# THE ENDOTRACHEAL TUBE: A CONSIDERATION OF ITS TRAUMATIC EFFECTS WITH A SUGGESTION FOR THE MODIFICATION THEREOF *

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The endotracheal tube has come into widespread use as an effective means of establishing and insuring a free airway. Its value in anesthesia is shown by its increasing usefulness for all types of surgery. The anesthetist's ability to provide a patient with a satisfactory airway by endotracheal intubation may make it possible to correct hypoxia resulting from cerebral respiratory depression or respiratory obstruction.

Intubation may be a life-saving measure in the treatment of asphyxia, drug and gas poisoning, pulmonary edema, maxillofacial and head injury, cerebrovascular accident, acute edema of the glottis, and other conditions which may interfere with the normal tidal exchange. Intubation has become an indispensable part of resuscitation since respiratory exchange often cannot be assured without it. Rovenstine (1) has recommended its use in the treatment of the comatose patient whose laryngeal reflexes are sluggish or absent. Foregger (2, 3) has written of its extensive use for the prolonged cleansing of the tracheobronchial tree.

It is generally admitted that endotracheal tubes may cause damage to the upper respiratory tract (4, 5, 6, 7, 8) but most traumatic effects have been ascribed to inept intubation. Little attention has been given to the damage which may result from the tube after it is in place. A search of the literature reveals few cases wherein the tube itself was indicated as the cause of untoward reactions. Cassels (9) described complete necrosis of the epithelium overlying the vocal cords in a child operated upon for repair of a tracheo-esophageal fistula. He believed that the endotracheal tube was responsible for the findings. Lundy (5) reported a case in which an endotracheal tube remained in place for thirty-eight hours. At autopsy, the patient showed

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diffuse hemorrhagic exudation and ulceration in the upper portion of the trachea. He stated that "when the tube remains in the trachea for periods up to seventy or eighty hours, it has been found at necropsy that a membrane has been formed much like that found about a tracheotomy tube and in addition ulcers and discolored pressure areas may be seen where the tube has pressed against the mucous membrane." Grimm and Knight (10) reported necrosis of the tracheal mucosa in a child who had a lobectomy for bronchial adenoma. They ascribed the pathologic change to the pressure of an inflated cuff on the endotracheal tube.

Several authors have favorably reported on the prolonged use of endotracheal tubes without permanent damage (2, 3, 11, 12). In 1880, MacEwen permitted an endotracheal tube to remain in place for thirty-six hours and Gillespie reported a case of intubation for fifty-one hours with only temporary ill effects. Foregger has described 7 cases in which the tube remained in the air passages for as long as eighty-three hours. Lundy stated that he has seen an untoward result only once when the tube was left in place for fifteen hours or less.

FIG. 1. Larynx and trachea from case with Magill tube in place fifteen and one-half hours. Trachea has been split posteriorly to show ulcerations on anterior tracheal wall.

Our interest in the trauma which may be caused by the endotracheal tube was stimulated by the following case.

A 29-year-old man was admitted to the hospital with a severe head injury. He had been a chronic alcoholic and had probably been unconscious for about eight hours. Because of respiratory obstruction and increasing accumulation of secretions in the upper respiratory tract, a 35 French, curved rubber endotracheal tube was inserted blindly through the nose without difficulty. The tube was left in place and secretions were frequently aspirated by means of a soft rubber catheter until his death, fifteen and a half hours later, at which time the tube was removed. During the treatment for his severe shock, he had received an excessive amount of fluid and salt, that is, 5000 cc. of physiologic saline solution, 1000 cc. of 10 per cent dextrose in physiologic saline solution and 1000 cc. of plasma. At autopsy, several areas of ulceration of the trachea were found in addition to the head injuries, and extensive edema of the lungs, mediastinum, and retroperitoneal tissues.

FIG. 2. Section taken through an ulcer shown in figure 1. The mucosa overlying a tracheal cartilage is destroyed.

Figure 1 is a photograph of the tracheal lesions. The ulcers occupied a longitudinal area, 4.5 cm. × 0.5 cm., on the anterior wall of the trachea in its midline. They consisted of a series of discrete areas denuded of epithelium, with gray bases and surrounded by ecchymosis. Each denuded area overlay a tracheal cartilage; the uppermost area was the largest and overlay the broad cricoid cartilage. Patches of remaining epithelium were seen overlying the inner spaces between the cartilages. The rest of the mucous membrane of the larynx and trachea was diffusely edematous, shiny and pale, similar to that seen in conditions of non-inflammatory edema of the larynx. Figure 2 is a microphotograph of a section of tissue taken from the trachea. The ulcer lies over a tracheal cartilage. Necrosis of tissue, fibrin deposits, extensive infiltration by inflammatory cells, vascular congestion, and edema are visible.

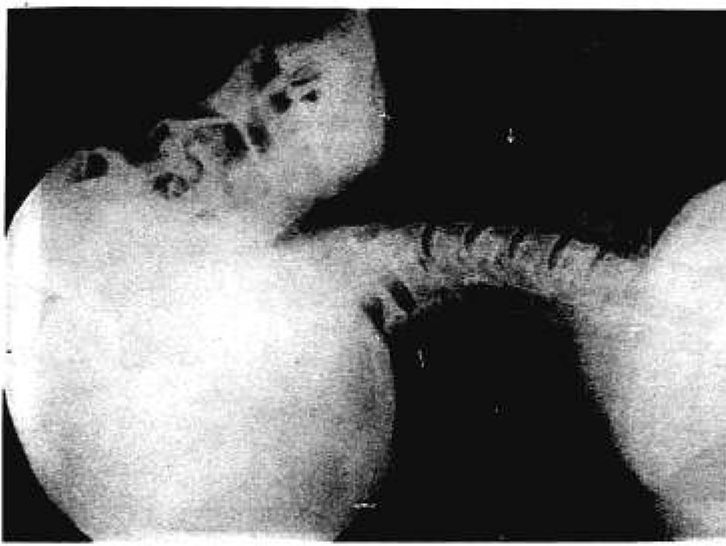

FIG. 3. Roentgenogram of air passages of head and neck. Head and shoulders on same horizontal plane and head is extended. The arrow shows approximate position of vocal cords.

We have studied 4 cases of prolonged intubation at autopsy and have bronchoscoped a number of other patients. The longest period of intubation was fifteen and one-half hours. In every case the pattern of lesions was the same as that described. Ulcerations of the tracheal mucosa have not been seen in those intubated for less than six hours. Traumatized congested areas have appeared within two to four hours after intubation regardless of the type of tube employed. The epiglottis may show an area of congestion where it has lain on the tube. The posterior third of each vocal cord often showed a similar area which was more severe when a tube of large diameter had been used. In none of our cases in which autopsy was performed, however, was true ulceration of the mucosa shown by histologic examination.

There appear to be important anatomic and physiologic factors which led to the tracheal damage in these cases.

*Constitutional Factors.*—Certain constitutional factors may lead to an easily traumatized respiratory passage. General debility from

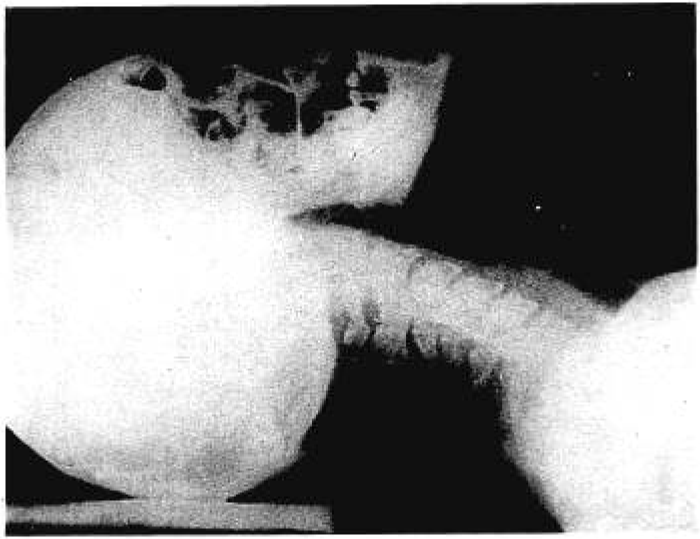

FIG. 4. Roentgenogram of air passages of head and neck. Head is raised in "amended" position. The arrow shows approximate position of vocal cords.

chronic illness, anemia, toxicity, vitamin deficiency, or alcoholism make for lowered resistance to trauma and infection. Dehydration leads to an increased friability of the epithelium of the respiratory tract and diminished secretion of mucus. The lubricating action of the protective mucus is decreased and injury may be readily produced. Generalized edema from hypoproteinemia, salt retention, advanced renal disease, cardiac failure, and so forth, may involve the tissues of the respiratory tract as in our first case. Resistance to inspiration caused by respiratory obstruction or tissue anoxia from any cause may precipitate congestion and edema of the mucous membrane. Edematous tissue has little ability to cope with trauma or infection. Allergic disturbances such as angioneurotic edema or drug sensitivity may involve the respiratory tract. Lundy (5) has pointed out that a few individuals react quite violently to even minimal trauma to the mucous membranes of the body. Edema may quickly follow intubation or catheterization. Diseases such as virus or bacterial pneumonia, tracheobronchitis, measles, whooping cough, diphtheria, smallpox, typhoid, diabetes mellitus or tuberculosis may be accompanied

FIG. 5. Outline drawing of air passages of head and neck to show the path of a nasal Magill tube and the changes its curve must undergo. The lower arrow shows the pressure on the anterior tracheal wall due to resilience of the tube.

by ulceration and edema of the mucosa. It should be borne in mind that ulcerations may already be present or may easily be produced in these conditions should intubation become necessary to maintain an airway.

*Local Factors.*—Certain local abnormalities of the upper respiratory passages may predispose to trauma from the endotracheal tube. Structural anomalies of the larynx or trachea, displacement, compression, or contraction of the passages from infections, deformities, or tumors about the respiratory tract may cause undue pressure of the tube upon the mucosa. Acute and chronic inflammation of the larynx and trachea may exist at the time of intubation and the anesthetist may be unaware of its presence. This may be especially true in the comatose patient. The presence of a duodenal catheter in the esophagus for several days may lead to ulceration in the region of the cricoid sphincter from whence inflammation may spread to involve the tracheal wall and thus help bring about traumatic effects from tracheal intubation. An endotracheal tube prevents the normal warming and humidifying of inspired air and gases unless special precautions are taken to humidify the atmosphere. The nose and pharynx are bypassed and cold dry gases may strike the mucosa of the tracheobronchial tree directly through the tube. The secretions rapidly become inspissated and have little protective effect on the mucous membranes.

*Movement.*—Movement of the tube or of the tissues with which it is in contact is another factor leading to injury. This motion is a to and fro movement with respiration. It increases the severity and extent of the damage. Jackson (13) has described the following changes in the tracheobronchial tree during respiration:

a. Elongation during inspiration
b. Shortening during expiration
c. Expansion during inspiration
d. Collapse during expiration

During ordinary quiet respiration, linear movement may be slight but is much increased by hyperpnea, hypoxia, respiratory obstruction, deep anesthesia, and so forth. The larynx may descend 2 to 3 cm. as the trachea moves posteriorly and caudad into the thorax. Movements due to coughing, swallowing, or hiccuping may become an important consideration in the treatment of coma, in resuscitation, or when the tube is left in place after operation. The presence of the tube itself may stimulate these reflexes.

*Shape of the Tube.*—The shape of the tube is, we believe, the most important factor in the production of the traumatic effects. The commonly used tubes are curved in one plane (as the Magill) or straight (as the Woodbridge or woven silk). Heretofore, attention has been primarily focused upon the ease of introduction of the artificial airway, while little consideration has been given to its contours in relation to those of the respiratory passages where it must remain. Figures 3 and 4 are roentgenograms taken to show the air passages of the head and neck. In figure 3, the head and shoulders are on the same horizontal plane and the head is extended. In figure 4, the head is raised in the "amended" position. The arrows show the location of the vocal cords. It can readily be seen that the straight or anteriorly curved tubes, since they tend to maintain their original shapes, will not easily conform to the configuration of the air passages.

Figure 5 is an outline drawing of the air passages of the head and neck and diagrammatically shows the path of a curved rubber tube as it is inserted through the nose into the trachea. As the tube is passed along the floor of the nose, the tip strikes the posterior wall of the nasopharynx. The curve of the tube must increase sharply at this point. The inherent curve of the tube tends to bring the tip forward toward the larynx as it passes through the hypopharynx. Since the air column turns abruptly posteriorly at the level of the vocal cords, the tip will strike the anterior wall of the lower larynx or upper trachea just below the cords. The anterior curve of the tube must be reversed as it passes down the trachea and this causes pressure against the anterior tracheal wall. The resilience of the tube will cause pressure at the posterior commissure of the larynx.

FIG. 6. Nasal Magill tube in cadaver. A hole has been cut in the anterior portion of the trachea to allow tube to follow its natural curve forward. The path of the trachea posteriorly into the thorax is shown.

The position of the head and shoulders is also important in regard to these pressure points. Raising and flexing the head will bring the upper pharynx forward and tend to lessen the curve the tube must make at the larynx. This will reduce the pressure at the posterior commissure and on the anterior trachea. Lowering and extending the head increases the angle at the vocal cords. Regardless of the position of the head, however, any resilient tube with an anterior curve passed by the nasal route will cause some degree of pressure at these points.

FIG. 7. Nasal woven silk tube in cadaver to compare with figure 6. A straight tube also passes forward through the hole in the anterior tracheal wall.

FIG. 8. Oral Magill tube in cadaver. Tube follows path through hole in trachea as in figure 6.

The same principles apply when a curved tube is inserted by the oral route but, in this case, the sharp curve at the nasopharynx is eliminated. The weight of the tongue with the mouth open tends to force the tube back against the pharyngeal wall. As with the nasal route, the larynx acts as a fulcrum and the tube curves down the trachea in a manner similar to that described. Raising and flexing the head or lowering and extending the head will have the same effect as in the nasotracheal method.

FIG. 9. Oral Woodbridge tube in cadaver. Path through hole in trachea similar to figure 7.

The various types of straight tubes such as the Woodbridge or woven silk will follow similar curves by the orotracheal route but, because they lack the anterior curve of the Magill tube, less pressure will be exerted against the posterior commissure and the anterior tracheal wall.

It has been possible to demonstrate in the autopsy room how the anterior tracheal wall may be traumatized by the lower end of the endotracheal tubes.

Figures 6, 7, 8, and 9 are photographs of a fresh cadaver with various types of catheters in place. The head and shoulders are on the same horizontal plane and the head is in a neutral position. The neck

FIG. 10. Nasal Magill tube made to follow curves of larynx and trachea. The trachea is pulled forward out of its bed by the rubber tube.

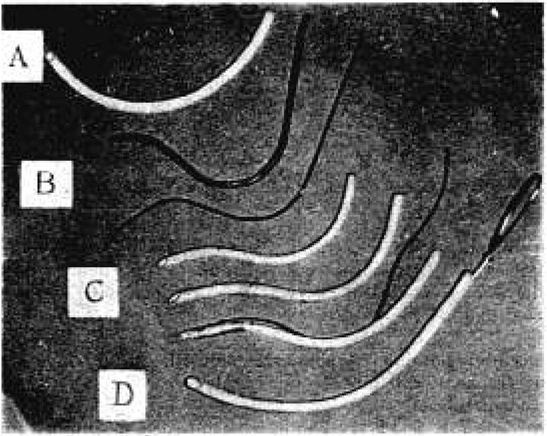


FIG. 11. A. Usual anteriorly-curved portex plastic endotracheal tube. B. Mandrels of copper tubing and stiff wire. C. Various sizes of modified portex tubes. D. Modified portex tube with stilet in place.

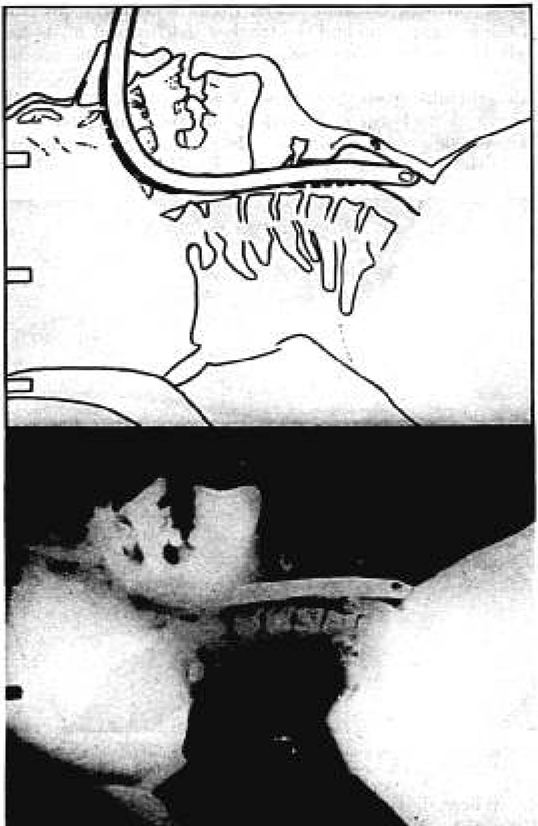

FIG. 12. Roentgenogram of nasal Magill tube in place. The tip of the tube is deformed by the pressure on the anterior tracheal wall. The posterior commissure is compressed.

has been dissected to show the larynx and trachea. A large hole in the anterior wall of the upper trachea permits the course of the tubes as they are pushed past the larynx to be seen. The path of the trachea as it descends posteriorly into the thorax is well illustrated. In all of these photographs it is evident that there would be a definite thrust against the anterior tracheal wall. In figure 10, a Magill tube has been made to follow the trachea instead of allowing it to take its natural course through the hole. The tip is seen to be pressing firmly against the anterior wall and the trachea is lifted out of its bed by this force. It is apparent that such pressure against the mucosa would eventually lead to ulceration.

It was obvious from these studies that a supple tube with a posterior curve at its lower end would avoid the damage to the anterior trachea. We devised a modified endotracheal tube by heating a portex plastic tube on a curved mandrel in boiling water and allowing it

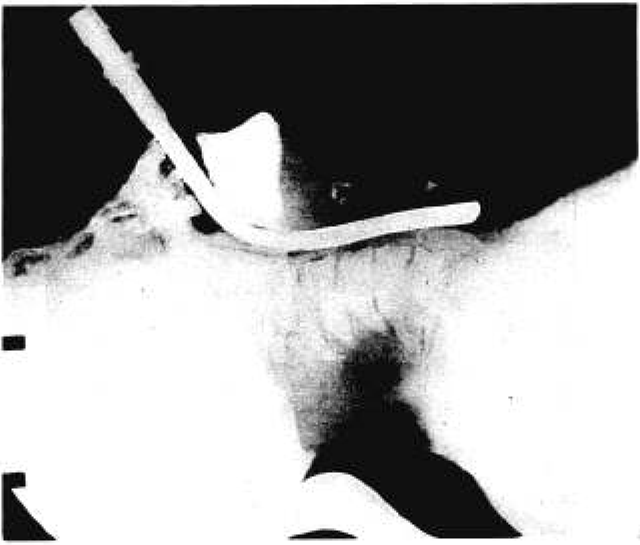

FIG. 13. Roentgenogram of oral Woodbridge tube in place. The tip can be seen against the anterior tracheal wall.

to cool. When the mandrel was removed, the tube maintained the curves desired. Figure 11 shows the usual portex tube, mandrels, modified endotracheal tubes and the modified tube with stilet in place for intubation.

For orotracheal intubation it is necessary to use a curved stilet to bring the lower portion forward into the glottic aperture. When the tip has entered the trachea, the stilet is withdrawn and the tube pushed along until the most convex part of it is between the vocal cords. We have marked the tube at 1 cm. from this point so that it can be visualized on insertion. Lubrication of the inside of the tube allows easy withdrawal of the stilet. For nasotracheal intubation, the stilet is

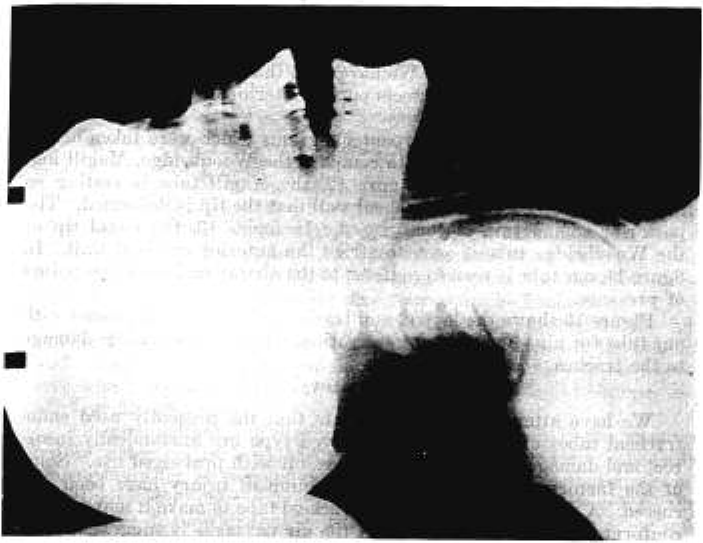

**Fig. 14.** Modified portex tube in place. The tube conforms to the curves of the air passages and shows no points of pressure on the anterior tracheal wall or on the posterior commissure.

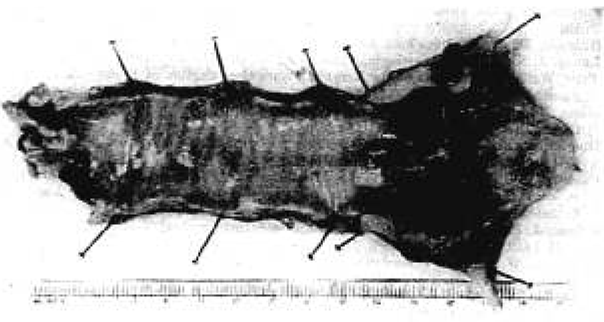

**Fig. 15.** Larynx and trachea of patient intubated for nine hours with modified portex tube. The mucosa is smooth and glistening with no evidence of trauma on the anterior tracheal wall.

employed until the tip of the tube has entered the oropharynx and the convex portion of the tube is within the nose. The stilet is then withdrawn and the tube advanced through the larynx while the tip is directed with Magill forceps. We have used this type of tube frequently and have seen no pressure effects on the anterior or posterior tracheal walls.

Figures 12, 13 and 14 are roentgenograms which were taken of patients under ether anesthesia to compare the Woodbridge, Magill and our tube in actual use. In figure 12, the Magill tube is resting so firmly against the anterior tracheal wall that the tip is deformed. The posterior commissure is compressed. In figure 13, the metal tip of the Woodbridge tube is seen to strike the anterior tracheal wall. In figure 14, our tube is seen to conform to the airway and shows no points of pressure.

Figure 15 shows the larynx and trachea of a patient intubated with our tube for nine hours during operation. There is no visible damage to the trachea.

## Summary

We have attempted to demonstrate that the presently used endotracheal tubes of the straight or curved type are anatomically incorrect and damage to the trachea may result with prolonged use. Some of the factors concerned in the production of injury have been discussed. A modification of the endotracheal tube to make it more nearly conform to the normal contours of the air passages is suggested.

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