Choice of Tracheostomy Tube: Does One Size Fit All?

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Introduction

Tracheostomy is performed on intensive care unit (ICU) patients to facilitate weaning and pulmonary toilet and to provide airway protection. The introduction of percutaneous techniques has led to the procedure being performed with increasing frequency. Much has been made of methods to improve safety during the procedure yet little attention is paid to the ongoing complications of the presence of tracheostomy tubes in the airway. Inappropriate tube choice can lead to short term complications such as local erosion and cutaneous infection and long term complications such as tracheal stenosis, tracheomalacia, and vascular and esophageal fistulation, and can also contribute to problems such as tube displacement.

Historical Perspective

Much is made of the history of tracheostomy as a surgical procedure but less is known of the tubes used. Early descriptions of tracheostomy describe the use of a reed inserted through the stoma, via which the operator could then blow air. Sanctorius (1561–1636) is widely credited with the first trocar and cannula technique. He recommended leaving the cannula in place for a period of two to three days. These early devices consisted of curved silver tubes with multiple fenestrations. Martine (1702–1743) introduced double lumen tubes, recognizing the need to clean the inner cannula without removing the tube in its entirety. The combination of these two designs was not dissimilar to Jackson's silver tubes from the twentieth century. Cuffs were first applied by Trendelenburg (1802–1872), and these were refined into high volume-low pressure cuffs by Grillo in 1967.

Evolution of the tracheostomy tube from these early cannulae has been guided by intended use. For much of its history, tracheostomy has been performed for the relief of airway obstruction. It was not until the poliomyelitis epidemics of the 1950s that tracheostomy was performed to allow mechanical ventilation for prolonged periods. These facts may seem interesting, but essentially irrelevant to modern practice, yet it is history and intended use that has guided the evolution of the tracheostomy tube. The devices we use today have changed little from early designs that were intended for different purposes when prolonged ventilation was not a consideration. It is only recently that designs have developed to reflect current practice.

Relevant Anatomy and Pathophysiology

The trachea consists of a membranous tube supported by a series of cartilaginous rings. These rings are incomplete posteriorly; the posterior membranous portion is suspended between the tips of the c-shaped cartilages. The adult trachea is 12 cm in length, with an external diameter of 2.3 cm in the coronal plane [1]. Each tracheal ring is approximately 4 mm wide, with a 2 mm membranous segment between each ring [2]. These measurements are particularly pertinent when considering the external diameter of commonly used tubes (11–13 mm). The female trachea is smaller in both length and diameter. The cross-sectional shape of the trachea varies but is classically ovoid with posterior flattening. With age, the lower trachea becomes flattened laterally and lengthened antero-posteriorly (the 'sabre sheath' trachea).

The angle of the trachea to the skin of the anterior neck is variable and changes with age. Similarly the depth of the trachea from the surface varies considerably between individuals. Our own research on an unselected group of adult ICU patients undergoing percutaneous tracheostomy demonstrated that the depth of the trachea from the skin was between 18 and 32 mm. The posterior wall of the trachea was between 40 and 56 mm from the skin. The angle of the trachea to the fixation point on the anterior neck was also found to vary between individuals and was found in our study to be between 104–122^0 (unpublished data).

Lesions of the skin, soft tissues, and trachea can be related either to tracheostomy insertion, or the ongoing presence of the tube. Formation of a stoma necessarily causes some degree of tissue disruption. Multiple studies have failed to show a persistent, significant difference in complication rates between surgical and percutaneous techniques, or between the many types of percutaneous technique available. The exception to this is infectious problems, which are generally higher in surgical tracheostomy, thought to be due to the larger skin defect generated in this procedure.

Post-insertion problems are more influenced by the ongoing presence of the tracheostomy than the method of insertion. Two mechanisms of pathogenesis of tracheal lesions have been proposed.

1. Pressure exerted by the tube or cuff on the tissues causes ischemia and tissue destruction. Application of this theory led to the introduction of high volume-low pressure cuffs [3, 4].
2. Movement of the tube against the tissues will produce erosion of the tissues. This movement may be obvious (e.g., coughing or other patient movement) or it may be microscopic (e.g., movement from the ventilator transmitted through the circuit). Flexible catheter mounts are an important measure in the prevention of erosive lesions [5].

After the initial defect has formed bacterial colonization occurs. This may not result in clinically evident infection, but will further limit tissue healing, and in the trachea can lead to softening of the cartilaginous rings [6]. Stenosis is due to healing with fibrosis and collagen formation; contraction of fibrotic tissue then leads to stenosis. This contraction is restricted by the rigid cartilages of the trachea. However if the cartilage has been damaged or softened this effect is limited and significant stenosis can occur [7].

Although these effects were originally described for tracheal lesions, it would seem reasonable to assume that similar mechanisms are responsible for any problems occurring in the skin and soft tissues of the neck.

Tube Design Considerations

Tracheostomy tubes are available in a number of sizes and designs for different intended uses. **Figure 1** shows a number of commonly available tubes used in our hospital. Size and shape vary significantly. Materials used in tube construction also vary with some tubes being essentially rigid and others being fully flexible. Tubes are chosen based upon internal diameter in most cases. Less attention is paid to external diameter, length, and angulation, yet all these factors are important in ensuring the correct fit of tube to the patient.

Sizing and choice of tracheostomy tubes has been recognized as an issue in pediatric practice for many years. This is due to the more obvious variation in size within the patient population, yet adult patients can also vary significantly; is a size 8.0 mm internal diameter tube suitable for both a 40 kg 80-year old and an obese 40-year old. Tracheal diameter may not change significantly, but the surrounding soft tissues will be significantly different. Ultrasound and other techniques to assess both depth and internal diameter of the trachea have been recommended in children in order to guide choice of tube [8].

Tube Construction

Most modern tubes are plastic and mass produced. Materials used in construction range from polyvinyl chloride (PVC) to the more expensive silicone rubber. These different materials display differing levels of rigidity, from entirely flexible to essentially rigid. Many manufacturers now label their tubes as 'thermoplastic' indicating a tendency of the material used to soften at physiological temperatures. This leads

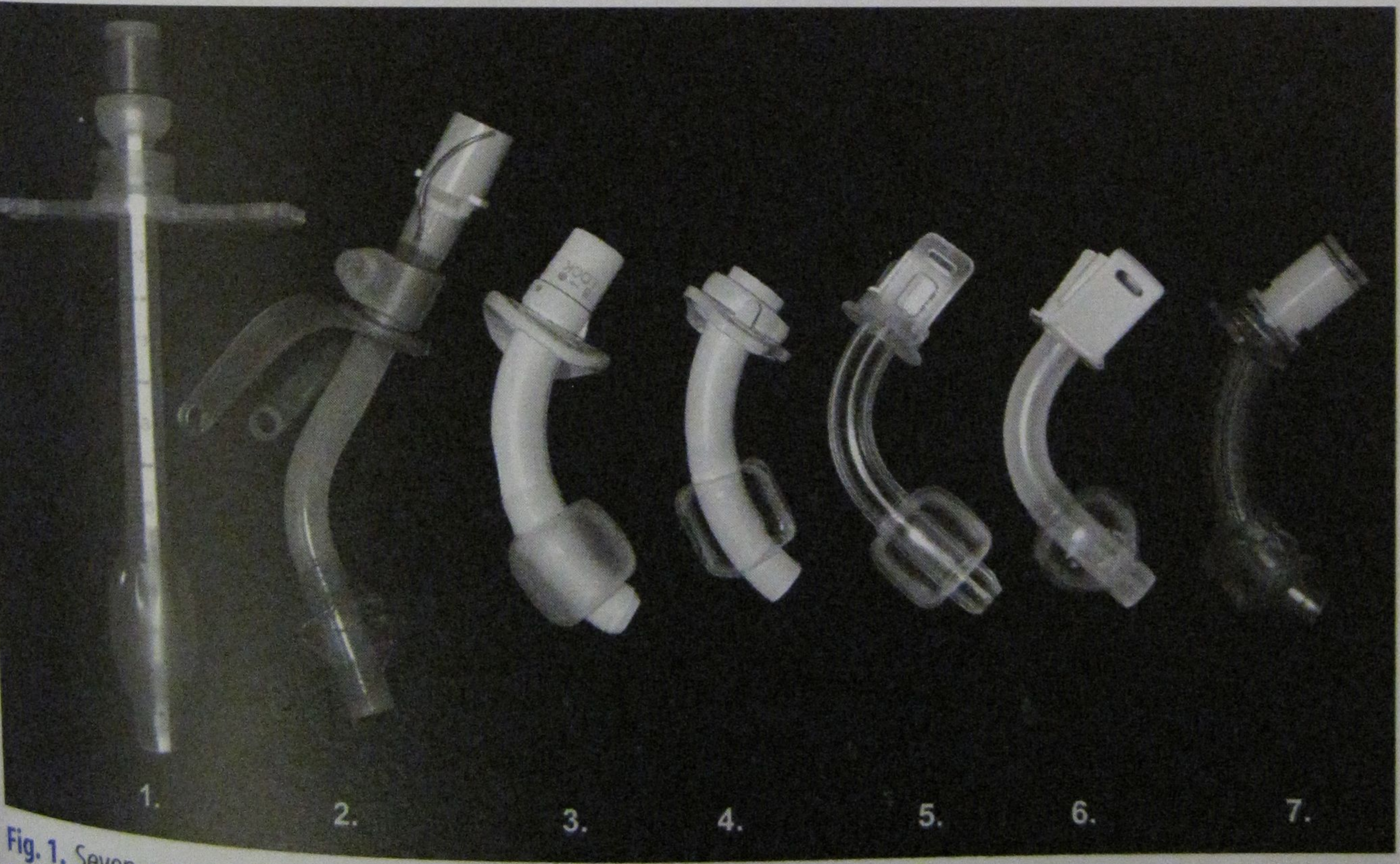

Fig. 1. Seven commonly available tracheostomy tubes. 1. Bivona armored, 2. Portex adjustable flange, 3. Shiley, 4. Tracoetwist, 5. Mallinckrodt Perc, 6. Portex blue-line, 7. Portex Blue-line Ultra. All the tubes in the image are size 8.0 internal diameter (Shiley is Jackson Size 8), yet there are large differences in length and external diameter. Angulation varies between 90–115°, and there are also differences in the length of the tube over which the angulation occurs.

to the tube being more flexible when inserted than when it is outside the body. Whilst this characteristic is appealing it may lead to tube kinking or render the device more liable to external compression.

Tubes made of rigid material (usually polyurethane) are still common. These devices can lead to pressure sores around the insertion site and will also transmit more movement from the ventilator circuit to the trachea than a fully flexible device, potentially leading to more erosion than softer tubes which may influence long term complication rates.

Sizing

Tube choice has traditionally been made based upon the internal diameter of the tube. This is a reflection of the standards set out in International Standards Organization EN ISO 5366-1:2004. This recommends that tubes are sized according to their functional internal diameter, which may disregard the internal diameter of an inner cannula unless it is required for connection to the ventilator or breathing circuit. In addition to this, some tubes are still sized by the (Chevalier) Jackson system. This focus on internal diameter is convenient but over simplistic, as it neglects dimensions such as length and external diameter, which are both important in ensuring the correct fit.

When considering length, tubes should be viewed as having two segments: Intrastomal and intratracheal, these being connected by the angle or curve of the tube (**Fig. 2.**). These components vary between different tube types and are common sources of poor fit. In the obese, the intrastomal segment can be too short, similarly in any patient not of 'average' height the intratracheal segment can be either too short or too long.

Use of a tube with an inadequate intrastomal segment can also lead to the angle of the tube being pulled into the stoma and the lumen opening against the posterior wall of the trachea. Erosion of the stoma by the angle of the tube is a major risk factor for tracheo-innominate fistula formation [9]. The tip of the tube can impinge

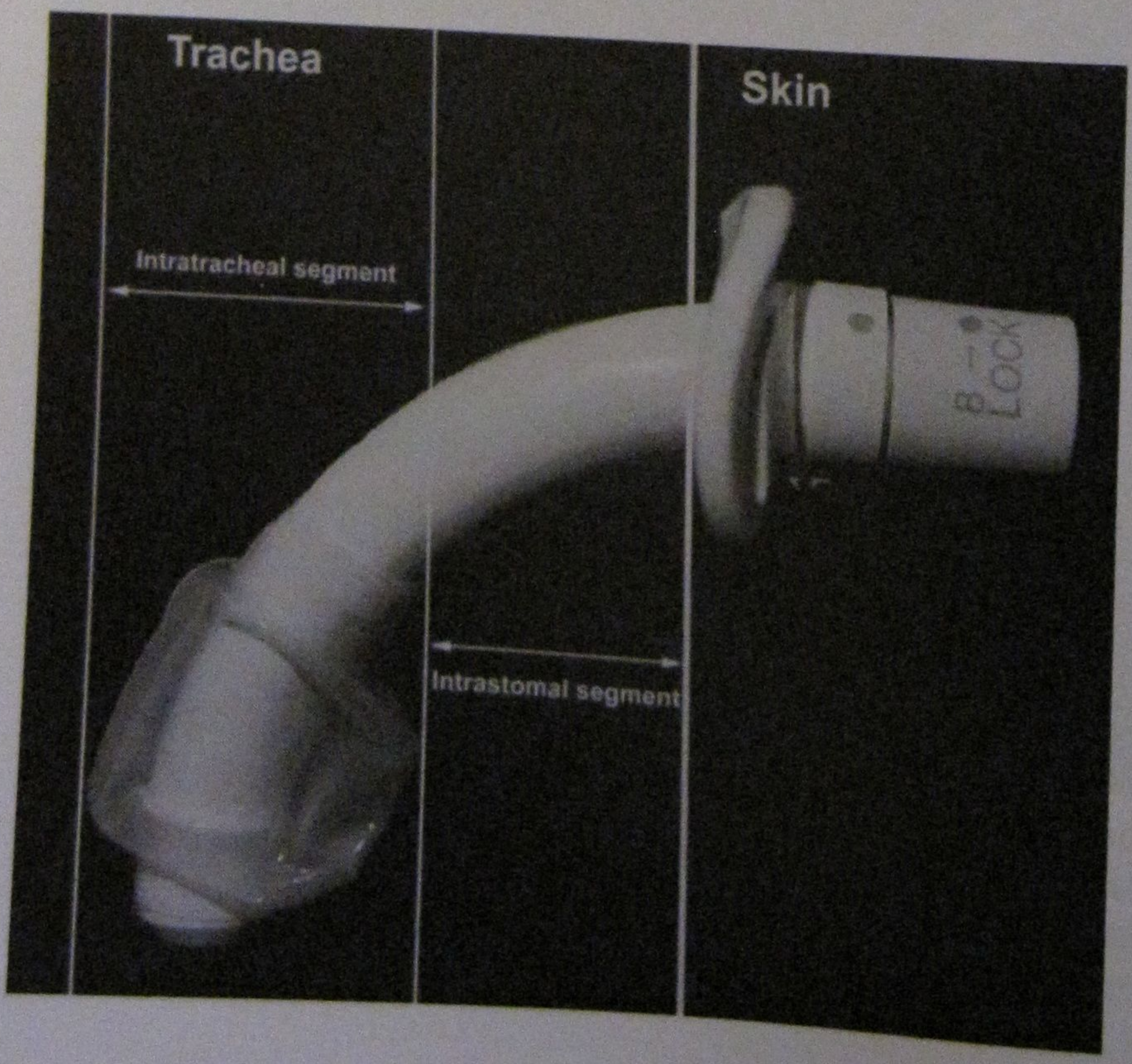

Fig. 2. Representation of intrastomal and intratracheal segments of the tube. Intrastomal length can vary significantly with body habitus and neck anatomy. Insertion of a tube with too short an intrastomal segment will result in limited length of the tube within the trachea and compression of the anterior tracheal wall and tissues of the anterior neck between the cuff and the flange.

upon the posterior tracheal wall and cause erosions and pressure necrosis which may lead to fistulation into the esophagus [10]. Use of a 'standard' tube in these scenarios can also produce excessive pressure at the skin and can lead to pressure sores at the stoma site or under the flange. This is of particular concern if the flange is relatively rigid.

An inadequate intratracheal segment can lead to there being too little of the tube inside the trachea, predisposing to tube dislodgement. Too long an intratracheal segment may lead to endobronchial intubation.

Some tubes have no straight segment, consisting of a tube which is curved throughout its length. Tubes of this nature may be very difficult to fit accurately.

External diameter is necessarily larger than the internal diameter and varies depending on manufacturer and type of tube. The external diameter defines the size of defect made in the anterior tracheal wall which in turn relates directly to the degree of long-term stenosis encountered [11, 12]. External diameter should, therefore, be kept to a minimum resulting in a compromise between adequate internal diameter, and excessive external diameter. Cuff function is also important (see below).

The angulation of tracheostomy tubes is often fixed between 90–110^0. Insertion of a tube with poorly fitting angulation may lead to the tip of the tube opening onto the anterior or posterior tracheal wall, causing obstruction of the tube and potentially leading to erosion of the trachea. It is also worth noting that continuously curved tubes (as opposed to those with a short angulated segment and two straight segments) may enter the trachea tangentially, potentially producing a larger defect in the anterior tracheal wall than tubes which enter the trachea perpendicularly.

Tube Design Features

The basic design of a tracheostomy tube is relatively simple, consisting of little more than a plastic tube and flange, a 15 mm connector and an inflatable cuff. There are however a number of additional features which are available which may be of value in the intensive care setting.

Adjustable flange

Adjustable flanged tubes allow tailoring of the length of the intrastomal, and in the case of fully flexible tubes without a fixed angle, the intratracheal, segments of the tube. These are particularly helpful in the obese when a longer intrastomal segment is of use.

Double cannula

Inner cannulae allow cleaning of the tube lumen without removing the whole tracheostomy tube. In this respect they are very valuable, in particular when dealing with acute obstructions due to secretions in the tube. However, these cannulae all decrease the internal diameter of any given tube. Most of these cannulae reduce the internal diameter by 1–2 mm, which can have significant effects on work of breathing [13] and which may be relevant in those who are difficult to wean.

Flexible/armored

Fully flexible tubes are usually armored to provide circumferential stability. Most currently available devices have no fixed angle, though some have a pre-molded angle of 110^0. In conjunction with an adjustable flange these devices allow individualization of all tube dimensions related to length. Their use has so far been limited by lack of inner cannulae, but newer devices are becoming available with this feature.

Double lumen

Double lumen tubes designed for single lung ventilation are available, though rarely needed on the ICU. They are particularly useful for very low tracheostomies (trans-manubrial) where the bronchial limb provides a degree of stability whilst allowing bilateral ventilation (the intratracheal component of normal tubes would tend to endobronchial positioning in these situations).

Oval tubes

Cicatricial tracheal stenosis following tracheostomy is more likely when a greater number of tracheal rings are disrupted as fibrotic shrinkage goes unopposed [11, 12]. Recognition of this fact has led to the development of tubes that have an oval cross section, being reduced in diameter in the vertical plane. Theoretically these devices will produce less tracheal ring disruption during insertion and ongoing residence in the airway. A preliminary study shows promising results [14].

Subglottic suction ports

The addition of subglottic suction ports to the tube allows aspiration of secretions from above the cuff, and has been associated with reduced incidence of ventilator-associated pneumonia (VAP) [15, 16]. Unfortunately the use of these devices was shown to produce excessive subglottic stenosis in an animal study [17] and their use cannot be recommended at present.

Adaptations to percutaneous insertions

Percutaneous tracheostomy requires a close fit between the leading edge of the tube and the dilator upon which it is introduced. This has led to the development of a number of modifications of both the tube and the dilator in order to streamline the tube during insertion. These modifications have little impact on the characteristics of the tubes as discussed above, but has led to tubes being packaged with the introducers. This could lead to operators picking a tube based on internal diameter rather than evaluating the requirements of individual patients.

Cuff Design

Through the years there have been a number of attempts to redesign the cuff in an attempt to reduce the incidence of tracheal stenosis. The most successful of these is the high volume-low pressure cuff introduced by Cooper and Grillo [18]. These devices allow the cuff to fill the trachea and produce a seal, without exerting excessive pressure on the tracheal wall. The performance of these tubes may be compromised by over inflation, which will convert them to a traditional high pressure cuff. The most common reason for a tube to be overinflated is use of a device with too small a diameter. High pressure ventilation compresses the cuff from below, and can cause it to distort. The distortion reduces the area of contact between the cuff and the trachea and increases the pressure within the cuff leading to a potentially hazardous situation.

Other cuff designs have been proposed including foam filled and 'gilled' cuffs, but none have become popular. 'Tight to shaft' cuffs have a cuff which is flush with the tube when deflated. These tubes are useful when deflation tests are required (such as in laryngeal obstruction) and may have similar characteristics to distensible cuffed tubes. Distensible cuffs have been suggested in order to limit micro-aspiration [19]. These cuffs exert minimal pressure on the tracheal wall and have recently been packaged with a fully flexible tube with a number of other desirable design features. Clinical trials are awaited.

Assessment of Tube Size and Position

It is clearly desirable to insert only one tube, and to have that tube fit perfectly. Unfortunately assessment may be difficult pre-insertion and a number of tubes may need to be tried before the best fitting device is found. It is, however, possible to make some assessment pre-insertion. Physical assessment may, for example, reveal the trachea to be significantly deeper than anticipated (through obesity or other causes). Ultrasound can be used to assess tracheal depth from the skin and can also give an estimate of tracheal diameter. Angle from the skin may also be assessed.

Post-insertion assessment of fit is done via bronchoscopy to assess the position of the luminal opening in relation to the center of the trachea, and also via observation of the inserted tracheostomy from above. The tube should lie centrally within the trachea and the cuff should be visible as an annulus around the tube. If the cuff is seen to lie above the tube then the intrastomal portion is too short. The cuff will abut the stoma and a different tube may be needed.

Fully flexible tubes with an adjustable flange are ideal in that they can be made to fit most patients.

Conclusion

The presence of a tracheostomy tube in the airway is associated with significant long-term complications. Some of these complications could potentially be reduced by better selection of tracheostomy tubes and individualization of choices according to factors related to patient size.

Much research has gone into defining the ideal method of tracheostomy insertion with no clear answers found. Perhaps it is time to look at the tubes, which may spend weeks in the airway, rather than further dissect the surgical procedure which is over in a matter of minutes?

References

1. Grillo HC, Dignan EF, Miura T (1964) Extensive resection and reconstruction of mediastinal trachea without prosthesis or graft: an anatomical study in man. J Thorac Cardiovasc Surg 48:741–749
2. Randestad A, Lindholm CE, Fabian P (2000) Dimensions of the cricoid cartilage and the trachea. Laryngoscope 110:1957–1961
3. Grillo HC, Cooper JD, Geffin B, Pontoppidan H (1971) A low-pressure cuff for tracheostomy tubes to minimize tracheal injury A comparative clinical trial. J Thorac Cardiovasc Surg 62:898–907
4. Cooper JD, Grillo HC (1969) The evolution of tracheal injury due to ventilatory assistance through cuffed tubes: a pathologic study. Ann Surg 169:334–348
5. Andrews M, Pearson F (1971) Incidence and pathogenesis of tracheal injury following cuffed

tracheostomy with assisted ventilation. Analysis of a two year prospective study. Ann Surg 173:249–263

6. Weymuller EA Jr (1988) Laryngeal injury from prolonged endotracheal intubation. Laryngoscope 98:1–15
7. Grillo H (2004) Post intubation stenosis. In: Grillo H (ed) Surgery of the Trachea and Bronchi. BC Decker, Hamilton, pp 291–339
8. Hardee PSGF, Ng SY, Cashman M (2003) Ultrasound imaging in the preoperative estimation of the size of tracheostomy tube required in specialised operations in children. Br J Oral Maxillofac Surg 41:312–316
9. Jones JW, Reynolds M, Hewitt RL, Drapanas T (1976) Tracheo-innominate artery erosion: Successful surgical management of a devastating complication. Ann Surg 184:194–204
10. Couraud L, Bercovici D, Zanotti L, Clerc P, Velly JF, Dubrez J (1989) Treatment of esophagotracheal fistula following intensive care An experience of 17 cases. Ann Chir 43:677–681
11. Lindholm C, Grenvik A (1985) Intubation and tracheostomy In: Sprung C, Grenvik A (eds) Invasive Procedures in Critical Care. Churchill Livingstone, New York, pp 94–96
12. Arola MK, Puhakka H, Makela P (1980) Healing of lesions caused by cuffed tracheostomy tubes and their late sequelae; a follow-up study. Acta Anaesthesiol Scand 24:169–177
13. Cowan T, Op't Holt TB, Gegenheimer C, Izenberg S, Kulkarni P (2001) Effect of inner cannula removal on the work of breathing imposed by tracheostomy tubes: a bench study. Respir Care 46:460–465
14. Lindholm CE, Randestad A, Gertzén H (2003) New design of a tracheostomy-cricothyroidostomy tube. Eur Arch Otorhinolaryngol 260:421–424
15. Gujadhur R, Helme BW, Sanni A, Dunning J (2005) Continuous subglottic suction is effective for prevention of ventilator associated pneumonia. Interact Cardiovasc Thorac Surg 4: 110–115
16. Dezfulian C, Shojania K, Collard HR, Kim HM, Matthay MA, Saint S (2005) Subglottic secretion drainage for preventing ventilator-associated pneumonia: a meta-analysis. Am J Med 118:11–18
17. Berra L, De Marchi ML, Panigada M, Yu ZX, Baccarelli A, Kolobow T (2004) Evaluation of continuous aspiration of subglottic secretion in an in vivo study. Crit Care Med 32: 2071–2078
18. Cooper JD, Grillo HC (1969) Experimental production and prevention of injury due to cuffed tracheal tubes. Surg Gynecol Obst 129:1235–1241
19. Young PJ, Pakeerathan S, Blunt MC, Subramanya S (2006) A low-volume, low-pressure tracheal tube cuff reduces pulmonary aspiration. Crit Care Med 34:632–639