Percutaneous tracheostomy and cricothyrotomy techniques

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Abstract
Percutaneous tracheostomy is currently accepted as a standard technique for longer-term airway care in the critically ill patients in many intensive care units (ICUs). Early tracheostomy has not shown any survival benefit compared to late tracheostomy following prolonged tracheal intubation in ICU patients. The main indications for tracheostomy in the ICU setting include weaning from artificial ventilation or airway protection. Nevertheless, many questions about choice of techniques, post-tracheostomy care and decannulation remain unanswered. This review gives an overview of current techniques.

Keywords Artificial airway; cricothyrotomy; critical care; tracheal intubation; tracheostomy

Percutaneous tracheostomy is one of the most frequently performed bedside surgical procedures in the intensive care unit (ICU) for long-term airway access. Conventional surgical tracheostomy is generally reserved for emergency airway obstruction, and in scenarios where percutaneous tracheostomy is contraindicated or considered difficult or failed. Emergency airway access in the settings of upper airway obstruction is achieved by either cricothyrotomy or tracheostomy. Cricothyrotomy is generally indicated where the airway obstruction is at or above the larynx, and cannot be relieved by other means, or the facility to perform a conventional surgical tracheostomy is not immediately available. Knowledge of applied anatomy of the larynx and trachea is essential to avoid serious and even life-threatening complications in both elective and emergency settings.1

Applied anatomy
The surface anatomy of the larynx and cervical part of the trachea is easily felt when palpating with a finger from chin downwards in the midline. The thyroid notch on the laryngeal prominence of the thyroid cartilage is easily felt, particularly in males. From this point the finger descends along the body of thyroid cartilage into a space between the lower border of the thyroid cartilage and upper border of the cricoid cartilage. This space is the cricothyroid ligament, the landmark for cricothyrotomy.

The cervical proportion of the trachea can vary with flexion, extension, spinal curvature, antero-posterior diameter of the thorax and body build.2 The depth of the trachea from the skin in the neck normally increases on moving downwards and this is more marked in patients with a thick short neck and in the presence of kyphosis, a goitre, tissue oedema and in obese individuals. On average it is 2.0–2.5 cm deep from skin at the level of the second tracheal ring below which a tracheostomy stoma is normally performed.3

The angle of tracheal slant from the vertical gradually increases with age; however, there can be significant individual variation. This is more prominent with severe kyphosis, with the larynx lying closer to the sternal notch, and the trachea loses its mobility on attempted cervical extension bringing up very little extra tracheal length into the neck.4 By contrast, in young adults more than half the trachea rises into the neck on extension and sometimes by as much as two-thirds. These anatomical changes should be taken into consideration during tracheostomy.

Posteriorly the oesophagus lies in close relation to the trachea throughout its course except at the level of carina, where the oesophagus lies slightly to the left. A thin layer of areolar tissue lies between the posterior membranous wall of the trachea and the oesophagus, making the walls of two organs closely juxtaposed.5 Any damage to the posterior wall of the trachea potentially also damages the oesophagus.

The left brachiocephalic vein generally lies well anterior to the pretracheal plane. The brachiocephalic artery crosses over the mid-trachea obliquely from its point of origin from the aortic arch to reach the right side of the neck. In young adults a large proportion of trachea and the brachiocephalic artery regularly rise into the neck on extension. If a tracheostomy tube is placed close to the sternal notch in a young adult, there is a possibility of formation of a life-threatening tracheo-arterial fistula.

Previous radiotherapy or surgery in the neck (e.g. radical neck dissection, thyroidectomy or carotid surgery) may cause scarring and retraction of vessels out of their normal position, making them vulnerable to damage during tracheostomy. The veins in the neck are also very variable, with some older patients having a very large plexus of dilated anterior jugular veins in the midline. In contrast to what is stated in some textbooks, the midline cannot be considered to be devoid of large veins or arteries. These larger blood vessels can...
be visualized by ultrasound examination with the neck extended before tracheostomy.

**Ultrasound anatomy of the neck**

Ultrasound examination of the neck can be performed routinely or selectively in problem cases, with the neck extended before performing a tracheostomy. This may help identify aberrant blood vessels (Figure 1), the thyroid isthmus and lobes, and estimate the distance from the skin to the trachea. This distance gives an indication of the length of tracheostomy tube required for that individual patient. Ultrasound guidance can be used for needle visualization during the tracheostomy procedure, but there is little space for the footprint of the probe. Therefore, tracheal needle placement is typically performed with the help of endoscopic guidance.5

**Tracheostomy tube length**

A tracheostomy tube can be divided into two segments: the section between the skin and anterior tracheal wall (stomal length); and a section within the tracheal lumen (the intra-tracheal length) (Figure 2). The distance from the skin to the anterior tracheal wall determines the required length of the stomal section. The functional intra-tracheal length of a tracheostomy tube will depend on the total length of the tube, the size and shape of its cuff, the angle of the tracheostomy tube and the angle at which the stoma is formed in an individual patient. A preformed tube will not lie comfortably in an individual patient if the stomal or intra-tracheal lengths are too short or too long with the risk of tissue damage at pressure points. Ventilator breathing systems, filters and closed suction apparatus when attached to a tracheostomy tube frequently drag on the tube, ultimately putting traction on its intra-tracheal length and increasing the risk of tube displacement. Standard-length tracheostomy tubes appear too short for a large proportion of ICU patients. Manufacturers have taken note of such findings and increased the stomal length of standard tubes. There are now a few adjustable flange long tubes available for deeper tracheal stomas with appropriate introducer kits (Figure 3).

**Cricothyrotomy**

This intervention is primarily indicated to gain control of an airway that cannot be otherwise accessed in an emergency situation. It is the final step in the difficult airway algorithm in the ‘cannot intubate and cannot ventilate’ scenario. This intervention is essentially life-saving if performed correctly. There are a number of techniques but two commonly used ones include: a wire-guided Seldinger method; or catheter-over-needle technique. Irrespective of the method used the head is held in the midline position with patient supine and neck fully extended in the absence of cervical spine injury. The catheter-over-needle technique appears to be quicker to perform than wire-guided techniques, including Patil’s and Melker airways.7

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**Figure 1** A transverse ultrasound image of the anterior neck just above the sternal notch at the level of the third to fourth tracheal ring in an elderly patient. There was noticeable arterial pulsation at this site. Ultrasound with colour Doppler demonstrated a large ectatic subclavian artery directly in front of the trachea. This was avoided by carefully siting a percutaneous tracheostomy higher up between the first and second tracheal rings.

**Figure 2** Demonstration of the stomal and intra-tracheal segments of a tracheostomy tube.

**Figure 3** Components of Smiths Uniperc kit consisting of from left to right; a) introducer needle graduated in centimetres connected to syringe, b) sheath for guide-wire, c) first dilator graduated in centimetres, d) main S-shaped dilator, e) drape with a rectangular transparent portion for the surgical site, f) guide-wire, and g) armoured longer tracheostomy tube loaded over a loading dilator. On the rear a) inner cannula and b) the sponge to clean the inner cannula.
The technique of ‘mini-tracheostomy’ can be used in emergency or semi-emergency settings.

Mini-tracheostomy (Smiths Medical, Watford, UK) involves a small skin incision over the second or third tracheal ring cartilages and a needle insertion through the incision into the trachea between the two rings. The needle position inside the trachea is confirmed by aspiration of air through a saline-filled syringe. A guide-wire is inserted through the needle and the needle is then withdrawn. A dilator followed by the mini-tracheostomy tube is placed over the guide-wire.9

In a crisis situation, cricothyrotomy should be faster, simpler, less invasive and less likely to be haemorrhagic compared with tracheostomy. However, most physicians involved in airway management have only very limited experience with cricothyrotomy as it is rarely used, and if used it is nearly always in a crisis situation. A recent study showed that accuracy of surface landmark identification of cricothyroid membrane is poor.9 This may lead to cannula malplacement in emergency settings. Regular practice in a learning model may improve the success rate. Placement of a cricothyrotomy cannula in an anticipated difficult intubation prior to intravenous induction agent and muscle relaxant may provide optimal conditions for laryngoscopy compared to traditional deep inhalational induction. Hence, the choice of individual cricothyrotomy technique should be based on the experience of the operator and equipments and facilities available.

Tracheostomy

Tracheostomy is required in about one-quarter of patients receiving mechanical ventilation.10 Originally this was a primary operation to secure and establish an airway, in patients with life-threatening airway obstruction secondary to infection or neoplasms. More recently, this has become an elective procedure in ICU patients, principally to help wean patients from mechanical ventilation and to protect the airway in those with impaired upper airway reflexes. Tracheostomy can be performed by open surgical technique in the operating theatre, or at the bedside either by open or percutaneous approaches. Current percutaneous techniques were introduced in the mid-1980s.11 It has been found to be safe in terms of immediate and late complications. There have been numerous developments in percutaneous techniques during the past 20 years, but there is no hard evidence to recommend one technique over another.

Ciaglia serial dilatational technique: in 1985 Ciaglia described a bedside percutaneous dilatational tracheostomy using a needle, guide-wire and multiple sequentially larger dilators.11 As a thoracic surgeon, he first came upon the idea of a safer tracheostomy technique by observing the removal of a kidney stone with an Arnplaza percutaneous nephrostomy kit. The kit (Cook Critical Care, Bloomington, IN, USA) has been widely imitated. This technique has been superseded by newer kits, which may be less likely to cause posterior tracheal wall damage with advancement of stiff dilators.

Griggs’s percutaneous tracheostomy is also known as a guide-wire dilator forceps technique.12 In this approach a modified Howard Kelly forceps is introduced over the guide-wire for a blunt single-step dilatation of the pretracheal tissues and tissue between the tracheal rings. The tracheostomy tube is then inserted into the trachea over the guide-wire. This technique is popular in Australia where it was initially developed and also in parts of Asia. This technique can be associated with both intraoperative and postoperative bleeding in patients with abnormal vascular anatomy. The unmeasured dilatation of the tracheal stoma is sometimes too large for the tracheostomy tube, leaving leaks from insignificant to large, which require additional interventions.

Fantoní’s translaryngeal tracheostomy: in 1997 Fantoni and Ripamonti described this technique, which involves retrograde passage of a combined dilator and tracheostomy tube down through the larynx and out through the anterior wall of the trachea and pretracheal tissues.13 Once the dilator is pulled through the stoma it is cut away from the tracheostomy tube. The tracheostomy tube is then facing upwards to the larynx and requires 180° rotation to face the carina. This technique involves multiple interventions requiring more personnel and equipment at the bedside. Because of the complexity of the kit a very experienced operator is required. This technique has not gained widespread acceptance outside Italy.

Ciaglia single-dilator tracheostomy: in 1999 Ciaglia modified his original technique by replacing multiple dilators with a single-tapered dilator known as the Ciaglia Blue Rhino (Cook Critical Care, Bloomington, IN, USA). This technique uses a simpler kit with fewer parts than the original kit and requires fewer dilation attempts, making it faster.14 This technique has been imitated by other manufacturers and is widely used in the UK.

Frova’s percutaneous tracheostomy was described in 2002 and is commercially available as the Percutwist kit (Rüschi GmbH, Kernen, Germany).15 Under endoscopic guidance a screw-type dilator is rotated clockwise over the guide-wire through the soft tissues into the lumen of trachea. The dilator is removed by anticlockwise rotation and followed by placement of a tracheostomy tube. Tracheal ring fractures and posterior wall damage were described in a series of case reports.

Balloon dilatational tracheostomy: in 2007 the second generation of this technique was introduced into clinical practice.16 It involves insertion of a modified angioplasty balloon over a guidewire into the trachea (Blue Dolphin kit, Cook Critical Care, Bloomington, IN, USA). The balloon is inflated with saline up to 11 atmospheric pressure for 15 seconds to make a stoma (Figures 4 and 5). This is followed by balloon deflation and tracheostomy tube placement over an integral loading dilator. This technique needs to be compared with existing devices to determine any superiority in terms of ease of use and complications.

Tracheostomy kits for obese patients: percutaneous dilatational tracheostomy is increasingly performed in obese ICU patients and has been found to be safe at the bedside without an increased incidence of complications compared to conventional open tracheostomy. In the past there have been difficulties in inserting a longer adjustable flange tube in morbidly obese ICU patients because of the lack of availability of suitable loading
dilators. Recently two kits (Uniperc™, Smith Medical, Kent, UK and Experc-set, Tracoe medical GmbH, Frankfurt, Germany) have been introduced into practice consisting of longer stoma dilators and adjustable flange armoured tracheostomy tubes (Figure 7).

Preoperative evaluation

The cervical and tracheal anatomy should be assessed by clinical examination and ultrasound scanning of the neck. Any lesions, scars and masses in the central thyroid and tracheal area should be noted. Previous operations on the thyroid gland, the larynx, trachea or cervical spine can alter the anatomy. A low-lying larynx or cricoid in elderly patients with kyphosis or any other cause is particularly difficult where there is limited neck extension. Any aberrant blood vessels should be identified with the help of ultrasound to prevent massive haemorrhage. The operator should feel the landmarks, including suprasternal notch, cricoid cartilage, and tracheal rings. Because the surrounding tissues are highly vascular, any anticoagulants, including heparin infusion, infusion of activated protein C or any other antiplatelet agents should be discontinued. The coagulation profile and platelet count should be routinely checked, and there may be a need for clotting-factor replacement if the international normalized ratio is greater than 1.5 or platelet count is less than 50,000. Patients requiring high inspired oxygen (FiO₂ > 0.5) and high positive end-expiratory pressure (PEEP > 10 cm H₂O) should be deferred until oxygenation and gas exchange have improved.

Due consideration should be given to determine the size of tracheostomy tube required for an individual patient. On cervical extension the trachea is pulled superiorly. It is important to remember that if a suitable-length tracheostomy tube is not placed during the procedure, the tracheostomy tube may project out of the stoma or its tip may press against a mucosal surface if the trachea moves downwards towards the mediastinum after the procedure. The tube may either pivot against the anterior tracheal wall or the stem of the tube may press on the trachea cephalad to the stoma, potentially contributing to cartilage injury, which can lead to tracheomalacia or stenosis.

Practical aspects of a percutaneous tracheostomy

Percutaneous tracheostomy can be performed under local anaesthesia but in the ICU it is usually performed under general anaesthesia, with the patient supine and the neck extended. Ultrasound scanning of the neck reveals any abnormal vessels near the surgical site. Landmarks are marked, including the suprasternal notch, cricoid cartilage and tracheal rings when palpable. Lido- caine with epinephrine 1:200,000 up to 10 ml is infiltrated into the surgical site. The patient is paralysed and ventilated with 100% oxygen. Continuous monitoring of ECG, blood pressure, saturation of oxygen in arterial blood flow (SpO₂) and capnography is essential. The components of the tracheostomy set and other equipment required can be organized as shown in Figure 6.

A small transverse incision is made at the level of the second tracheal ring (the midpoint between cricoid cartilage and suprasternal notch in patients with normal anatomy). Blunt dissection is carried out until the trachea is felt with a finger. The existing endotracheal tube is withdrawn over the endoscope until the cuff is near the vocal cords. The authors recommend a Bonfils...
semi-rigid scope (or similar) rather than a flexible scope, to prevent needle damage and expensive repair to flexible scopes. The diameter of the Bonfils-type scope allows for adequate ventilation during the procedure. Display of endoscopic images on a monitor is required for the operator to visualize the needle and dilator placement within the trachea.

The introducer needle and cannula is inserted into the trachea preferably below the second tracheal ring in the midline under endoscopic visualization (Figure 7). Following removal of the needle, a J-tipped guide-wire is inserted. A small starter dilator is inserted into the trachea to open a tract and is then removed. A guiding catheter is then inserted over the guide-wire and followed by an appropriate dilator (e.g. single-tapered dilator; Figure 8). This dilator completes the dilatation in one step. A tracheostomy tube of appropriate size is then inserted over the loading dilator via the stoma (Figure 9). The entire procedure is performed under continuous endoscopic guidance to help reduce the risk of malposition and false passage.

As with any other operation, tracheostomy has complications, some related to the procedure and others related to the tracheostomy tube. Late complications are difficult to quantify as many patients are lost to follow-up. Bleeding is reported as the most common early complication. Other early complications include wound infection, subcutaneous emphysema, tube obstruction and false passage. Orottacheal intubation is indicated in case of accidental decannulation or dislodgement within 5 days of procedure if the tract cannot be re-established immediately. Late complications include swallowing problems, granuloma formation, tracheo-innominate artery fistula, tracheo-oesophageal fistula, persistent stoma and tracheal stenosis.

Post-tracheostomy care

Patients with tracheostomies in situ are increasingly seen in hospital wards, where there may be a lack of appropriate infrastructure to care for this vulnerable group of patients. The UK National Patient Safety Agency (NPSA) has recently reported numerous incidents associated with tracheostomies in hospital wards. Similar issues were reported in the UK 4th National Airway Audit project (NAP4, 2011). In the UK, an outreach team in some hospitals generally supervises patients with tracheostomy as a routine part of ICU follow-up, to ensure optimal post-tracheostomy care.

Nursing care: the stoma wound has to be kept clean and dry to prevent peristomal wound infection. An inner cannula should be used and it should be cleaned or replaced every 24 hours and this usually avoids the need for changing the tracheostomy tube.

Tube cuff pressure: the tracheostomy tube cuff requires monitoring to maintain pressures in a range of 20–25 mmHg. Mucosal ischaemia is likely with a cuff pressure greater than 25 mmHg. Cuff pressures below 15 mmHg may cause the cuff to develop

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Figure 7 Insertion of the introducer needle and cannula. Inset shows endoscopic view.

Figure 8 Dilatation of stoma using the tapered dilator.

Figure 9 Insertion of tracheostomy tube over the loading dilator.
longitudinal folds, promote microaspiration of secretions collected above the cuff, and increase the risk of nosocomial pneumonia.

Humidification of inspired air: inadequate humidification of the inspired air can lead to loss of mucociliary transport and thickening of airway secretions. These changes in turn increase the risk of hospital-acquired pneumonia or provoke airway obstruction by mucus plugs. A heat and moisture exchange (HME) filter helps in humidification when breathing room air via tracheostomy tube.

Clearance of secretions: tracheal suction is uncomfortable and should be performed when required rather than at a fixed frequency. Frequency of suctioning should be individualized, taking into account the viscosity and quantity of mucus, neurological and muscular performance, presence of active cough reflexes and respiratory effort. The upper airway should also be suctioned periodically to remove oral secretions and minimize pooling of secretions above the cuff, with subsequent potential aspiration into the lower airways. Tracheostomy tubes with a channel for supraglottic suction may reduce such problems.

Swallow test: patients with tracheostomy tubes may have swallowing problems. The tracheostomy tube may decrease laryngeal elevation during swallowing and an inflated cuff may compress the oesophagus. A swallow test using methylene blue is indicated before resuming oral feeding to prevent aspiration.

Decannulation: removal of a tracheostomy tube should be considered on a daily basis. Removal can be considered when the patient has been weaned from mechanical ventilation, when they are able to cough well, and when there are acceptable arterial blood gases without high-flow oxygen or continuous positive airway pressure. It should be delayed if the patient is agitated or delirious, to prevent airway compromise.

REFERENCES