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The Shape of the Human Adult Trachea

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The adult trachea has been described as triangular,[1] elliptical,[2] C-shaped,[3] and non-circumferential[4] in cross-section. Tracheal shape has been suggested as a possible reason for trauma occurring as a result of intubation in reference to Morquio's disease, where malformation of the tracheal cartilage is found.[5] The adult trachea is not circular,[6] but the cuff of a freely inflated endotracheal tube is circular in cross-section. To seal the airway this cuff must either conform to or deform the trachea.[4] A high-compliance cuff should conform, but damage to the trachea has been reported.[7] There appears to be no single etiologic factor in the development of tracheal damage, although many predisposing factors have been reported.[8–10] The cross-sectional shape of the trachea would seem to be another important determinant of damage. For this reason, cross-sectional tracheal shapes were studied.

METHOD

One hundred eleven adult tracheas were dissected at autopsy and specimens obtained. Cross sections were taken between the fourth and seventh tracheal rings at the point where the cuff of a tracheostomy or orotracheal tube would be expected to be positioned. To prevent gravitational shape changes the specimens were stored in individual 50-ml containers and were preserved in formalin.

The age, weight, height, sex, and race of every patient were recorded. All specimens examined were from non-intubated patients admitted to the Medical Examiners Office in Baltimore, Maryland. There was no pathologic abnormality in or around any of the tracheas that would have caused any distortion of tracheal shape.

To classify tracheal shape the ratio of the transverse diameter to the anteroposterior (AP) diameter and the angle between the posterior membranous portion and the cartilage of the tracheal ring were recorded. Two observers made independent classifications of the specimens. These were repeated four weeks later without reference to the first findings.

Computerized axial tomography (CAT) of the neck at the level of the sternoclavicular joint was used to show the cross-sectional shape of the trachea *in vivo*.

RESULTS

Six distinct tracheal shapes were seen (fig. 1). The most common (48.6 per cent) was the C shape (table 1). This type was circular except for the posterior membranous portion. The cartilaginous portion made an obtuse angle with the membrane, and anteroposterior and transverse diameters were equal. The next most frequent was the U shape (27 per cent). This had a larger anteroposterior than transverse diameter, and the cartilage made an obtuse or right angle with the membranous portion. Two other

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shapes were also seen frequently. These were the D shape (12.6 per cent) and the elliptical (8.2 per cent). The D-shaped trachea had a large membranous portion, the transverse diameter was larger than the anteroposterior diameter, and the cartilage made an acute angle with the membranous portion. The elliptical trachea had a larger transverse than anteroposterior diameter, and the cartilage made an obtuse angle with the membrane.

Rarely, tracheal shapes were circular (1.8 per cent) or triangular (1.8 per cent). The circular trachea was an almost complete ring of cartilage, with a small, practically nonexistent membranous portion. The triangular trachea had approximately equal anteroposterior and transverse diameters, and the cartilage made an acute angle with the membrane.

Of the 111 specimens, 103 were similarly classified by independent observers. Differences in classification were due to the problem of differentiating U, C and elliptical shapes when the anteroposterior and transverse diameters were nearly equal. These eight transitional specimens were classified by mutual agreement between observers.

There was no correlation between patient age, weight, height, sex, or race and any of the tracheal shapes studied. Mean age was 42.3 years (range 16–69), mean weight 70.9 kg (37.7–138.6) and mean height 170 cm (147–196). Eighty-two patients were male. Sixty-four patients were white, 45 black, and two oriental.

CAT scans at the level of the sternoclavicular joint in 31 patients confirmed the presence of all the above shapes *in vivo*. The distribution of shapes is shown in table 1. There was no difference between frequencies of CAT scan and anatomic shapes (χ^2 test, $P > 0.05$).

Discussion

The specimens showed considerable variation in tracheal cross-sectional shape. The same shapes were confirmed in non-intubated patients by CAT scan.

TABLE 1. Incidences of Anatomic and CAT Scan Cross-sectional Tracheal Shapes

	Tracheal Shape					
	C	U	D	Elliptical	Circular	Triangular
Anatomic						
Number	54	30	14	9	2	2
Per cent	48.6	27	12.6	8.2	1.8	1.8
CAT scan						
Number	13	9	4	3	1	1
Per cent	42	29	12.9	9.7	3.2	3.2

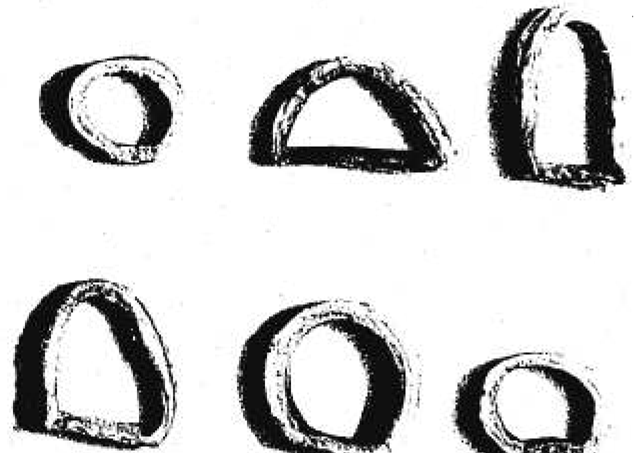

FIG. 1. Examples of tracheal cross-sectional shapes at autopsy (left to right) *Top row*: circular; D; U. *Bottom row*: triangular; C; elliptical.

There is no evidence that these shapes are influenced by postmortem changes or formalin-induced shrinkage. However, during ventilation and coughing tracheal shape is known to change. The compliance of the trachea decreases with age, and its length and volume increase with positive pressure in the airway.[11] Shape may also be influenced by the effect of the supporting tissues around the trachea.

It is important to differentiate between tracheas that have larger anteroposterior than transverse diameters and those that have larger transverse diameters. U-shaped tracheas fall into the former group, D-shaped and elliptical tracheas into the latter.

If anteroposterior and lateral diameters could be identified prior to endotracheal intubation, an anatomically designed cuff might reduce the damage inflicted during prolonged intubation. We are presently studying anteroposterior and lateral air tracheograms as a noninvasive technique of tracheal measurement. Although CAT scanning is the ideal method of identification of tracheal shape, it is not presently practical in most situations.

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Spontaneous Dislocation of Endotracheal Tubes

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The concern about laryngeal and tracheal injury from prolonged endotracheal intubation has led to development of softer tubes with large-diameter/low-pressure cuffs. While these innovations have decreased the incidence of pressure necrosis of the tracheal mucosa, they have also created new problems. For instance, nasogastric tubes and other esophageal devices may accidentally enter the trachea, unimpeded by the soft cuff of the tracheal tube.[1]

During 1975, in 18 ICU patients, we tested an experimental polyvinylchloride (PVC) tube, softer than those commercially available. Six of the 18 patients managed to "extubate" the trachea without using their hands, and despite firm fixation of the tubes to the face. On inspection, the six tubes were all found to be either looped in the mouth and pharynx or tortuously deformed. At that time, the mechanisms of tracheal tube dislocation were believed to include chewing, coughing, bucking, "tongueing," and moving the head. Because of the problem, the manufacturer was advised not to produce this soft PVC tube or to modify it to avoid this dangerous complication. More recently, however, patients in our intensive care unit have had similar spontaneous dislocations of commercially available PVC tubes. Two of these cases are reported here, and the likely causes of dislocation discussed, based on observations during experimental ventilation of a lung model and of cadavers.

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REPORT OF TWO CASES

Case 1. A 56-year-old white man was hospitalized for elective total colectomy because of uncontrolled ulcerative colitis, unresponsive to medical therapy. Colectomy was uncomplicated, but during the first two postoperative days, severe respiratory distress developed. Roentgenograms of the chest revealed dense pulmonary infiltrates. At bronchoscopy, a large quantity of purulent material was removed. It grew *Pseudomonas aeruginosa.* The patient's condition deteriorated, and he was admitted to the intensive care unit for mechanical ventilation. A PVC tracheal tube, 8.5 mm I.D. was inserted orally under direct vision without difficulty. The cuff was seen to pass well below the vocal cords. Roentgenograms of the chest showed the tube in good position. The tube was secured to the face using tincture of benzoin and adhesive tape. Three hours later, an air leak developed. The tube was still firmly fixed to the face but distorted in the mouth, the cuff completely above the cords. This tube was removed, a second tube placed, and the cuff was again seen to pass below the cords. Exit of air from the tube was ascertained by pushing on the chest. The cuff was inflated with air until it just sealed. Breath sounds were heard by two examiners to be equal on both sides. Once more, the tube was routinely secured to the face as described above. Over the next 15 minutes, the patient's condition was stable. However, after a routine post-intubation roentgenogram of the chest, he became agitated, bradycardic, and then asystolic. When manual assistance of ventilation through the orotracheal tube was begun, a large air leak was immediately apparent, necessitating extubation and insertion of a third tube of the same type. The roentgenogram obtained immediately prior to cardiac arrest showed the orotracheal tube to be completely dislodged from the trachea, and its tip in the esophagus. Following cardiopulmonary resuscitation, until death 12 hours later, the patient remained totally unresponsive. A post-cardiopulmonary resuscitation portable chest x-ray film showed the tip of the third endotracheal tube 4 cm above the carina. Ventilation with a tidal volume of 1,000 ml and a positive end-expiratory pressure (PEEP) of 5 cm H_2O caused peak airway pressure to oscillate between 30 and 35 cm H_2O. Another roentgenographic examination 8 hours after cardiopulmonary