Developmental Changes of Laryngeal Dimensions in Unparalyzed, Sedated Children

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Background: Knowledge of the influence of age on laryngeal dimensions is essential for all practitioners whose interest is the pediatric airway. Early cadaver studies documented that the larynx is conically shaped, with the apex of the cone caudally positioned at the nondistensible cricoid cartilage. These dimensions change during childhood, as the larynx assumes a more cylindrical shape. The authors analyzed laryngeal dimensions during development to determine if this relationship continues in unparalyzed children in whom laryngeal muscles are tonically active. The authors determined the relationships between the vocal cord, sub–vocal cord, and cricoid ring dimensions and the influence of age on these relationships.

Methods: Infants and children undergoing magnetic resonance imaging with propofol sedation had determinations of the transverse and anterior–posterior (AP) dimensions of the larynx at the most cephalad level of the larynx (vocal cords) and the most caudal level (cricoid). Most patients had an additional measurement (sub–vocal cord) at a level between the vocal cords and the cricoid ring. Relationships were obtained by plotting age against laryngeal dimensions and the ratio of laryngeal dimensions at different levels within the larynx.

Results: The authors measured transverse and AP laryngeal dimensions in 99 children, aged 2 months–13 yr. The relationship between the transverse and AP dimensions at all levels of the larynx did not change during development. Transverse and AP dimensions increased linearly with age at all levels of the larynx. In all children studied, the narrowest portion of the larynx was the transverse dimension at the level of the vocal cords. Transverse dimensions increased linearly in a caudal direction through the larynx (P < 0.001), while AP dimensions did not change relative to laryngeal level. The shape of the cricoid ring did not change throughout childhood.

Conclusions: In sedated, unparalyzed children, the narrowest portions of the larynx are the glottic opening (vocal cord level) and the immediate sub–vocal cord level, and there is no change in the relationships of these dimensions relative to cricoid dimensions throughout childhood.

The development and growth of the larynx during childhood has been a subject of interest for over a century.1 Knowledge of the influence of the age of the child on laryngeal dimensions is essential for all practitioners whose interest is the pediatric airway. Early studies in cadaver specimens documented the cartilaginous and bony framework of the larynx throughout childhood.1–3 These studies determined that the larynx is conically shaped, with the apex of the “cone” caudally positioned at the nondistensible cricoid cartilage. These dimensions change during childhood as the larynx assumes a cylindrical, rather than a conical shape.4 It is unknown if this relationship continues to exist in unparalyzed children in whom laryngeal muscles demonstrate tonic activity.5 Therefore, we undertook this study to determine the influence of age on laryngeal dimensions. Most specifically, we were interested in the relationships between vocal cord, sub–vocal cord, and cricoid ring dimensions, and how these relationships change as children grow. We hypothesized that these relationships change during development and may influence clinical airway management.

Materials and Methods

The Research Subjects’ Review Board of the University of Rochester (Rochester, New York) approved this study, and written informed consent was obtained from all parents of children in the study. Children who were old enough to understand that they were participating in a research study gave their assent. Children aged 0–14 yr who presented for an elective magnetic resonance imaging scan with deep sedation were eligible to participate. Consecutive children were enrolled within the limits of investigator-related and clinical situations. Exclusion criteria included obvious anatomical deformities of the head or neck, or any other condition the investigators felt would cause abnormal laryngeal anatomy. Children who received airway management with either a laryngeal mask airway or endotracheal tube were also excluded.

The study was performed in children who were deeply sedated with 200 μg · kg⁻¹ · min⁻¹ propofol. Most children did not previously have an indwelling intravenous catheter and therefore initially received a mask anesthetic with sevoflurane and nitrous oxide, both of which were discontinued after intravenous catheter placement. Spontaneous ventilation was maintained throughout the procedure. A nasal cannula provided oxygen, usually at 2 L/min. Monitors included continuous electrocardiography, pulse oximetry, capnography (via the nasal cannula), and intermittent automated blood pressure determinations (Medrad, Inc., Indianola, PA). A best attempt was made to position the child’s head in the neutral position, usually with a folded sheet beneath the neck or shoulders. Occasionally, a nasal or oral airway device was used to assist with maintenance of upper
airway patency if excessive head or neck movement occurred with each breath. No attempt was made to obtain images at a certain point in the respiratory cycle.

Magnetic resonance imaging was performed on a 1.5-T unit with a quadrature head coil (GE Medical Systems, Milwaukee, WI). T1 spin-echo images were obtained with 3-mm slices at 0.5-mm intervals.

Measurements
Axial scans were obtained with the oropharynx as the most cephalad limit and the trachea below the cricoid cartilage as the most caudal limit. A reference sagittal image was used to help identify the proper level of the vocal cords. The cricoid cartilage was identified as the most caudal part of the larynx that was continuous posteriorly. In each child, transverse and anterior–posterior (AP) dimensions of the larynx were measured at a minimum of two levels—the vocal cords and cricoid cartilage, depending on their size. Two authors measured each child’s larynx independently. When there was a discrepancy between the two, the final value was decided upon by consensus or with assistance from a third author. A radiologist author was involved with measurement of every child.

Results were obtained by plotting the dependent variable (age) against the independent variables—laryngeal dimensions, and the ratio of laryngeal dimensions at different levels (Origin, Microcal Software, Northampton, MA). The sub–vocal cord level was defined as the magnetic resonance imaging slice immediately caudal to the vocal cords but above the cricoid ring.

Statistical Analysis
Linear regression was used to determine the relationship between dependent and independent variables. Kruskal-Wallis and Mann-Whitney tests were used to compare continuous nonparametric data (difference between laryngeal dimensions at different levels). A P value of 0.05 or less was used to indicate statistical significance.

Results
One hundred nine children initially enrolled in the study. Ten were excluded because of various reasons that included movement artifact (4), scanner malfunction (1), abnormal laryngeal anatomy (2), and corrupted optical disks that prevented retrieval of the scans (3). Therefore, 99 children are presented for analysis and are described in Table 1. In the initial data analysis, males and females were analyzed separately. However, since their results were essentially the same, we report the aggregate results.

Table 1. Demographic Characteristics of Children Included for Analysis

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<tr>
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<th>Boys (n = 53)</th>
<th>Girls (n = 46)</th>
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<tbody>
<tr>
<td>Age (months)</td>
<td>61.1 ± 41.6</td>
<td>62.1 ± 41.9</td>
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<tr>
<td>Weight (kg)</td>
<td>21.1 ± 11.7</td>
<td>22.2 ± 16.3</td>
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<td>Height (cm)</td>
<td>106.0 ± 25.9</td>
<td>107.5 ± 27.5</td>
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Values are expressed as mean ± SD.

The relationship between the transverse and AP dimensions at all levels of the larynx, including the cricoid ring, did not change during development. Transverse dimensions were narrower than AP dimensions at all levels of the larynx above the cricoid ring and in most children at the cricoid ring (fig. 1). Transverse and AP dimensions increased linearly with age at all levels of the larynx (fig. 2, P < 0.001 for all dimensions).

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![Fig. 1. Transverse to anterior–posterior (AP) dimension ratios at different levels within the larynx. These ratios do not change during development. Vocal cord level: r = −0.2, P = 0.04; sub–vocal cord level: r = −0.1, P = 0.4; cricoid level: r = 0.2, P = 0.1.](http://anesthesiology.pubs.asahq.org/pdfaccess.ashx?url=/data/journals/jasa/931210/)
vocal cords. Transverse dimensions increased linearly in a caudad direction through the larynx \((P < 0.001, \text{fig. 3, top})\), while AP dimensions did not change relative to laryngeal level (\text{fig. 3, bottom}). Thus, during spontaneous breathing in unparalyzed, sedated children, the larynx is conical shaped in the transverse dimension (with the apex of the cone at the level of the vocal cords) and is cylindrical shaped in the AP dimension. These relationships are demonstrated in a representative scan (\text{fig. 4}).

**Discussion**

The major finding of this study is that in sedated, unparalyzed children, the shape of the larynx is conical in the transverse dimension (with the apex of the cone at the level of the vocal cords) and cylindrical in the AP dimension, and does not change throughout development. This is in contrast to that of the atonic larynx, in which cadaver specimens have demonstrated that the larynx is conical shaped with the apex of the cone at the caudally positioned cricoid ring during early childhood.\(^1\)\(^-\)\(^3\) During development, the transverse dimension of the atonic larynx assumes a more cylindrical shape, although the age at which this occurs is not precisely known.\(^4\)

In publications that used measurements from cadaver specimens, the portions of the larynx cephalad to the cricoid ring could be distended since these areas do not contain full circumferential cartilage. The patients included in the present study were deeply sedated and not paralyzed. Active contraction of the laryngeal muscles influenced the dimension of the larynx above the cricoid ring, especially at the level of the vocal cords, which continue to move during spontaneous respiration.\(^5\) Indeed, lightening of consciousness in anesthetized adults is associated with increasing tracheal cuff pressures,\(^6\) and lack of paralysis in anesthetized children is associated with an audible leak at an increased airway pressure.\(^7\) This is further borne out by the increased variability of the transverse dimensions at the level of the vocal cords compared with other levels of the larynx (\text{fig. 2, top left}). Thus, although our measurements describe the glottic opening to be the narrowest portion of the larynx...
in spontaneously breathing, unparalyzed children, the rigid cricoid ring is functionally the narrowest portion of the larynx.

A limitation of these findings is that we did not attempt to image the larynx in any particular phase of respiration. Since vocal cord dimensions likely change in spontaneously breathing, sedated children, the dimensions that we measured should be considered to be an average measurement during movement of the vocal cords during spontaneous respiration. Therefore, it is possible that in some children, the vocal cords were “captured” in a more adducted state than usual, as in expiration. If this occurred in a significant number of our subjects, the shape of the larynx in the transverse direction would be more cylindrical than conical. An alternative explanation for our findings is the possible influence of propofol on vocal cord position. In dogs, propofol depresses vocal cord abductor (posterior cricoarytenoid muscle) and vocal cord tensor (cricothyroid muscle) activity and may have influenced vocal cord positions in the children we studied.

In 1951, Eckenhoff published a seminal article on characteristics of the infant larynx and their influence on endotracheal anesthesia. This article was one of the first to emphasize that the cricoid cartilage is functionally the narrowest point of the upper respiratory tract of the child. Eckenhoff described the cricoid plate as “inclined posteriorly at its superior aspect, so that the larynx is funnel shaped with the narrowest point of the funnel at the laryngeal exit.” This narrowest point is described as possibly smaller than more cephalad portions of the trachea. Eckenhoff stated that as the child grows, the cricoid plate becomes vertical, and the larynx becomes more cylindrical shaped. He derived this information from Bayeux, who used moulages and anatomic sections of 15 children, aged 4 months to 14 yr. Bayeux documented that the circumference of the cricoid ring was narrower than that of the trachea or the glottis. Our results do not allow us to make direct comparisons with the findings of Eckenhoff and Bayeux since we measured dimensions in the tonically active larynx.

The clinical importance of our findings is speculative. On one hand, our results indicate that choosing an endotracheal tube based on the size of the cricoid ring may not prevent mucosal damage to the larynx cephalad to the cricoid ring in unparalyzed children. On the other hand, these more cephalad portions of the larynx consist of yielding structures that distend with placement of a relatively larger endotracheal tube. The cricoid ring is unyielding and prone to development of edema and scarring in response to excessive mucosal pressures.

Fig. 3. Box plots demonstrating the relationship between tracheal transverse (top) and anterior–posterior (A-P; bottom) diameters at the levels of the vocal cords, subglottic area, and cricoid ring. Transverse diameters increased linearly in a caudad direction ($P < 0.001$). The middle line of the box is the 50th percentile, the ends of the boxes are the 25th and 75th percentiles, and the whiskers represent the 5th and 95th percentiles. The square box represents the mean, the 1st and 99th percentiles are denoted by Xs, and the dashed lines are the minimum and maximum values.

Fig. 4. Representative sample of axial magnetic resonance imaging slices through the vocal cords (A), subglottic levels (B and C), and cricoid ring (D). Transverse diameters increase in a caudad direction.
Autopsy studies have described the laryngeal pathology that occurs with prolonged intubation and mechanical ventilation in children. The entire larynx is often involved, and the most severe damage often occurs at the level of the vocal cords. Our findings are consistent with these pathologic observations. Although it is not specifically mentioned in these studies, one can speculate that the children included in these autopsy studies did not consistently receive neuromuscular blockade, and therefore, the glottic regions above the cricoid were the most narrow and bore the brunt of endotracheal tube irritation and mucosal damage.

In summary, we found that in sedated, unparalyzed children, the narrowest portions of the larynx are the glottic opening (vocal cord level) and the immediate sub–vocal cord level, and there is no change in the relationships of these dimensions, relative to cricoid ring dimensions, throughout childhood. In addition, we found that the shape of the cricoid ring does not change during development. Our findings offer a plausible mechanism for the more cephalad laryngeal (glottic) damage that occurs in chronically intubated children.

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References
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