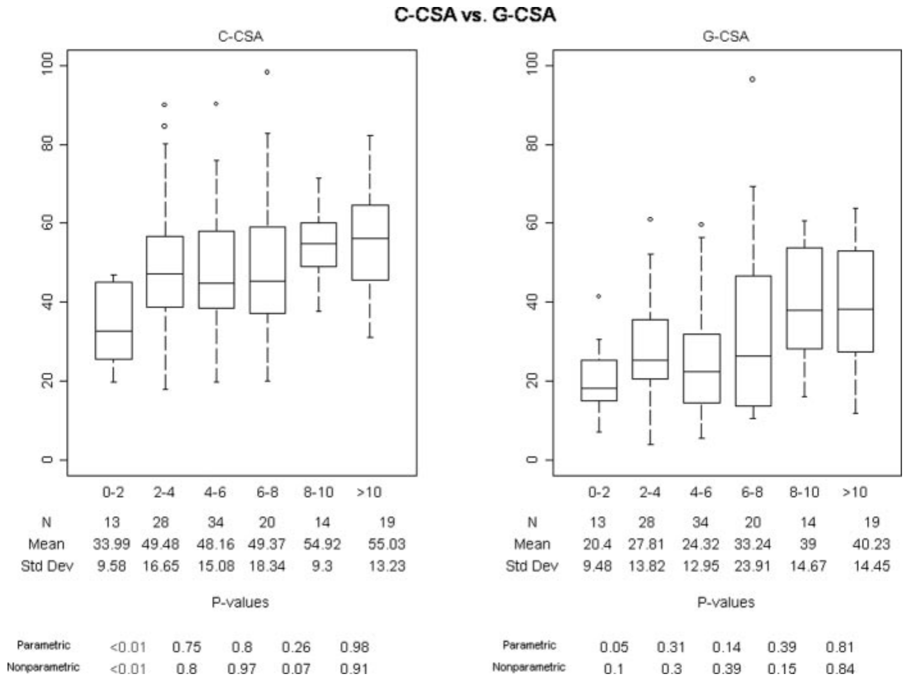

Figure 4. Box and whiskers plot for the study population stratified per age. C-CSA = cricoid cross-sectional area; G-CSA = glottic cross-sectional area; n = number of patients in each group; 6 mo to 2 yr, (0–2) older than 2–4 yr, (2–4) older than 4–6 yr, (4–6) older than 6–8 yr, (6–8) older than 8–10 yr (8–10), and older than 10 yr (>10) of age.

was larger than the G-CSA in all subjects. The relationship of the six measured variables, i.e., G-CSA, G-AP diameter, G-trans diameter, C-CSA, C-AP, and C-trans diameters with age, height, and weight were measured by linear regression analysis and Pearson product moment correlation (r, Table 1). We observed no significant gender differences in the mean values of the studied variables. Although age, height, and weight were good predictors for glottic dimensions and the C-CSA, they were poor predictors for cricoid diameters (except for C-trans versus height, $P = 0.03$). Both, the G-CSA and the C-CSA increased linearly with increasing age (Fig. 2). The relationship between the diameters of the glottic and cricoid regions in the trans and AP planes is as shown in Figure 3. The mean ratio for C-CSA:G-CSA was 2.1 ($\pm$1.2). Overall, a decrease in this ratio was observed with increasing age, height, and weight, although a statistical significance was achieved only in case of this ratio versus age ($P = 0.037$) data. We also noted that the C-CSA:G-CSA ratio remained relatively constant until the children were >25 kg weight when it decreased to a mean of 1.7. The mean and SD values across groups based on age are as depicted in Figure 4, i.e., 6 mo to 2 yr, (0–2) older than 2–4 yr, (2–4) older than 4–6 yr, (4–6) older than 6–8 yr, (6–8) older than 8–10 yr (8–10), and older than 10 yr (>10) of age are as shown in the box and whiskers plot (Fig. 4).

DISCUSSION

Our study agrees with recent studies that describe the pediatric larynx as conical in the transverse dimension with the apex of the cone being at the level of the vocal cords, but also that it is cylindrical in the AP dimension.[4,5]

Although there was considerable variability in the absolute dimensions of the larynx, the relative dimensions are consistent in the range of ages. Based on the regression lines (Fig. 2 and web images 1 and 2 available at www.anesthesia-analgesia.org), the relationship between the CSAs of the two regions closely approximate each other with growth and development. This finding suggests that the pediatric larynx and cricoid are more cylindrical in infants and children rather than funnel-shaped with the apex of the funnel at the cricoid. Although the airway does rapidly taper to a funnel at the level of the glottis, in healthy children, the airway dimensions do not decrease further at the cricoid. This observation differs from the common description of the pediatric larynx, perhaps because of the fact that the previous description was based on a small number of postmortem pediatric upper airway measurements associated with changes in mucus membranes and muscle tonicity.[19–22] In this study, airway measurements were made under anesthetized paralyzed conditions at zero (or atmospheric pressure) peak airway pressures. Spontaneous respiration may lead to additional glottis abduction and considerable additional mechanical displacement of the vocal cords may occur when an ETT is inserted. For this reason, the more mobile, expandable vocal cords may function to enlarge the glottic opening more than the cricoid. In our study, we found a good correlation between G-CSA, C-CSA, G-AP, and G-trans diameters versus age, height, and weight of the patient. Our observations are somewhat similar to those made by Too-Chung and Green[20] in which the authors reported weight to be a predictive variable for the cricoid area rather than age and height. Our study, in keeping with some previous studies, reveals that overall the C-AP dimension is larger than its C-trans dimension (7.7 vs 7.2 mm, respectively), suggesting that the cricoid is ellipsoid rather than round.[4,19,20] This is in contrast to that described by Eckenhoff.[1] This finding may form the anatomical basis for the use of cuffed ETTs in children.[13,14]

Unlike many other studies,[4,23] we chose to compare the CSA at the level of the glottis and the cricoid because this area more effectively quantifies the area for tracheal tube passage (e.g., an ETT in our case). In addition, this area measurement offers an indication of growth in all planes.[20] Based on these findings, in clinical practice, the glottis must be distended by the ETT and structural damage both short and long-term is a potential, albeit, uncommon event in children.[24–26] Although Masters et al.[23] report their interesting study on airway sizes and proportion measurements in anesthetized, spontaneously breathing children younger than 10 yr of age using the CSA and similar measurement techniques, their study focused on cricoid, tracheal, and bronchial measurements rather than glottic measurements.

In this study, the youngest patient was 6 mo of age, and we did not include a large number of infants. Hence, we were not able to assess the major changes in laryngeal dimensions that occur during infancy. This assessment would warrant a separate study.

CONCLUSION

In summary, these findings suggest that in anesthetized paralyzed children, the glottis was narrower than the cricoid in children from infancy to adolescence. The pediatric larynx is more cylindrical than funnel-shaped and an age-based transition from a pediatric funnel-shaped to the cylindrical adult larynx was not observed. Future studies are needed to determine the *in vivo* dynamics of the larynx with and without an ETT.

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