

ENDOTRACHEAL ANESTHESIA IN CHILDREN: ADVANTAGES AND DISADVANTAGES *

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Received for publication September 21, 1953

WHEN first introduced, the endotracheal technique for administration of inhalation anesthesia was regarded as an unnecessary complication (1). The marked advantages of this technique have caused this early opinion to be abandoned, and endotracheal anesthesia has become a widely accepted procedure for adults. For some new operations it is considered to be an indispensable part of the preparation of the patient. This wide acceptance of endotracheal anesthesia for adults has taken place in spite of the complications reported to have occurred following its use. Frequent injury to the pharynx, larynx and trachea following intubation in adults has been reported by some authors (2-8), and tracheotomy has occasionally been necessary (5, 6, 9, 10).

ADVANTAGES

The advantages of endotracheal anesthesia are the same for children as they are for adults: consistently adequate airway, quiet respiration, stable level of inhalation anesthesia, decreased aspiration of foreign material into trachea, avenue for aspiration of material from the trachea, decrease in respiratory dead space and effective means of artificial respiration. The small size of the child brings the fields of operation of the surgeon and anesthesiologist closer together and makes them more likely to overlap. If the anesthesiologist must yield working space to facilitate a more successful outcome of the operation, he must use an endotracheal tube to insure an adequate airway at all times in his relatively inaccessible area. Endotracheal anesthesia is especially advantageous for operations about the head and neck and the respiratory tract, as evidenced by the fact that more than 80 per cent of the intubations in children over a six-year period at the Mayo Clinic were for surgical procedures about the head and neck (table 3).

The narrow air passages of the child are more readily obstructed than are the wider passages of the adult. It is therefore more necessary that precautions be taken to prevent pharyngeal contents from entering the trachea and that preparation be made to insure adequate aspiration of material from the upper and lower portions of the

* Read before the Section on Anesthesiology at the meeting of the American Medical Association, New York, New York, June 1 to 5, 1953.

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respiratory tract as frequently as indicated. An endotracheal tube provides a certain and an accessible avenue for passage of the aspirating catheter to the lower portion of the respiratory tract. From a review of the cases of lung abscess at the Massachusetts General Hospital (11, 12), it was concluded that more than one half arose in consequence of aspiration of infected material from the upper part of the respiratory tract.

Eckenhoff (13) expressed the opinion that the advantages of endotracheal anesthesia in children outweigh the disadvantages and reported intubation in 65 per cent of all anesthesia administered at

TABLE I
SUMMARY OF REPORTED COMPLICATIONS FOLLOWING
ENDOTRACHEAL ANESTHESIA IN CHILDREN

	No. of Children	Complications						
		Laryngitis	Cough	Sore Throat	Tracheitis	Bronchitis	Mild Respiratory Obstruction	Severe Respiratory Obstruction
Baron and Kohlmoos ³	?							1
Beecher ¹⁷					1			
Crispell and Hampton ¹⁸	337							2
Eckenhoff ¹³	?							1
Donnelly and co-workers ¹	?						2	
Gillespie ¹⁸	197	2	5			2	2	1
Gillespie ¹⁹	?							1
Grimm and Knight ²⁰	?							1
Leigh and Belton ²¹	?							
McCarthy ²²	?					1		1
Segal ²³	250						1	
Slater and Stephen ¹⁴	2,026	Few				2		
Smith ¹⁸	560	43	32	14			6	
Turner ²⁴	?				1			

Philadelphia Children's Hospital. At the same institution, intubation was used during 98 per cent of anesthesia administered to patients 2 weeks of age or younger.

DISADVANTAGES

Endotracheal anesthesia has not been as readily accepted for children as for adults. This is probably the result of the general belief that complications, especially those of the larynx and trachea, are more frequent and more severe following endotracheal anesthesia for children than for adults. However, reports in the medical literature of complications following endotracheal anesthesia in children are no more numerous than of those following the same procedure in adults. One must therefore assume either (1) that the general belief about complications being more frequent in children than in adults is not

well founded or (2) that the complications are so commonplace as not to merit sufficient interest for publication.

The evidence for establishing the incidence of complications following endotracheal anesthesia in children is meager and variable. Slater and Stephen (14) found no serious complications following endotracheal intubation and use of nonbreathing valves in 2,026 children. On the basis of this experience they expressed the belief that postintubation complications are less common in children than in adults and that in pediatric anesthesia the advantages outweigh the disadvantages of intubation. After intubation in 560 children in 1952, Smith (15) found only 6 instances of respiratory embarrassment as evidenced by supra-

TABLE 2
RELATION OF AGE OF PATIENTS TO ENDOTRACHEAL COMPLICATIONS

Age of Patient, years	Intubations		Complications	
	Number	Per Cent*	Number	Per Cent†
0-1	65	2.0	3	4.6
1-2	99	3.1	3	3.0
2-3	158	4.9	8	5.1
3-4	246	7.7	1	0.4
4-5	306	9.5	5	1.6
5-6	331	10.3	4	1.2
6-7	336	10.5	2	0.6
7-8	265	8.2	8	3.0
8-9	239	7.4	3	1.3
9-10	171	5.3	1	0.6
10-11	188	5.9	5	2.7
11-12	181	5.6	1	0.6
12-13	188	5.9	3	1.6
13-14	226	7.0	3	1.3
14-15	214	6.7	2	0.9
Total	3,213	100.0	52	1.6

* Per cent of 3,213.

† Per cent of intubations of patients in given age class.

sternal or subcostal retraction and none of 3,000 children intubated during a six-year period required tracheotomy. On the other hand, Crispell and Hampton (16) reported 2 tracheotomies after intubation in 337 children.

Table 1 summarizes some reported complications from endotracheal anesthesia in children. Since this evidence did not seem to justify the general reluctance to employ endotracheal anesthesia in children, some experience with this technique at the Mayo Clinic was reviewed.

REVIEW OF CASES

During the six years from 1946 to 1951 inclusive, tracheal intubation was performed 3,213 times on 2,861 patients less than 15 years of age.

The distribution of the ages of the patients is shown in table 2. In 52 of these patients complications developed which possibly might have been related to intubation. These complications have been classified into four groups: (1) nonobstructing respiratory, (2) mildly obstructing respiratory, (3) severely obstructing respiratory requiring tracheotomy and (4) miscellaneous.

✓ The nonobstructing respiratory complications included 3 of sore throat, 4 of mild cough and 14 of hoarseness or other voice changes. It is possible that similar symptoms in other patients in this series were not detected, especially in the very young who could not reliably answer questions.

Mild respiratory obstruction occurred in 8 patients. In none was tracheotomy necessary and all were successfully treated with oxygen and humidification.

Three patients required tracheotomy for postoperative respiratory obstruction. A girl, 2 years of age, who received nitrous oxide, oxygen and ether anesthesia, was intubated on the second attempt and a large hairy mole was removed from the right temporal preauricular region in one hour and forty minutes. The next day respiratory obstruction from laryngeal edema made tracheotomy necessary. For some unexplained reason slight laryngeal edema was still present four weeks later and the tracheotomy tube was not removed until four months later. After removal of the tracheotomy tube, the wound promptly closed and the patient's airway and voice were normal.

The second patient was a boy, 10 years of age, who received nitrous oxide, oxygen and ether anesthesia; a 26 French gauge rubber endotracheal tube was inserted with ease and a suboccipital craniotomy was performed in one hour and fifty minutes. Four hours after completion of the operation respiratory "stridor" occurred which lasted only three hours, but the stridor recurred the next day and tracheotomy was performed. Since the larynx was not visualized and the patient was unconscious and had Cheyne-Stokes type of respiration, it is not possible to determine whether the respiratory obstruction was the result of laryngeal edema or of relaxation of the pharyngeal and lingual muscles.

The third patient was a girl, aged 7 years, who received nitrous oxide, oxygen and ether anesthesia, and was intubated with a 26 French gauge rubber endotracheal tube without difficulty. Subtotal thyroidectomy was performed in one hour and twenty minutes. The next day marked edema of the neck occurred and the patient had respiratory stridor and dyspnea, so a tracheotomy was done. The tracheotomy tube was left in place until after further surgical treatment of the thyroid gland one month later. Immediately after the second operation the tracheotomy tube was removed and no further symptoms were experienced. It was impossible to determine whether the edema of the larynx was the result of the thyroidectomy, as was the edema of

the neck, or whether the edema of the larynx was caused by the intubation. The former etiologic factor seems more logical than the latter.

The miscellaneous group of 20 complications included 8 patients who had muscular twitching during anesthesia and operation; 5 patients in whom temporary teeth were loosened or removed during intubation; 4 technical difficulties caused by kinking of the tube or its retraction from the trachea during the operation; one patient with postoperative parotitis; one patient in whom subacute otitis media developed on the fourth postoperative day and one patient who had an ineffectual cough after a suboccipital craniotomy. The relationship between the tracheal intubations and the last 3 complications was uncertain but since it was not possible to say definitely that these complications had no relation to the intubations, they were included in the count of complications. The most frequent cause of muscular twitchings in children during anesthesia is elevation of body temperature. Such an increase in temperature is more likely to be the result of atropine given as preanesthetic medication or of the closed technique used for administration of anesthesia than a result of the intubation.

FACTORS INFLUENCING COMPLICATIONS

Many children have been intubated. Why have only a few developed complications? Are there any common etiologic factors about those who did develop complications? The answers to those questions are not readily available, but some possible factors have been suggested.

Age of the Patient.—The anatomy of the upper respiratory passages of the child is different from that of an adult. In an infant the larynx is at the level of the fourth cervical vertebra and during growth descends to reach the level of the sixth cervical vertebra in the adult (25). Therefore, it would seem that an endotracheal tube would have to be in a curve with a shorter radius when in the larynx of an infant, and it would seem that the ordinary rubber tube with a "built-in curve" might exert more pressure on the arytenoid area of the larynx of the infant than of an adult.

Eckenhoff (13) has pointed out that the epiglottis of an infant is proportionately longer, stiffer, more "V" shaped, and extends out into the pharynx rather than along the base of the tongue because the hyoid is more closely attached to the thyroid cartilage than in the adult. About half the vocal cord of an infant is cartilaginous arytenoid vocal process which is less elastic than the ligamentous anterior half where almost all growth occurs. The cricoid ring is the only place where larynx or trachea is completely enclosed by cartilage and may be the narrowest point. At this point in the larynx any edema results in encroachment on the airway. In a cricoid ring 4 mm. in diameter, 1 mm. of edema reduces the cross sectional area 75 per cent whereas in

an adult with a cricoid ring 20 mm. in diameter, 1 mm. of edema reduces the cross section only 19 per cent.

Holinger and Johnston (26) have calculated the area of the glottic chink of the newborn to be 14 sq. mm. which is reduced by 1 mm. of edema to 5 sq. mm. or only 35 per cent of normal.

Whereas adults can be encouraged to cough up dried secretions and products of inflammation causing obstruction in the larynx and trachea, children frequently will not respond to such encouragement; so these secretions more frequently have to be removed from children with a bronchoscope (24), or tracheotomy has to be performed to prevent respiratory obstruction.

In this series there was no definite evidence that age was an important factor in determining the incidence of complications, although the two highest percentages of complications, 4.6 and 5.1 (table 2), occurred in the 0 to 1 year and 2 to 3 year age group respectively. Twenty-six complications (1.7 per cent) occurred in 1,541 intubations in patients less than 7 years of age, while 26 complications (1.6 per cent) occurred in 1,672 intubations in patients 7 years or more of age.

Trauma During Intubation.—The mucous membranes of children are less resistant to injury than those of adults and more gentleness is required during exposure of the larynx and insertion of the endotracheal tube. Beecher (27) stated that trauma on insertion increases directly as the skill of the anesthetist is deficient. Smith (15) suggested that the use of light, easily handled laryngoscopes with long, narrow blades discourages the use of force. Miller (28) described a laryngoscope with a straight blade and curved tip which allows exposure of the vocal cords without pressure on the epiglottis.

The opinions concerning the relative ease of intubation in children and adults vary. Eckenhoff (13), Gillespie (19) and Kaye (29) believe that, in general, intubation is technically more difficult in children than in adults while Leigh and Belton (21) and Segal (23) think children are intubated far more readily than adults. My experience coincides with that of the latter authors. Many of the intubations in this series were performed by residents under instruction and it was unusual for them to experience any difficulty. It is important that the young patient be anesthetized deeply enough at the time of intubation to allow the mouth to be easily opened, to relax the pharyngeal muscles and to abolish the laryngeal reflexes. If a child must be intubated under light anesthesia, prior cocaineization of the larynx as advocated by Hawksley (30) might be helpful. Decreased frequency of post-tonsillectomy scarring of tonsillar pillars in children decreases the incidence of tears in these structures which can be a cause of sore throat following intubation under direct vision. As in adults anatomic variations may make intubation very difficult in certain children and the anesthesiologist must decide whether the advantages of intubation

will be greater than the increased risk of complications in the individual case.

Physical Characteristics of the Endotracheal Tube.—In the explanation of complications, varying degrees of importance have been attached to the size, length, shape and material of the endotracheal tube employed. Charts of suggestions for tube size according to age of patient have been prepared by Leigh and Belton (21), Hewer (31) and Flagg (6), but most agree that variation is marked for children of the same age. Woodbridge (32) found the size of the glottis to bear a closer relationship to the child's height than to his age or weight.

In Beecher's (27) opinion, the tube of smallest bore that will insure ventilation to keep oxygen saturation of hemoglobin and carbon dioxide tension normal throughout prolonged anesthesia is the optimal size. According to the physics of gases, Macon and Bruner (33) found a tube with internal diameter of 4.5 mm. adequate for the respiratory exchange of the average child from 3 to 7 years of age. Gillespie (18) recommended passage of the largest tube possible to avoid narrowing an already small airway. McCarthy (22) reported the occurrence of laryngeal edema in a child after use of too large a tube during tonsillectomy. In Smith's (15) opinion, forceful passage of tubes of excessive caliber may tear or stretch the vocal cords and during the course of the operation lead to edema or sloughing of the tissues. Kaye (7) found complications less frequent and less severe after passage of small bore tubes than of large bore tubes. In the opinion of Crispell and Hampton (16) the size of the tube may be of minor importance since edema occurs in loose areolar tissue overlying the arytenoids, aryepiglottis and ventricular folds and upper part of the trachea, while the greatest pressure of the tube is on the vocal cords which have no areolar tissue.

Dwyer and co-workers (34) convincingly showed that with the ordinary curved rubber tube, pressure is exerted on the posterior pharyngeal wall, arytenoids and anterior wall of the trachea. They advocated use of a plastic tube molded on a mandrel to the shape of the upper respiratory tract. A case has been reported by Grimm and Knight (20) in which acute tracheitis was caused by too great pressure on the tracheal mucosa by the cuff on the endotracheal tube. Beecher (17) quoted the necessity for removal of a cast from the trachea of a 6-year-old girl after use of an inflatable cuff.

My practice has been to use as large a tube as can be passed easily through the larynx. Before intubation is attempted, thin-walled tubes of several sizes are prepared so that if the first tube selected is too small or too large, the proper size can be quickly chosen before the level of anesthesia becomes light. It is desired that the tube fit the larynx snugly in order to provide as large an airway as possible and to prevent aspiration of pharyngeal contents into the trachea. How-

ever, if there is the least resistance to the passage of a tube through the larynx, a smaller size is used.

Frequent use of intubation for children was not justified until thin-walled kink-resistant tubes, like the King tubes, became available. The lumen of an endotracheal tube must be large enough to allow the flow of the respiratory gases of the patient without undue resistance. The external diameter of a thin-walled tube with an adequate lumen for a given patient is much less than the external diameter of a thick-walled tube with the same size of lumen. Fewer complications can therefore be expected from the use of thin-walled tubes made especially for tracheal intubation of children. The practice of making tracheal tubes for children out of thick-walled urethral catheters or stock rubber tubing is to be condemned.

TABLE 3
RELATION OF ENDOTRACHEAL COMPLICATIONS TO SURGICAL PROCEDURES

Operation	Cases	Complications									
		Total		Nonobstructing Respiratory		Mildly Obstructing Respiratory		Tracheotomy		Miscellaneous	
		Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent
Tonsillectomy and adenoidectomy	1,050	3	0.3	0	—	0	—	0	—	3	0.3
Neurosurgery on head and neck	334	18	5.4	10	3.0	3	0.9	1	0.3	4	1.2
Other operations on head and neck	1,282	19	1.5	7	0.5	1	0.1	2	0.2	9	0.7
Chest operations	239	4	1.6	0	—	2	0.8	0	—	2	0.8
Abdominal operations	101	3	3.0	1	1.0	1	1.0	0	—	1	1.0
Spinal and extremity operations	207	5	2.4	3	1.4	1	0.5	0	—	1	0.5
Total	3,213	52	1.6	21	0.7	8	0.2	3	0.1	20	0.6

The tip of the tube should extend into the trachea far enough so that it will not be dislodged during the operation, but not far enough to enter a bronchus or impinge on the cord. Just after the bevel of the tube has passed the cords the anesthesiologist should focus his eyes on the length of the tube extending out of the patient's mouth in order to be able to judge how much farther to advance the tip down the trachea.

The size of the endotracheal tubes used seemed to have little influence on the resulting complications in my patients. There were 32 complications of a respiratory nature after 3,213 intubations, an incidence of 1 per cent (table 3). Of these respiratory complications only 3 followed intubation with an endotracheal tube with an external circumference more than 2 mm. greater than the most frequently used

tube size for the age group of each, as determined in a previous study.

Duration of Intubation.—Prolonged intubation with a tube of correct size is rarely the primary cause of complications and has only an indirect effect in that more time is allowed for other factors to exert their effect. If the gases passing through the tube have not been humidified, secretions in the trachea and bronchi may become inspissated and form crusts after a prolonged period of intubation. Dwyer and co-workers (34) found no ulceration in adult patients intubated for less than six hours, while in 4 similar cases in which the duration of intubation was six to fifteen and one half hours, there was ulceration overlying the cricoid and tracheal cartilages. Cassels and Yeager (35) intubated a newborn infant for a total of fifty-three hours without producing laryngeal edema, and Urry (36) reported intubation of an adult for seventy-seven days without evidence of tracheal or laryngeal damage. Flagg (37) quoted Dr. Chevalier Jackson as believing that there was less reaction to keeping a bronchoscope in the trachea for an operation of as long as two or three hours than allowing ether-laden mucus to bubble back and forth as occurs during the open method with ether. Iglauer and Molt (38), Kaufman and co-workers (39) and Wangenstein and co-workers (40) have reported severe laryngeal edema caused by prolonged use of even small duodenal tubes in the esophagus.

The evidence from this series would seem to indicate that duration of intubation has some influence on the incidence of complications after intubation (table 3). Complications occurred with the greatest frequency (5.4 per cent) after neurosurgical operations on the head and neck, which had the longest mean duration of intubation (138 minutes) of any of the six groups of operations. The least frequency (0.3 per cent) occurred after tonsillectomy and adenoidectomy, which had the shortest mean duration of intubation (forty-one minutes). Of the 32 patients in whom respiratory complications developed, the mean duration of intubation was 105 minutes, the shortest being forty minutes and the longest 225 minutes.

If too small an endotracheal tube is used, duration definitely becomes an important factor. An infant is easily exhausted by resistance to respiration, and tidal volume may become so small as to allow an increase in carbon dioxide tension in the blood. The child may be able to overcome the resistance of the small tube for a short period of time but will lose his accommodation if the unfavorable conditions are prolonged.

Motion of Tube or Larynx During Period of Intubation.—Even though the tube is well lubricated, trauma is increased by movement of the tube against the larynx and trachea. This motion may occur in many ways. Unless the head is well fixed it may be moved repeatedly during the operation, especially during operations on the head and neck. Crispell and Hampton (16) thought position of the patient's

head and motion during craniotomy were possible etiologic factors in 2 patients who required tracheotomy after intubation. Since coughing and swallowing, which may result from light anesthesia, increase trauma, the endotracheal tube should be removed as soon as practical after the laryngeal reflexes become active in the postanesthesia period. Respiratory obstruction causes an exaggeration of the normally slight motion of the larynx and trachea occurring during respiration. The attachment of anesthetic equipment to the endotracheal tube causes increased motion of the tube and prevents the tube from moving with the head.

Infection and Chemical Irritation.—It is well known that severe edema may occur from infections in the pharynx and larynx. Gillespie (19) expressed the belief that many cases of acute edema of the glottis occurring after intubation were the result of infection superimposed on mechanical trauma at the time of intubation and passage of the tube. Crispell and Hampton (16) related the experience of Eckenhoff in being able to culture streptococci from the tube of lubricant applied to the endotracheal tubes used for 5 patients in whom laryngeal edema developed following intubation. Decreased resistance to infection in debilitated patients would seem to make them more susceptible to this type of complication, but in my experience complications from intubation have not been more frequent in this type of patient than in other types.

Ransom (9) was able to prevent rash on the face of patients where the masks rested and markedly reduced the number of sore throats after intubation by discontinuance of the use of biniodide of mercury to clean masks and tubes. Smith (15) has reported allergic reactions to lubricants used on endotracheal tubes and has almost abandoned lubricants in favor of dipping tubes in water immediately before passage.

My practice is to wash thoroughly all used tubes and laryngoscope blades, both inside and out, with soap and water and a brush. The tubes are then boiled for about five minutes or soaked for a half hour or longer in a 1:1,000 solution of zephiran®, then thoroughly rinsed. The tubes are then dried and stored in curved plastic containers. When ready for use, a tube is touched with bare hands only on the part that is to be in the patient's mouth. Sterile petrolatum or water-soluble lubricant is applied with sterile gauze to the part of the tube that is to pass through the larynx. While holding the tip of the tube, I straighten it so that I can see through the lumen and inspect for foreign bodies.

Neither the review of the literature nor the analysis of my series can prove the relative importance of the above-mentioned factors on the incidence of complications after endotracheal anesthesia in children. In some patients several or all the factors may exert some influence. Only by careful attention to all the factors in all patients can the frequency and severity of complications be minimized.

SUMMARY

Advantages of endotracheal anesthesia are as great as or greater for children than they are for adults.

Disadvantages of properly executed endotracheal anesthesia in children have been overemphasized.

An analysis of the complications occurring during and after 3,213 intubations is presented.

Factors affecting complications of endotracheal anesthesia in children are discussed.

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