The Shape of the Pediatric Larynx: Cylindrical or Funnel Shaped?

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For many years, it had been commonly accepted knowledge that the larynx in infants and children is "funnel shaped with the narrowest point of the funnel at the laryngeal exit." As a child matures, the transverse dimension of the larynx assumes the more cylindrical shape of the adult larynx. These statements have been taken from the often quoted article by Eckenhoff,[1,2] a well-respected anesthesiologist and scholar, that appeared in *Anesthesiology* in 1951. Many anesthesiologists in the field may not realize, however, that Eckenhoff's description of the pediatric larynx was not a finding of his own study but was taken primarily from a description written over half a century earlier, by Bayeux,[3] in 1897. Bayeux[3] had based his description on plaster castings (moulages) and anatomical sections of cadaveric larynxes from 15 children between the ages of 4 mo and 14 yr. It is important to note that, in the same article, Eckenhoff cautioned that "the measurements so derived may not be completely applicable to the living."[1] It was probable in retrospect that the laryngeal soft tissues proximal to the rigid cricoid cartilage could have been stretched in the process of moulage in relation to that of the rigid cartilaginous cricoid ring.

Litman et al.[4] published a study on the laryngeal dimensions with magnetic resonance imaging scans in 99 infants and children, neonates to 14-yr-old, spontaneously breathing under deep sedation with propofol. Contrary to Eckenhoff's conclusions based on Bayeux's study in cadaveric specimens, Litman et al.[4] found that the shape of the pediatric larynx was "conical in the transverse dimension with the apex of the cone at the level of the vocal cord and cylindrical in the AP dimension and does not change throughout development." Unfortunately, this extremely important, if not monumental, publication did not receive the attention it deserved, and there was no editorial article accompanying this important article.

In this issue of *Anesthesia & Analgesia*, Dalal et al.[5] present data on laryngeal dimensions from 128 infants and children, 6 mo to 13 yr old. The data generally confirm the findings of Litman et al.[4] that the larynx of children is more cylindrical, as in adults, than funnel shaped and does not change with age. The findings by Dalal et al.[6] are significant in that they reach a conclusion similar to that of Litman et al. by using an entirely different approach with different instrumentation called video-bronchoscopic imaging. One important difference between the two studies is the condition of the patient population: Litman et al.'s patients were breathing spontaneously under heavy sedation, whereas Dalal et al.'s subjects were anesthetized and paralyzed and were apneic when the measurements were made.

Before the actual procedure, Dalal et al.[5,6] calibrated a video-bronchoscopic image by pasting a tiny suction catheter to a Hopkins glass rod telescope with the tip of the catheter protruding a fixed distance (1.5 or 2.0 cm) from the tip of the telescope, and the image was photographed when the catheter tip was touching a graph paper. At the start of the study, a bronchoscope was inserted into the pharynx and larynx of an anesthetized and paralyzed patient. The anteroposterior (AP) and transverse dimensions, as well as the cross-sectional areas of the larynx, were photographed at the glottic and subglottic positions (the distance from the glottis was not mentioned) and at the cricoid ring. The patient was in a supine position and the head and neck extended with a pillow.

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There are similarities in, as well as some important differences between, the data from the two studies, although a direct comparison is somewhat difficult: Litman et al. measured AP and transverse diameters, whereas Dalal et al. primarily analyzed and reported on the cross-sectional areas. Also, as mentioned above, the children in Litman et al.'s[4] study were breathing spontaneously with the glottis in motion (no attempt was made to obtain images at a particular phase of the respiratory cycle), whereas Dalal et al.'s[5] subjects were paralyzed and apneic with the glottis in the relaxed or cadaveric position. At the cricoid level, both studies show the cross-section mildly elliptic with smaller transverse diameters (Tr/AP ratio, 0.8–0.9 in Litman et al. vs approximately 0.95 in Dalal et al.). At the glottis level, the transverse versus AP diameter ratio of the paralyzed children was small, as expected: roughly one quarter (Tr/AP approximately 0.23) with the glottis in the "cadaveric" position.[5] In contrast, in those children spontaneously breathing the ratio appears much larger (Tr/AP, 0.5–0.9).[4]

Where is the narrowest portion of the larynx in children? This is a very important question for pediatric anesthesiologists, especially in relation to the potential site of damage to the larynx after an endotracheal (ET) intubation. Eckenhoff[1] states in his classic article that, although the lima glottidis is assumed to be the narrowest point within the upper respiratory tract in adults, in children "the narrowest point may be at the level of the crioid cartilage." Indeed, in all 15 children of Bayeux's study (including the oldest, a 14 yr old), the internal circumference of the cricoid ring was the narrowest in comparison with the circumferences of both the glottis and the upper trachea.[1,2] Not surprisingly, Dalal et al. found the narrowest portion of the larynx to be the lima glottidis in children whose glottis were in the semiopen cadaveric position. Is this finding clinically important? Eckenhoff[1] went on to state in 1951 that "it should be kept in mind that the vocal cords are yielding structures and can thus be distended but that the cricoid ring is unyielding and cannot be distended to accommodate a tube larger than its fixed internal circumference." Litman et al.[4] also found that the lima glottidis was the narrowest point in the larynx in spontaneously breathing children under sedation, but they echoed Eckenhoff's comments by stating that "the rigid cricoid ring is functionally the narrowest portion of the larynx."

Is there clinical significance in the findings of the two studies by Dalal et al. and Litman et al. and, if so, how might these findings affect our clinical practice in pediatric anesthesia? One important finding appears to be the confirmation that the rigid cricoid aperture is not entirely circular but slightly elliptic. Eckenhoff did not describe the shape of the cricoid aperture in his 1951 article, but it was assumed to be circular and has been misquoted as such by some authors. It is important to note that a tight-fitting ET tube in the elliptic cricoid opening would exert more compression and ischemia on the lateral or transverse mucosa than on the mucosa lining the AP segments of the cricoid ring. With this new information on the anatomy of the pediatric larynx, it now makes more sense to choose uncuffed ET tubes with a smaller external diameter as opposed to uncuffed ET tubes snuggly or "appropriately" fitted to the cricoid opening.

Until the late 1980s, the cuffed ET tubes were not recommended in most text books for children younger than 5–8 yr, depending on the authors.[7,8] The primary stated reason was that the diameter of a cuffed ET tube had to be 1–2 sizes smaller than the uncuffed tube diameter, to accommodate the passage of a bulky cuff through the larynx. Consequently, flow resistance would be drastically increased in those children most commonly breathing spontaneously under general anesthesia, during the period before mechanical ventilation became a common practice.[9] Another argument against the use of cuffed ET tubes was based on earlier reports of laryngeal and tracheal mucosal injury caused by the cuffed ET tubes with overinflated high-pressure/low-volume cuffs after prolonged intubation in intensive care unit settings.[10,11] The current trend of more liberally using cuffed ET tubes in infants and young children demonstrates a different reality. The use of cuffed ET tubes has been associated with decreased, rather than increased, incidence of postintubation croup. This decrease is, in part, a consequence of choosing a cuffed ET tube 1–2 sizes (0.5–1.0 mm internal diameter) smaller than a properly fitting uncuffed ET tube, thereby markedly reducing the frequency of reintubation attempts.[12–15] Indeed, after completely eliminating uncuffed ET tubes at a prominent children's hospital in Paris, France, there was not a single case of postintubation croup over a 3-yr period.[16]

The recent development and increasing clinical use of more advanced thin-walled ET tubes with a very short, high-volume, low-pressure cuff allow the ET tube to stay away from the cricoid mucosa while the airway is sealed at the upper trachea where the posterior membranous wall can stretch and accommodate a complete seal with low-cuff pressure of <15 cm H_2O without increases in airway complications.[17] Indeed, the current guidelines of Pediatric Advances Life Support by the American Heart Association recommend the use of cuffed ET tubes as an acceptable alternative to uncuffed ET tubes.[18,19]

The presence of a cuffed or an uncuffed ET tube through the glottis appears relatively benign in pediatric surgical patients who are mostly given muscle relaxants, and the vocal cords are relaxed and immobile in general, except for a relatively brief period before extubation. The situation may be quite different, however, for patients, who are intubated for prolonged periods of time in intensive care unit settings, often without muscle relaxants, and whose vocal cords could be vigorously moving and pushing against the ET tube during the respiratory cycle and especially during coughing or bucking. As pointed out by Litman et al.,[4,20–22] autopsy studies in children with prolonged intubation demonstrate damage to the entire larynx, with the most severe damage often occurring at the level of the vocal cords. Further investigation is needed to find out whether a cuffed advanced ET tube affects the vocal cords differently under these circumstances.

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