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SOME ANATOMIC CONSIDERATIONS OF THE INFANT LARYNX INFLUENCING ENDOTRACHEAL ANESTHESIA*

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THE endotracheal technic of administering anesthetic agents to infants and children is being employed with increasing frequency. Anesthesiologists trained in pediatric anesthesia are more often than not likely to consider this technic the one of choice for general anesthesia. Leigh and Belton (1) mentioned using the endotracheal route in over 50 per cent of their anesthesias. At the Children's Hospital of Philadelphia the method is used in over 65 per cent of all anesthesias. There the technic is employed most often with the newborn (98 per cent of all infants two weeks of age or less) and somewhat less frequently with older age groups. It is obvious from these statistics that it is believed the advantages far outweigh the disadvantages of the method.

The successful and innocuous intubation of the infant larynx and trachea requires an intimate knowledge of the anatomy of these structures, since in many respects they differ from those of the adult. Failure to recognize such variations can lead to laryngeal trauma and edema and even to death, as will be described in one of the accompanying case reports. The difficulties encountered generally are different from those described in adults by Dwyer, Kronenberg and Saklad (2). The purpose of the present paper is to describe the major anatomic differences of the infant larynx from the viewpoint of the anesthesiologist and to discuss their significance. Figure 1 is presented as a guide to the terminology used in the report.

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Position of the Larynx.—In the infant the larynx is situated more cephalad than in the adult. With advancing age the structure moves lower in the neck so that in the adult the rima glottidis is, as a rule, opposite the level of the interspace of the fourth and fifth cervical vertebrae. The positions are well demonstrated in a sketch redrawn from Negus (3) (fig. 2).

In Piersol's "Human Anatomy" Mehnert (4) is quoted as stating that at birth the lower border of the cricoid cartilage is opposite the lower border of the fourth cervical vertebra. At 6 years it is at the level of the fifth cervical vertebra and at 13 years at the top of the seventh cervical vertebra.

MEDIAN SECTION OF THE LARYNX

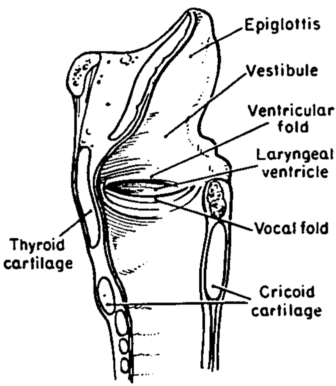

FIG. 1.

The Epiglottis.—The epiglottis of the infant is a considerably different structure from that of the adult; it is relatively longer, stiff and "U" or "V" shaped, whereas in the adult it is more flexible and tends to be flat. The child's epiglottis also assumes a different angle in relation to the anterior pharyngeal wall than that of the adult. In the former it approximates a 45 degree angle from the anterior pharyngeal wall, while the epiglottis of the adult lies closer to the base of the tongue. The reason for the epiglottis assuming such a different angle lies in the fact that the hyoid bone of the infant is intimately attached to the thyroid cartilage (5). Separation of the two structures in an anatomic dissection can be accomplished only with difficulty (fig. 3). This position of the hyoid bone causes the base of the tongue to depress the epiglottis and therefore to protude further into the

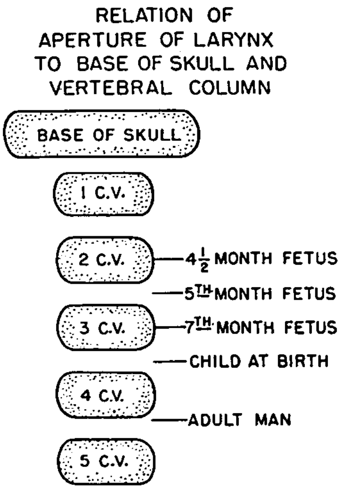

FIG. 2.

pharyngeal cavity. With advancing age the hyoid bone and the thyroid cartilage separate, allowing the epiglottis to become more erect.

The Vocal Cords.—Literally, the vocal cord is the ligament extending from the thyroid cartilage to the vocal process of the arytenoid cartilage. As reference to figure 4 will indicate, however, the rima glottidis is bounded not only by ligamentous vocal cords but also by the

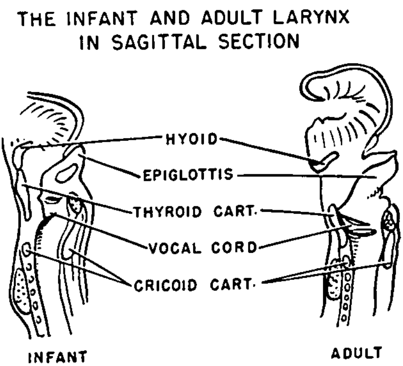

FIG. 3.

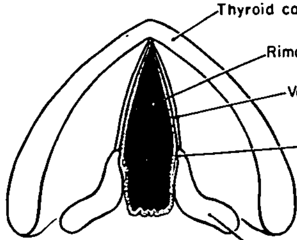

FIG. 4.

vocal processes of the arytenoid cartilage. Thus the vocal fold is made up of a ligamentous portion and a cartilaginous portion. When the anesthesiologist speaks of the vocal cords, he is usually including both parts. This may be important because the relationship of ligamentous to cartilaginous portions of the vocal cord is not constant in all stages of development and because of this inconstancy, the shape and direction of the vocal cords change.

As indicated in table 1, with advancing age the increase in length of the vocal cord is almost entirely accomplished in the ligamentous portion. In the infant, about one-half the vocal cord is cartilaginous. Since the vocal process of the arytenoid cartilage is inclined inferiorly and medially (down the trachea and inward), the vocal cord is concave

TABLE 1

RELATIONSHIP OF LIGAMENTOUS PORTION OF THE VOCAL CORD TO THE INTERNAL ANTEROPOSTERIOR DIAMETER OF LARYNX (REPRODUCED IN PART FROM NEGUS (3))

Sex	Age	Internal A-P Diameter of Larynx, mm.	Length of Ligamentous Portion of Vocal Cord, mm.
F	3 days	7	3
M	6 days	8	4.5
F	14 days	7.5	4
M	5 weeks	6.5	4
M	2 months	8	5
F	3 months	7.5	4.5
M	9 months	9	6
M	1 year	8.5	5.5
F	2½ years	8	5
F	5 years	10	7.5
M	8½ years	10.5	7
F	15 years	14	9.5
M	19 years	23	17

(fig. 3). In the adult, since the cartilaginous portion of the vocal cord is relatively small, the concavity is not significant or is absent.

The anterior attachment of the vocal cords is at the interval surface of the angle of the thyroid cartilage, immediately below the attachment of the epiglottis. With growth, as the superior aspect of the thyroid cartilage inclines forward, the attachment of the vocal cords also moves forward, tending to straighten the cords.

As will be mentioned in the discussion, these structural differences may lead to difficulty when the anesthesiologist attempts to intubate the larynx in the infant.

The Cricoid Ring.—It is usually assumed that the rima glottidis is the narrowest point within the upper respiratory tract. Although this is most often true in the adult, it may not be true in the infant and small child. The narrowest point may be at the level of the cricoid cartilage (6, 7).

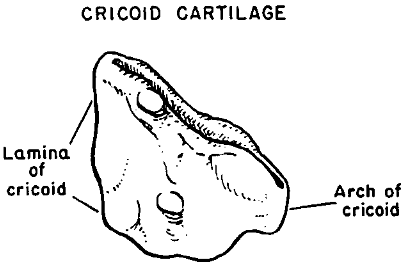

FIG. 5.

The cricoid cartilage is composed of two parts: a posterior plate-like portion (lamina) and an inferior ring portion (arch) (fig. 5). The plate forms the posterior wall of the larynx and the ring the inferior circumference of the larynx. The ring is the only point where the larynx is completely enclosed in cartilage. In the infant the plate is inclined posteriorly at its superior aspect, so that the larynx is funnel shaped with the narrowest point of the funnel at the laryngeal exit (fig. 3). This point of exit, the cricoid ring, may be smaller than the rima glottidis or the internal diameter of the trachea. As the child grows, the cricoid plate becomes vertical, the ring enlarges and the point of narrowing disappears.

In infants and children Bayeux (6), using moulages and anatomic sections, found that the circumference of the cricoid ring was narrower than that of the trachea or the glottis (table 2). It must be remembered, however that Bayeux studied cadavers and the measurements so derived may not be completely applicable to the living. Nevertheless, with the cords widely abducted, the anesthesiologist can occasionally see that

TABLE 2

INTERNAL CIRCUMFERENCE OF LARYNX AND TRACHEA IN CHILDREN (AFTER BAYEUX)

Age	Glottis, mm.	Cricoid Ring, mm.	Trachea, mm.
4 months	23–26	20	22–25
6 months	26	20	24
7 months	26	22	25
8 months	24	21	24
10 months	25	22	26
13 months	25	22	26
17 months	26	22	25
23 months	30	23	28
2 years	30	24	30
3 years	27	23	27
4 years	30–33	26	30–33
5 years	30	26	33
7½ years	42	28	33
10 years	39	30	39
14 years	42	36	42

the aperture at the cricoid ring is smaller than at the vocal cord level. Also 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.

Mucous Membrane.—Both squamous and columnar epithelium can be found within the larynx. The squamous epithelium is located in the upper part of the epiglottis and upper lateral walls of the vestibule as well as over the vocal cords. In the latter position it is tightly bound down to fibrous tissue and cartilage.

Ciliated columnar epithelium lines the ventricle and inferior portion of the vestibule and the entire cavity of the larynx below the rima glottidis. All of this columnar epithelium is loosely attached by submucous

TABLE 3

EFFECT OF 1 MM. OF UNIFORM EDEMA ON REDUCING THE CROSS SECTIONAL AREA OF LARYNX AT CRICOID RING

Diameter at Cricoid Ring, mm.	Area, mm²	Area if 1 mm. Uniform Edema, mm²	Decrease in Area, per cent
4	12.6	3.14	75
5	19.6	7.1	64
6	28.3	12.6	55.5
7	38.6	19.6	49.2
8	50.2	28.3	43.6
9	63.3	38.6	39.0
10	78.6	50.2	36.2
12	113.0	78.6	30.4
14	154.0	113.0	26.7
16	202.0	154.0	23.4
20	314.1	259.0	19.0

tissue which is liable to become infiltrated with fluid to form edema. Some bronchologists (8) consider the columnar epithelium of the larynx of the infant and child to be physiologically similar to the erectile epithelium found in the lower turbinate region.

A final fact for consideration is the influence edema of the larynx has upon reducing the cross sectional area of the space through which the respired gases must pass (9). A reference to Table 3 will indicate the effect a uniform edema of 1 mm. will have upon reducing the cross sectional area of the laryngeal cavity at the level of the cricoid ring. It becomes readily apparent why a slight amount of edema in an infant causes so much difficulty and why adults rarely manifest respiratory distress after endotracheal anesthesia. Of added significance is the fact that the edema may not be limited to 1 mm. and that it may not be uniform but is usually more pronounced laterally.

Discussion and Clinical Implications

Direct laryngoscopy in the infant may be considerably more difficult than in the adult because of the following: (1) the larynx is situated more cephalad than in the adult, (2) the infant tongue is relatively larger and depresses the epiglottis owing to the position of the hyoid bone and (3) the epiglottis is short, stiff and "U" shaped.

To visualize the larynx the laryngoscope blade may have to be passed perpendicularly downward, with the head in neutral position, to expose the epiglottis. At this angle, elevation of the epiglottis may not be accomplished readily. The bulky tongue may offer a further hindrance. A maneuver the anesthesiologist can employ in difficult cases to facilitate elevation of the epiglottis is to pass the blade of laryngoscope beneath the epiglottis into the postericoidal space, then slowly withdraw it until the arytenoid cartilages appear into view. Elevation of the tip of the blade and slight forward movement (1 to 2 mm.) will then usually result in good exposure of the vocal cords. With this method the epiglottis may be doubled upon itself, but straightens out with withdrawal of the laryngoscope blade.

Passage of the endotracheal tube between the cords may be impeded because of the direction and shape of the arytenoids and vocal cords. The concavity and the slightly inferior anterior attachment of the cords may offer points for impingement of the tip of a curved tube and prevent it from being advanced into the larynx and trachea, but it would be less of a problem when a straight rigid tube is used as in bronchoscopy. This may be the common difficulty in failure to pass successfully a nasotracheal tube blindly when the anesthesiologist is sure the tip of the tube is situated at the glottis yet it cannot be advanced. In blind tracheal intubation slight flexion of the head may permit easy advancement of the tube. This causes the tube to move posteriorly, thus clearing the point of obstruction. In visual intubations in which the tube cannot be advanced, a slight depression of the tip of the laryngoscope blade pushing the tube posteriorly allows it to be advanced.

Another explanation for failure to advance an endotracheal tube into the trachea might be proposed. Occasionally a tube cannot be advanced even though the tip of the tube is beyond the cords. Under these circumstances, the laryngoscope may be lifting the entire larynx upward, causing a forward angulation of the trachea. If the lift to the laryngoscope is relaxed, the larynx moves posteriorly into its normal position, the angulation of the trachea disappears and the tube can be advanced. This difficulty is similar in some respects to that described in adults by Dwyer et al. (2).

From the data presented it is evident that in an infant, an endotracheal tube that will pass between the cords with ease may not go through the cricoid ring. The following case report is a typical example of this difficulty.

Case 1. J. C., a 7 months girl weighing 22 pounds, had a sacrococcygeal tumor excised. Premedication consisted of nembutal, ¼ grain, morphine sulfate, 1/96 grain, and scopolamine, 1/450 grain, at 7:15 a.m. Anesthesia was begun at 8:15 a.m. using a mixture of nitrous oxide, cyclopropane and oxygen for induction and cyclopropane, oxygen and ether until the patient was in plane 3 of the third stage. The larynx was visualized and the cords were seen to be widely abducted. Since the aperture seemed large, a number 21 French endotracheal tube was inserted between the cords, but it could not be advanced into the trachea. A number 19 French tube was next tried. It also passed between the cords easily but could not be advanced. The patient was reanesthetized with cyclopropane, ether and oxygen and the larynx again visualized. Definite narrowing of the larynx was visible about 1 cm. below the cords. A number 16 French tube was passed into the trachea with ease.

A tube that cannot be advanced through the cricoid ring should not be left *in situ* but should be replaced with a smaller tube or the anesthesia completed without an endotracheal tube. If a tube that is too large to enter the trachea is allowed to remain between the cords, the movement of the larynx which is synchronous with respiration will cause irritation of laryngeal mucous membrane against the endotracheal tube. The type of mucous membrane and the looseness and vascularity of the submucous tissue predispose to the formation of edema, so that with irritation laryngeal edema results. The following is a case report of a child in whom an endotracheal tube too large to go through the cricoid ring was left *in situ* during anesthesia which lasted one and one half hours.

Case 2. A 2-year-old, well-developed white boy was admitted for repair of cleft palate. Preanesthetic medication consisted of morphine sulfate, 1/72 grain, atropine sulfate, 1/300 grain, and nembutal, ¼ grain at 1:40 p.m. Sedation was adequate. Nitrous oxide, cyclopropane and oxygen with a to-and-fro system was begun at 2:30 p.m. Ether was added slowly. Administration of nitrous oxide was stopped in forty-five seconds. At 2:45 p.m. a number

2 Magill nasotracheal tube was passed under direct vision after one blind attempt had failed. The tip of the tube was placed between the vocal cords and the laryngoscope was removed. When the tube was advanced, complete respiratory obstruction occurred. With slight withdrawal a good airway was re-established. The vocal cords were again exposed and the tube could be seen passing between them. Advancement of the tube with the glottis exposed resulted in intralaryngeal kinking of the tube. It was recognized that this probably indicated a narrow cricoid ring, but since a satisfactory airway could be maintained with the tip of the tube just inside of the cords, it was decided to leave the tube *in situ*. The tube was connected to an Ayre tube and the operation (repair of cleft palate) was completed at 4:00 p.m. without further incident, using nitrous oxide, ether and oxygen insufflation.

At the end of the operation, the endotracheal tube was removed after tracheobronchial toilet. The patient remained in the Recovery Room for thirty minutes, following which he could be aroused satisfactorily, and was then returned to the ward. At 8:00 p.m. a croupy cough developed. Steam inhalations and penicillin were ordered and the nurse instructed to watch the patient closely. Respirations became raspy in character, but after codeine sulfate, $\frac{1}{8}$ grain, hypodermically, the child breathed easier and slept at ten to fifteen minute intervals. In between he awakened and coughed. At 10:15 p.m. his respirations seemed to be more labored. He was pale but not cyanotic. He appeared exhausted and lethargic. At this time a number 2 Magill endotracheal tube was passed under direct vision. Some subglottic edema could be visualized which was thought to compromise 40 to 50 per cent of the airway. The endotracheal tube was not advanced, but considerable thick and blood-tinged mucus was aspirated from the trachea. The tube was then advanced with difficulty. The respiratory exchange was good for two to four minutes and then diminished and disappeared. At no time was the patient cyanotic.

Spontaneous respirations never returned. A tracheotomy was performed and artificial respiration was maintained for forty-eight hours with the electrophrenic respirator and then, because of skin maceration from the phrenic electrode, the child was placed in a Drinker respirator. He succumbed twelve hours later. Autopsy revealed edema and ulceration 0.5 cm. beneath the vocal cords and a narrowed larynx at the level of the cricoid ring. The brain was edematous and there was bronchopneumonia. Death presumably was the result of cerebral anoxia.

Comment.—When it was recognized that this child probably had narrowing at the level of the cricoid cartilage, the endotracheal tube should have been removed and a smaller one inserted past the obstruction or the operation completed without a tube. The tip of the large tube situated just superior to this obstruction undoubtedly led to edema because of the motion of the trachea against the tube. Since it was recognized that such difficulties existed during anesthesia and operation, the child should have been placed in an oxygen tent with 60 to 70 per cent oxygen and 70 to 75 per cent humidity. This would have insured an adequate supply of oxygen and helped to prevent formation of edema. Although this should have been instituted immediately following the patient's return to the ward, it would have been helpful had oxygen been started at the first sign of respiratory difficulties. Unfortunately, this was not done. Again, when it was recognized that a croupy cough had developed, the child should have been bronchoscoped, the secretions distal to the obstruction removed and, if indicated, a tracheotomy performed. The urgency of the situation was not recognized. Despite the absence of cyanosis, the child experienced a period of relative anoxia, probably of two to three hours' duration. This emphasizes the fact that the pale, restless child may well be an anoxic child. This period of relative anoxia was long enough to produce irreversible brain damage. When an airway was re-established and 100 per cent oxygen administered, he continued to breath for several minutes, possibly because of continued chemoreceptor stimulation, but when this was removed, the damage was too severe for survival and the child ceased breathing.

SUMMARY

The major anatomic differences between the larynx of the infant and the adult have been described from the point of view of the anesthesiologist. The clinical implications of these variations have been discussed. Two case reports pertaining to the subject matter have been presented and discussed.

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