Cricothyrotomy and Transtracheal Jet Ventilation

Randy B. Hebert, Sudip Bose, and Sharon E. Mace

Few situations evoke more concern in the mind of the emergency department (ED) clinician than a patient's airway that cannot be controlled through traditional endotracheal (ET) intubation. Although the surgical airway is rarely required,1-4 when the circumstances arise, the ED clinician may be required to perform this procedure under the most stressful and chaotic conditions that accompany an airway emergency.

Often, cricothyrotomy is a procedure of last resort. Both surgical cricothyrotomy and percutaneous transtracheal jet ventilation (TTJV) entail cricothyroid membrane puncture through the overlying skin to gain access to the airway. These are not easy procedures, are not always successful, and can be nearly impossible in obese patients and those with other anatomic restrictions.

Surgical cricothyrotomy refers to the technique in which the cricothyroid membrane is incised with a scalpel blade and a tracheostomy tube or modified ET tube is used to maintain the opening in the airway. Needle cricothyrotomy refers to the insertion of a catheter via percutaneous needle puncture of the cricothyroid membrane to allow a ventilation apparatus to be attached. As the name implies, tracheostomy differs from both of the other techniques in that access to the airway is gained between two of the tracheal rings inferior to the cricothyroid membrane. Other terms such as cricothyrosectomy, laryngotomy, and cricothyroidotomy are sometimes used interchangeably with cricothyrotomy. Regardless of what technique is used, securing the airway is invariably the first step in any critical care algorithm.5

BACKGROUND CAN BE FOUND ON EXPERT CONSULT

ANATOMY

The central structure of importance is the cricothyroid membrane, which is an elastic membrane located anteriorly and midline in the neck. The membrane is bordered superiorly by the thyroid cartilage and inferiorly by the cricoid cartilage. The lateral aspects of the cricothyroid membrane are partially covered by the cricothyroid muscles, but the central triangular portion is subcutaneous, making it an ideal location to access the airway.

Identify the cricothyroid membrane by first locating the prominent thyroid cartilage superior to it. The thyroid cartilage consists of two lateral laminae that join at an acute angle in the midline to form the laryngeal prominence, which is more pronounced in males and is commonly known as the “Adam’s apple.” The internal aspect of the anterior body of the thyroid cartilage provides the attachment for the vocal ligaments. Superior to the thyroid cartilage and connecting it to the hyoid bone is the thyroid membrane, which allows for the passage of the superior laryngeal vessels and the internal branch of the superior laryngeal nerve through its laterally located foramina.

The cricoid cartilage forms the inferior border of the cricothyroid membrane and is the only completely circumferential cartilaginous structure of the larynx. It is composed of a broad posterior segment that tapers laterally to form a narrow anterior arch. The tracheal rings descend inferiorly to the cricoid cartilage.

Identify the cricothyroid membrane between the previously mentioned structures as a shallow depression measuring about 9 mm longitudinally and 30 mm transversely. If the depression is obscured by soft tissue swelling, estimate the location of the cricothyroid membrane at about 2 to 3 cm inferior to the laryngeal prominence or four fingerbreadths above the sternal notch.14-16

The area overlying and immediately adjacent to the cricothyroid membrane is relatively avenascular and free of other significant anatomic structures. The cricothyroid arteries branch from the superior thyroid arteries and may form a small anastomotic arch traversing the superior aspect of the cricothyroid membrane. The external branch of the superior laryngeal nerve runs along the lateral aspect of the larynx and innervates the cricothyroid muscles inferior to the membrane. The isthmus of the thyroid gland most often overlies the second and third tracheal rings, although an aberrant pyramidal lobe of the gland may extend just superior to the cricothyroid membrane. The anterior attachments of the vocal cord structures are protected by the thyroid cartilage17,18 (Fig. 6–1).

SURGICAL CRICOXYROTOMY

Indications and Contraindications

The chief indication for surgical cricothyrotomy is the inability to secure the airway by noninvasive techniques in a patient with impending or ongoing hypoxia.39

Surgical cricothyrotomy, like any invasive procedure, has significant complications and should not be attempted until less invasive measures have failed. When the time and clinical situation allow, it may be appropriate to attempt to intubate multiple times or to try alternative intubation techniques. However, at some point, it becomes clear that further attempts at intubation become futile and the benefits of the surgical airway outweigh the risks the patient will incur from ongoing hypoxia.28 In summary, when approaching a patient in respiratory distress, the clinician must have a clear algorithm in mind with a well-defined point at which attention is shifted from laryngoscopy to cricothyrotomy.

The anesthesia and emergency medicine literature are filled with attempts at identifying factors that accurately predict a difficult intubation. As the patient is being prepared for intubation, take a moment to look for external clues that intubation or bag-mask-valve ventilation may be difficult. Some clues include marked obesity, trauma, deformity of the face and neck, macroglossia, edema, or hemorrhage in and around the airway.11-23 Table 6–1 is a list of relative indications for surgical cricothyrotomy. Use the “3-3-2 rule” to assess the adequacy of the oropharynx for intubation. If three fingers can be placed between the patient’s upper and lower teeth with the mouth open, three fingers can be placed in the
distance from the mentum to the hyoid bone, and two fingers can be placed in the space between the thyroid notch and the hyoid bone, there is sufficient space in the oropharynx to perform ET intubation. Any distance shorter than that indicates a difficult intubation. Use the Mallampati score as another method to assess for a difficult intubation. It was initially developed as a preoperative examination to assess the patient’s oropharynx prior to a controlled intubation in the operating room. Ask the patient to sit on the edge of the stretcher and lean slightly forward. Ask the patient to open his or her mouth as wide as possible without vocalizing. Determine the score by the degree to which the faucial pillars, soft palate, and base of the uvula can be visualized (Fig. 6–2). Mallampati\textsuperscript{26} concluded that the higher the score, the more difficult ET intubation would be. Unfortunately, many conditions that prohibit ET intubation also make cricothyrotomy difficult.

TABLE 6–1 Indications for Surgical Cricothyrotomy

| Failure of oral or nasal endotracheal intubation |
| Massive oral, nasal, or pharyngeal hemorrhage |
| Massive regurgitation or emesis |
| Masseter spasm |
| Clenched teeth |
| Structural deformities of oropharynx (congenital or acquired) |
| Stenosis of upper airway (pharynx or larynx) |
| Laryngospasm |
| Mass effect (cancer, tumor, polyp, web, or other mass) |
| Airway obstruction (partial or complete) |
| Nontraumatic |
| Oropharyngeal edema |
| Laryngospasm |
| Mass effect (cancer, tumor, polyp, web, or other mass) |
| Traumatic |
| Oropharyngeal edema |
| Foreign body obstruction |
| Laryngospasm |
| Obstruction secondary to a mass effect or displacement |
| Stenosis |
| Traumatic injuries making oral or nasal endotracheal intubation difficult or potentially hazardous (relative) |
| Maxillofacial injuries |
| Cervical spine instability |
| Need for prolonged intubation |
| Need for definitive airway during procedures on face, neck, or upper airway |
| Laryngeal surgery |
| Oral surgery |
| Maxillofacial surgery |
| Laser surgery |
| Bronchoscopy |

Given that surgical cricothyrotomy is often resorted to only after other techniques have been unsuccessful and/or the patient is not oxygenating or ventilating, most authors state that the only absolute contraindication is age. Because of the anatomic differences between children versus adults including the smaller cricothyroid membrane and the rostral funnel shaped more compliant pediatric larynx, surgical cricothyrotomy has been contraindicated in infants and young children. However, the exact age at which a surgical cricothyrotomy can be done is controversial and not well defined. Various textbooks list the lower age limit from 5 years to 10 years or 12 years and only one of these textbooks cites any references. ACLS and PALS define the infant airway as age up to 1 year, and the child airway as age 1–8 years.

Equipment

The equipment necessary to perform a traditional surgical cricothyrotomy includes a scalpel with a No. 11 blade, a Trousseau dilator, a tracheal hook, and a tracheostomy tube or modified ET tube (Fig. 6–3). Bent 18-gauge needles may substitute for tracheal hooks. In addition, the sterile tray may include a syringe and lidocaine with epinephrine for local anesthesia, sterile drapes or towels, antiseptic preparation solution, 4 x 4 sterile gauze, scissors, hemostats, and suture material.

Figure 6–3 A and B, Equipment required for traditional surgical cricothyrotomy. Eighteen-gauge needles bent to 90° may be used in place of a tracheal hook. (A and B, From Thomsen T, Setnik G [eds]: Procedures Consult—Emergency Medicine Module. Copyright 2008 Elsevier Inc. All rights reserved.)

Given that the average adult’s cricothyroid membrane is about 9 mm longitudinally and 30 mm horizontally, familiarize yourself with the dimensions of several standard tracheostomy and ET tubes in order to select the appropriate size. Cuffed tracheostomy tubes are recommended, and they come in various sizes. Shiley tracheostomy tubes are commonly available in most EDs. The No. 4 tube has an inner diameter of 5.0 mm and an outer diameter of 9.4 mm, and the No. 6 tube has an inner diameter of 6.4 mm and an outer diameter of 10.8 mm. Shiley tracheostomy tubes come with three parts: the cuffed outer cannula, a removable inner cannula, and a removable obturator that is solid and removed after insertion (Fig. 6–4). ET tubes are often used temporarily in place of a tracheostomy tube. ET tubes with an inner diameter of 6.0 and 8.0 mm have outer diameters of 8.2 and 10.9 mm, respectively. Scalpel blades are also available in different sizes, and although a No. 11 blade is most commonly used, a No. 20 blade is recommended in some variations of the technique. Commercially available kits include the Melker Cricothyrotomy Kit for percutaneous cricothyrotomy (Melker Cricothyrotomy Kit, Cook Critical Care, Bloomington, IN) in which the Seldinger technique is used to place a cuffed or uncuffed airway catheter.

Procedure

Positioning plays a critical role in success; however, the ideal positioning may be impossible, based on clinical parameters. For example, hypoxic patients often cannot recline. Ketamine anesthesia does not suppress respiratory drive and may aid patient cooperation and positioning if not otherwise contraindicated. When feasible, use the supine position with the neck exposed. Unless the patient has a known or suspected cervical spine injury, it is important to hyperextend the neck to more readily identify the landmarks. Surgical cricothyrotomy can be safely and successfully performed with minimal cervical spine movement. Preoxygenate the patient by way of bag-mask ventilation. Prepare the skin of the anterior neck with antiseptic solution and create a sterile field using drapes or towels. If the patient is awake or responding to pain, give a subcutaneous and transtracheal injection of lidocaine with epinephrine as a local anesthetic. Test the integrity of the balloon on the tracheostomy or ET tube by injecting it with 10 cc of air. Wear sterile gloves and take standard precautions by wearing a mask, goggles, and gown. All preparatory steps
are time permitting and depend on the urgency with which the procedure is to be performed.

**Traditional Technique**
Most EDs use a prepackaged kit, with or without a Seldinger apparatus. However, the “traditional” (open) cricothyrotomy technique is described here (Fig. 6–5). This technique has changed little since the original description of elective cricothyroidotomy by Brantigan and Grow in 1976.\(^{12}\) McGill and coworkers\(^{33}\) described the addition of a tracheal hook for emergency cricothyrotomy in 1982. In a follow-up report in 1989, Erlandson and associates\(^ {34}\) emphasized the importance of making an initial vertical skin incision and using a relatively small (No. 4 Shiley) tracheal tube. These modifications have generally been accepted and are commonly described as part of the traditional technique.\(^ {35}\)

**Figure 6–5** Step-by-step diagram of traditional surgical cricothyrotomy. Step 1: Immobilize the larynx and palpate the cricothyroid membrane with the index finger. *Inset* to step 1: As an option to guide subsequent surgery, advance an 18-gauge needle on a syringe into the trachea, and when air is aspirated, remove the syringe and leave the needle in the trachea. Step 2: Make a vertical midline skin incision, 3–5 cm in length. *Inset* to step 2: Palpate the cricothyroid membrane through the skin incision to confirm anatomy. Step 3: Incise the cricothyroid membrane horizontally. Note that the skin incision was vertical. Step 4: Insert the tracheal hook and have an assistant provide upward traction. Step 5: Insert the Trousseau dilator with the blades horizontal, and expand the incision vertically. Step 6: A, Rotate the dilator 90° B, Insert the tube through the blades into the trachea. C, Keep the thumb on the obturator throughout the procedure. Step 7: Remove the obturator. Step 8: Replace the inner cannula and inflate the tube. (From Custalow CB: Color Atlas of Emergency Department Procedures. Philadelphia, Elsevier Saunders, 2005.)
Figure 6–5, cont’d
If you are right-hand dominant, stand on the patient’s right side. Stabilize the larynx with the nondominant hand by grasping both sides of the lateral thyroid cartilage with the thumb and middle finger. Palpate the depression over the cricothyroid membrane with the index finger. Control the larynx throughout the procedure by stabilizing it in this manner. At this juncture, an option is to enter the trachea through the membrane with an 18-gauge needle on a syringe (see Fig. 6–5 step 1 inset). When air is obtained, disconnect the syringe and leave the needle in place as a guide to further surgical procedures.

Holding the scalpel with a No. 11 blade in the dominant hand, make an approximately 2- to 3-cm vertical incision through the skin and subcutaneous tissues (see Fig. 6–5 step 2). With the index finger of the nondominant hand, palpate the cricothyroid membrane through the incision (see Fig. 6–5 step 2 inset). It is important to understand that the remainder of the procedure should be performed by palpation of the anatomy, not visualization, because bleeding may obscure the field and there is no time to delay while trying to achieve hemostasis. If the cricothyroid membrane cannot be palpated, extend the initial incision superiorly and inferiorly and try to palpate again. Using the stabilizing index finger as a guide, make a horizontal incision of less than 1.0 cm in length through the cricothyroid membrane (see Fig. 6–5 step 3). Note that the skin incision is vertical, but the membrane incision is horizontal. Place the index finger into the stoma momentarily to exchange the scalpel for the tracheal hook.36

Using the dominant hand, place the tracheal hook into the opening in the cricothyroid membrane and grasp the inferior border of the thyroid cartilage with it. Rotate the handle cephalad and ask an assistant to provide upward traction or provide traction yourself by passing the handle of the hook to the nondominant hand (see Fig. 6–5 step 4). Use the tracheal hook to stabilize the larynx and keep it in place throughout the remainder of the procedure.

With the dominant hand, place the tips of the Trousseau dilator into the opening in the membrane with the spreading action oriented initially in the longitudinal or vertical plane so that the handle is facing horizontally or perpendicularly to the direction of the neck (see Fig. 6–5 step 5). It is important to note that this instrument works opposite to most ordinary instruments, such as hemostats, so that when you squeeze the handles, the blades open rather than close. This can be confusing the first time you try to use the instrument; it is worth practicing before you need it in an emergency. If this instrument is not available to you in an emergency, a Mayo scissors, a hemostat, or even the blunt end of a scalpel handle can be used to dilate the incision in the cricothyroid membrane.37

Dilate the incision vertically with the Trousseau dilator. There is no need to dilate the incision horizontally because the cricothyroid membrane is the widest (∼30 mm) in this direction. Hold on to the handles of the Trousseau dilator with the nondominant hand, palm upward and rotate the handle 90° until the handle is vertical or parallel to the neck (see Fig. 6–5 step 6A). Perform this rotation because, if the dilator is still horizontal, the blades of the dilator prevent passage of the trachestomy tube into the trachea. Prepare the trachestomy tube by testing the balloon, removing the inner cannula, and inserting the solid white obturator. While holding the dilator with the nondominant hand, insert the obturator, take the tube in the dominant hand and insert it between the blades of the dilator until the flanges rest against the skin of the neck (see Fig. 6–5 step 6B). Keep the thumb on the obturator throughout the procedure (see Fig. 6–5 step 6C). Carefully remove the Trousseau dilator (see Fig. 6–5 step 7). Insert the inner cannula and inflate the balloon (see Fig. 6–5 step 8). Remove the tracheal hook, being especially careful not to puncture the cuff.18,39 If a tracheostomy tube is not available, or if there is difficulty placing the trachestomy tube into the opening in the cricothyroid membrane, try using a 6-0 cuffed ET tube cut to a shorter length. The inner-to-outer diameter ratios of tracheostomy tubes are comparable with those of ET tubes. Use of a semirigid ET tube stylet or a gum elastic bougie may facilitate the placement of an ET tube through the cricothyroid membrane into the trachea. The advantage of using the bougie is that you can get immediate confirmation that the device is inside the trachea, owing to the “washboard” vibration that the curved tip makes as it contacts the tracheal rings. The operator can modify the ET tube by cutting the distal end and replacing the adapter to the cut end (Fig. 6–6). Be careful not to cut the balloon inflation tube. If the ET tube is shortened, it is less likely to kink once it is attached to a ventilator. Advance the ET tube only about 5 cm from the tip to avoid main stem intubation. Keep in mind that standard ET tubes do not have centimeter markings at the distal end. Inserting the ET tube so that the distal cuff is about 2 cm beyond the cricothyroid membrane usually ensures proper placement.

Confirm proper placement in the same manner as with ET tube placement: end-tidal CO₂, bilateral chest movement, and breath sounds. Secure the trachestomy tube with a circumferential tie around the neck or with sutures. Order a postprocedure portable chest x-ray.

Rapid Four-Step Technique (Brofeldt)
Brofeldt and colleagues40 developed a rapid four-step technique (RFST) to decrease the amount of time required to establish an airway and thus reduce complications of hypoxia (Fig. 6–7). It combines aspects of traditional cricothyrotomy and ET intubation. If you are right-hand dominant, stand at the bedside to the patient’s left. Palpate the depression over the cricothyroid membrane with the nondominant hand. With the dominant hand, make a single horizontal stab incision with a No. 20 blade scalpel approximately 1.5 cm in length through the skin, the subcutaneous tissue, and the cricothyroid membrane. With the scalpel blade as a guide, pick up the cricoid cartilage with the tracheal hook and provide traction in the caudal direction to stabilize the trachea.
Place a No. 4 cuffed tracheostomy tube or a 6-0 cuffed ET tube through the opening. The hardest part of this modification is passing the tracheostomy tube through the smaller incision. Try advancing a gum elastic bougie (or similar introducer) into the trachea first. Then railroad the tube over the bougie with a twisting motion. The advantage of using the bougie, as noted previously, is the ease of placement and the immediate feedback (washboard feeling) of the device as it is advanced inside the trachea.

Bair and coworkers modified this technique further by introducing a new device called a “Bair Claw” to replace the tracheal hook. The technique is similar to the four-step method except for advocating that the operator stand at the head of the bed instead of to the side of the patient and the use of a double-hook device instead of the single hook. By replacing the single hook with the double hook, they found a decrease in the incidence of cricoid ring fractures in cadavers (Fig. 6–8).

**Melker Percutaneous Cricothyrotomy Technique**

The Melker Cricothyrotomy Kit (Cook Critical Care, Bloomington, IN) is a prepackaged commercial kit that employs the Seldinger technique to place a tracheostomy tube over a guidewire (Fig. 6–9). The kit comes supplied with a 6-mL syringe, an 18-gauge needle with an overlying tetrafluoroethylene (TFE) catheter (the TFE catheter not included in some kits), a guidewire, a tapered dilator, and a Melker airway catheter in lieu of a tracheostomy tube. Similar to retrograde intubation or needle cricothyrotomy with TTJV, the cricothyroid membrane must be easy to identify because no initial skin incision will be made. Anatomic distortion will make locating the cricothyroid membrane with a needle more difficult.

The preparation for this technique is similar to that of the other techniques. Palpate the cricothyroid membrane with the nondominant hand. With the dominant hand, attach the needle to the syringe and insert it through the cricothyroid membrane, pointing it caudally at a 45° angle relative to the skin surface. Be careful not to advance the needle too far because this may result in perforation of the posterior trachea. To help recognize when the trachea has been entered, place a small amount of saline in the syringe before the procedure. Apply gentle negative pressure while advancing the syringe. When the membrane is pierced and the trachea is entered, air will be aspirated into the syringe and bubbles will appear in the saline.

When the needle is in the trachea, pull back the syringe and needle and advance the flexible TFE catheter through the distal trachea to its hub. If the needle does not have an overly-
ing catheter, leave the needle in place and remove the syringe. Thread the guidewire through the needle or the catheter. Once the guidewire is in place in the trachea, remove the needle or catheter. With a disposable No. 15 scalpel, make a small incision in the skin at the point at which the guidewire enters to facilitate passage of the dilator and airway catheter.

Place the gray-tipped dilator into the airway catheter and thread it over the wire as one unit. Once it is through the skin and into the trachea, advance the airway catheter to its hub until it is flush against the neck. Remove the guidewire and dilator. Secure the kit in place with “trach tape.”

Melker kits on the market differ with respect to airway catheter inner diameter and whether the airway catheter is cuffed or not. Some kits do not contain a needle with an overlying catheter.

Complications

Given that surgical cricothyrotomy is infrequently performed, under circumstances that are inherently chaotic, on a patient population who frequently has confounding medical issues and high morbidity and mortality rates, the evaluation of short- and long-term complications is difficult.

Regardless of which surgical technique is used, surgical cricothyrotomies have been studied to assess what periprocedure and short-term complications occur with significant frequency. Acute complication rates have been reported between 8.7% and 40%. The most frequent complications are uncontrollable bleeding and misplacement of the tube. Most bleeding is from small superficial vessels and can be controlled. Bleeding leading to significant hemorrhage can also occur as a result of the procedure. The cricoid arteries branch from the superior thyroid arteries and anastomose at the anterior superior aspect of the cricothyroid membrane. The laterally running superior thyroid arteries are more often damaged when the initial incision is broad and horizontal. To prevent hemorrhage from these vessels, make the initial incision longitudinal as in the traditional technique and maintain

Figure 6–9 Melker Kit with Seldinger technique. (Courtesy of Cook Critical Care, Bloomington, IN.)

Figure 6–10 A–D. Percutaneous Seldinger technique cricothyrotomy using a catheter, a wire placed into the trachea, and a dilator/tube advanced over a guidewire. Make a skin incision to allow passage of the dilator. (From Thomsen T, Setnik G [eds]: Procedures Consult—Emergency Medicine Module. Copyright 2008 Elsevier Inc. All rights reserved.)
careful awareness of the landmarks.46 When making the hori-

zontal incision in the cricothyroid membrane, avoid the

cricoid artery by incising the membrane at its inferior aspect.

Misplacement of the tracheostomy tube or ET tube during

cricothyrotomy is a concern, just as esophageal intubation is

a concern with ET intubation. If the openings in the crico-

thyroid membrane and larynx are not carefully stabilized

during the procedure, the tube may be inadvertently inserted

into the subcutaneous tissue, which may be recognized by the

presence of subcutaneous emphysema when attempting to

ventilate the patient. It is essential to recognize this immedi-

ately to prevent the development of hypoxia. In addition,

failure to detect end-tidal CO₂ and absence of breath sounds

by auscultation should alert the physician to a misplaced tube.

If suspected, remove the tube and re-assess the airway. Mis-

placement of the tube during cricothyrotomy may refer to any

location other than through the cricothyroid membrane, such

as the larynx or trachea, but the most crucial locations are

those that do not enter the airway and thus lead to hypoxia

and death if unrecognized.

Many other more occult complications have been

reported less frequently or have been described in case reports

such as main stem bronchial intubation,37 laryngotracheal

injury,48 tension pneumothorax,39 and clogging of the trache-

ostomy tube with blood or secretions.40 Slobodkin and associ-

ates51 reported one case of retrograde pharyngeal intubation

(Table 6–2).

Chevalier Jackson’s 1921 report11 highlighted the concern

that subglottic stenosis was a major and frequent complication

of cricothyrotomies. It was later refuted by Brantigan and

Grow’s 1976 study13 that reported not only an overall com-

plication rate of just 6.1% but also no occurrences of chronic

subglottic stenosis as a long-term complication. Since the

publication of this latter report, numerous other studies have

corroborated their findings that chronic subglottic stenosis is

an infrequent long-term complication of surgical crico-

thyrotomy.52–56 Factors that increase the likelihood of develop-

ing subglottic stenosis include predisposing laryngotracheal

pathology, prolonged time to decannulation, old age, and
diabetes.57,58

Occurrences of long-term complications resulting in

“minor airway problems” have been reported more frequen-
ty than subglottic stenosis.59 Of these complications, sub-

jective voice change is the most frequently reported.60 Other

reported complications include difficulty with swallowing,

subjective shortness of breath, wound infection, and “noisy

breathing.”61

In order to decrease the morbidity and mortality associ-

ated with prolonged hypoxia and other factors inherent to an

airway emergency, researchers have attempted to determine

whether any one of the techniques is superior with regard to

 complication rate and time needed to secure the airway.

When comparing Brofeldt and colleagues’ RFST with the

traditional five-step technique, Davis and colleagues64 found

an increased incidence of cricoid ring fracture when the single

hook was used for cephalad traction on the cricoid cartilage,

concluding that the traditional technique produced a lower

 complication rate. A study by Holmes and coworkers36 com-

paring the same two techniques as performed by inexperi-

enced medical students and residents on human cadavers

concluded that the single-hook RFST was executed signifi-

cantly faster than the traditional technique. They noted that

there were more complications using the RFST but that the

difference in complication rates failed to reach statistical sig-

nificance. Davis and associates62 revisited this comparison in

a later study, replacing the single hook in the RFST with the
double-hooked Bair Claw. The revised study showed that

the airway could be secured faster using the RFST and that

the complication rate was comparable, further observing

that the Bair Claw did not cause any cricoid cartilage frac-
tures.62 Bair and colleagues’ own retrospective report63 of ED

cricothyrotomy showed a lower complication rate of the

RFST when compared with the traditional technique.

Similarly, consensus cannot be drawn from the literature

comparing the traditional method with the percutaneous

Seldinger (Melker kit) method. Some studies show no dif-

ference between time to ventilation or complication rate when

the traditional technique is compared with the Seldinger tech-
nique.64 Some studies report that the surgical method is faster

than the Seldinger method,55–58 and others conclude the

opposite.69

Many complications of cricothyrotomy seem relatively

minor compared with those caused by prolonged hypoxia.

The clinician should be aware of the potential complications

in order to be prepared if they do occur but not to delay per-

forming the procedure out of fear of them. As with any inva-

sive procedure in emergency medicine, complication rates can

be reduced by maintaining a sterile field and being familiar

with the techniques and anatomy.

When deciding which technique to use to perform a

surgical cricothyrotomy, consider the advantages and disad-

vantages of each technique, the clinical scenario, equipment

availability, and finally, your own comfort and familiarity with

each individual technique as your guide.

Success Rates

Success rates for ED intubations are quite high (for first

try: 90% success for all ED intubators including resi-

TABLE 6–2 Complications of Surgical Cricothyrotomy

<table>
<thead>
<tr>
<th>Immediate or early complications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common</td>
</tr>
<tr>
<td>- Bleeding, hematoma</td>
</tr>
<tr>
<td>- Incorrect tube placement</td>
</tr>
<tr>
<td>- Subglottic stenosis</td>
</tr>
</tbody>
</table>

| Unsuccessful tube placement                                      |
| Prolonged procedure time                                         |
| Subcutaneous emphysema                                           |

<table>
<thead>
<tr>
<th>Obstruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infrequent</td>
</tr>
<tr>
<td>- Esophageal perforation</td>
</tr>
<tr>
<td>- Mediastinal perforation</td>
</tr>
<tr>
<td>- Pneumothorax, pneumomediastinum</td>
</tr>
<tr>
<td>- Vocal cord injury</td>
</tr>
<tr>
<td>- Laryngeal fracture or disruption of laryngeal cartilage</td>
</tr>
<tr>
<td>- Aspiration</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Late complications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most common</td>
</tr>
<tr>
<td>- Obstructive problems</td>
</tr>
<tr>
<td>- Voice changes or dysphonia</td>
</tr>
<tr>
<td>- Infections</td>
</tr>
<tr>
<td>- Late bleeding</td>
</tr>
<tr>
<td>Persistent stoma</td>
</tr>
</tbody>
</table>

| Subjective feeling of lump in the throat                         |
| In frequent complications                                        |
| - Subglottic or glottic stenosis                                  |
| - Tracheoesophageal fistula                                       |
| Tracheomalacia                                                   |

118
Cricothyrotomy with the Seldinger technique found successful in intensive care unit clinicians comparing a standard surgical cadaver, the first-time performance of cricothyrotomy by passive exhalation to resemble a more physiologic respiratory effort. Although one study found only a 62.5% success rate. The success rate for cricothyrotomy similarly has been quite high (89%–100%) in most studies, although one study found only a 62.5% success rate. The incidence of failed cricothyrotomy (e.g., the tube is misplaced into pretracheal space/failed attempts) is 3.6% in the ED in one study, with earlier ED studies in the 7.9% to 10% range. In the prehospital setting, the reported cricothyrotomy failure rates are 6% to 12% for paramedics, 0% for clinicians and 32% to 38% for flight nurses. One of these studies found the incidence of tube misplacement into the pretracheal space to be 3.6% in the ED versus 31.8% for the air medical transport service at the same institution. In a cadaver, the first-time performance of cricothyrotomy by intensive care unit clinicians comparing a standard surgical cricothyrotomy with the Seldinger technique found successful tracheal placement in only 70% for the standard technique and 60% for the Seldinger technique. In an animal model, paramedics had a 90.9% success rate using a percutaneous technique and a 100% success rate with the open surgical technique.

TTJV

TTJV is a procedure in which oxygen is delivered through a catheter inserted through the cricothyroid membrane. Anatomically, the cricothyroid membrane is part of the larynx and the trachea begins at the cricoid cartilage, but the term tracheal jet ventilation is generally used to refer to supplying oxygen through the cricothyroid membrane. To maintain consistency, this terminology is used in this chapter. The use of TTJV to ventilate and oxygenate a patient in a crash airway situation differs from surgical cricothyrotomy in some ways. For TTJV, the initial needle cricothyrotomy does not differ greatly from that used for the Seldinger technique variation of cricothyrotomy. Jet ventilation means that oxygen is administered through a small-caliber catheter, usually on the order of a 12- to 14-gauge catheter, rather than through a relatively larger-caliber tracheostomy tube. The method by which oxygen is supplied through a needle-inserted catheter has evolved over the recent years, moving from one of continuous oxygen flow, which provided adequate oxygenation but not ventilation, to one of shorter bursts of oxygen flow followed by passive exhalation to resemble a more physiologic respiratory state.

Indications and Contraindications

The indications and contraindications for needle cricothyrotomy with TTJV are similar to those for surgical cricothyrotomy. Needle cricothyrotomy with TTJV can be used in place of surgical cricothyrotomy in adults in the same failed airway scenarios. Its indications include failed attempts at ET intubation with the inability to bag-mask ventilate or airway obstruction above the level of the cricothyroid membrane. Needle cricothyrotomy may be relatively indicated over surgical cricothyrotomy in adults based on the operator’s experience. Much of the otolaryngology literature supports the use of TTJV as a means of nonemergent ventilation during head and neck surgeries owing to the fact that the smaller ventilation catheter provides a relatively unobstructed field to work around. With regard to an emergent airway situation, needle cricothyrotomy has been shown to be a successful bridge to establishing an airway via the ET route. Case reports describe TTJV to be relatively indicated over the more invasive surgical cricothyrotomy when ET intubation has failed owing to copious oropharyngeal secretions. Providing temporary ventilation through the needle catheter may allow sufficient time to clear the upper airway of secretions or obstructions, giving the operator more time to establish an ET intubation.

As mentioned previously, surgical cricothyrotomy is contraindicated in infants and young children. The contraindication arises from the fact that the cricothyroid membrane is too small to insert a tracheostomy tube and there is a significant risk of injury to the surrounding structures. Therefore, needle cricothyrotomy is the preferred method of securing the airway in crash airway situations in infants and young children.

Absolute contraindications to needle cricothyrotomy in adults include transection of the distal trachea, because the airway would need to be established below this injury. Complete upper airway (oropharyngeal) obstruction may be considered a contraindication to needle cricothyrotomy because there is nowhere for exhaled gas to escape, thus leading to a buildup of CO₂ and increased lung volumes. The operator may, therefore, elect to perform a surgical cricothyrotomy if this situation presents itself.

Equipment

The essential materials needed for TTJV include a needle with an overlying catheter, oxygen tubing, an oxygen source with a means to regulate the pressure, and a means to connect the apparatus together.

Commercial kits are available, but a standard 12- or 14-gauge angiocath attached to a 3- or 5-mL syringe normally found in the ED can be used to make the puncture through the cricothyroid membrane; then the catheter can be left in place to serve as the conduit for oxygen delivery. The larger the diameter of the catheter, the greater the oxygen flow will be, depending on the method of oxygen delivery. Commercial catheters such as wire-coiled nonkinking catheters and fenestrated catheters are available as part of prearranged kits (Fig. 6–11). Larger-caliber 3.0- to 4.0-mm interior diameter percutaneous tracheal catheter devices are also available.

There are two different basic means, and thus two different armories of equipment to choose from, to deliver oxygen through the transtracheal catheter. In one method, use a standard ventilation bag to supply oxygen through the needle. This requires the constant efforts of manual bag insufflation as long as the patient is being oxygenated and ventilated this way. Attach the bag to the adapter of a 7.0-mm ET tube inserted into the back of a plungerless 3-mL syringe connected to the transtracheal catheter. Alternatively, attach the bag directly to the catheter with the adapter of a 3.5-mm pediatric ET tube. An inherent problem with this setup is that the whole system is rigid. Although the transtracheal catheter itself is flexible, there is no flexibility or give from the hub of the catheter to the bag. Thus, slight movements of the bag relative to the patient may cause dislodgment of the catheter. To ameliorate this obstacle, connect standard intravenous infusion tubing directly to the transtracheal cath-
eter and attach the distal cut end to a 2.5-mm ET tube attached to the bag.

In an alternative method, supply oxygen from a standard 50-psi wall source. High-pressure oxygen tubing is needed to connect the system with a manual on/off valve along with a Luer-Lok or three-way stopcock to connect the oxygen tubing to the hub of the catheter. The on/off valve can be as simple as holes placed at the end of the oxygen tubing (see Fig. 6–11) that the operator manually covers in order to control oxygen flow through the catheter and the inspiratory-to-expiratory (I/E) ratio. A pressure gauge connected to a hand-triggered jet injector may also be used to control the amount of air pressure reaching the catheter. Commercial kits are available that contain prepackaged systems already assembled. Otherwise, assemble the apparatus in the ED. In an emergency situation, it is unlikely that one would be able to assemble a TTJV apparatus from individual components in a timely manner. If a prepackaged TTJV kit is not available, prepare the appropriate components from the ED ahead of time and place them with other airway supplies for easy access.

Assemble additional equipment such as antiseptic preparation solution, sterile drapes, sterile gauze, and suture material or trach tape in the kit.

Procedure

As with the surgical cricothyrotomy technique, place the patient in the supine position with the neck exposed. Prepare the skin of the anterior neck. Wear appropriate protective equipment such as sterile gloves, gown, and protective eyewear and face shield. Hyperextend the patient’s neck unless a suspected cervical spinal injury prohibits it. Infiltrate the skin with local anesthetic.

Similar to the needle insertion technique employed for guidewire-assisted surgical cricothyrotomy, locate the cricothyroid membrane with the nondominant hand by locating the thyroid cartilage and cricoid cartilage and palpating the cricothyroid membrane in the depression between these, keeping in mind that this depression will be proportionately smaller in children.

Attach a 12- to 14-gauge angiocath to a 3- or 5-mL syringe filled with 1 to 2 mL of saline or lidocaine. Once the cricothyroid membrane has been located, insert the catheter through the overlying skin, subcutaneous tissue, and membrane directed at a 30° to 45° angle caudally. While doing so, aspirate gently with the syringe (Fig. 6–12). The cricothyroid membrane has been pierced and the airway entered when bubbles are seen in the fluid or there is an increase in the ease with which air is aspirated. Once through the membrane, hold the needle in place and advance the catheter to the hub, then remove the needle. Hold the catheter by hand until the oxygen supply is connected and appropriate placement is confirmed. Make sure that the hub of the catheter is flush against the skin to avoid air leak and then secure it with a circumferential tie around the neck. Keep one hand on the hub of the catheter until the entire procedure is completed and the airway is secured to prevent it from being dislodged.

Oxygen can be supplied to the catheter in two different ways. The choice of whether to use the ventilation bag setup or the high-flow oxygen system is determined primarily by what tidal volumes are needed to ventilate the patient. The high-flow oxygen system connects to a wall oxygen source at full output and provides a maximal output pressure of 50 psi. When connected through a 14-gauge catheter, a pressure of 50 psi will flow at 1600 mL/sec. Therefore, if you want to provide a tidal volume of 10 mL/kg in an 80-kg adult (800 mL/breath), you must provide 0.5 second of oxygen flow per cycle. The operator also controls the I:E ratio by letting go of the distal openings in the oxygen tubing or of the jet injector valve. Commercial kits are available (Figs. 6–13 and 6–14).

With the ventilation bag, you manually inflate the lungs through the catheter. Children, especially those under 5 years old, have small total lung capacities and need smaller tidal volumes; therefore, the bag should be used instead of the jet ventilator to prevent barotrauma. Using this setup, you can control the volume of air inspired and adjust it breath-by-breath based on chest wall motion and pulse oximetry. This method is not appropriate for adults because the operator cannot both provide appropriate tidal volumes and allow enough time for exhalation (Fig. 6–15).

Complications

As with any invasive procedures, TTJV and needle cricothyrotomy are associated with certain risks and complications. The clinician should be aware of these potential risks and balance them against the need to reverse ongoing hypoxia in a critical patient. An important and debated concern regarding TTJV is that it is regarded as only a temporizing measure, owing in part because it is labor-intensive, but more so because of its inability to provide adequate ventilation for a long period of time. It has been reported that TTJV in adults inevitably causes retention of CO₂, leading to acidemia because of poor ventilation despite adequate oxygenation. This assumption may be a remnant of earlier oxygenation techniques in which continuous low-flow “apneic oxygenation” was used without ventilation. Many animal studies show that adequate ventilation, and thus normal blood pH and normal arterial CO₂ partial pressure, can be maintained with TTJV for 30 or even 60 minutes. Factors that seem to improve ventilation are increased expiratory time and normal arterial CO₂ partial pressure, can be maintained with TTJV for 30 or even 60 minutes. Even with regard to partial or nearly complete oropharyngeal obstruction, adequate ventilation has been achieved. Unfortunately, none of these studies looked at ventilation for extended periods of time.
There have been reports of mechanical failure with the materials used for TTJV, one of which is catheter kinking. A number of solutions have been proposed to prevent this from occurring. There is a commercially available wire-coiled catheter that does not kink as readily as the standard angiocath found in the ED. One study found that if the distal 2.5 cm of the tip of the catheter is bent at 15° anteriorly and if a greater angle of insertion relative to the skin surface is used, the catheter has less of a chance of kinking while it is being advanced into the trachea. It has also been proposed that a 7- or 9-French vessel dilator be used instead of an angiocath to prevent kinking.

Although needle cricothyrotomy may involve less trauma to the skin surface and anterior laryngotracheal structures than surgical cricothyrotomy, the force one must apply to puncture the cricothyroid membrane is proportional to the caliber of the needle being used. Larger-bore needles carry with them a higher risk of perforating the posterior trachea. Barotrauma is a significant risk associated with TTJV and occurs when there is upper airway obstruction that does not allow air to be passively exhaled. This causes an increase in
lungs volumes and pressures, leading to lung injury.\textsuperscript{101,102} Other reported complications include minor bleeding, malposition of the catheter, subcutaneous emphysema, dislodgment of the catheter, and pneumothorax.\textsuperscript{101,104}

One would assume that a transtracheally placed catheter would not afford any airway protection against aspiration in that the diameter of the catheter is not nearly large enough to occlude the lumen of the trachea. However, a few studies have shown a decreased rate of aspiration in dog models that were ventilated with TTJV versus control animals not ventilated, suggesting some airway protection from this mode of ventilation\textsuperscript{105,106} (Table 6–3).

Commercial hybrid kits, such as the Quicktrach, combine qualities of both cricothyrotomy and TTJV. They have the

### TABLE 6–3 Complications of Percutaneous Translaryngeal Jet Ventilation

<table>
<thead>
<tr>
<th>Complications</th>
<th>Common</th>
<th>Infrequent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subcutaneous emphysema—most common (less occurrence if there is a “secure” fit at the skin)</td>
<td>Blockage or obstruction of the catheter</td>
<td>Bleeding (minor), hematoma</td>
</tr>
<tr>
<td>Kinking of the catheter</td>
<td>Coughing (in a conscious patient)</td>
<td>Infections</td>
</tr>
<tr>
<td>Blockage or obstruction of the catheter</td>
<td>Incorrect or unsuccessful catheter placement</td>
<td>Aspiration</td>
</tr>
<tr>
<td>Persistent stoma</td>
<td>Prolonged procedure time</td>
<td>Incorrect or unsuccessful catheter placement</td>
</tr>
<tr>
<td>Subjective feeling of a “lump in the throat”</td>
<td>Pneumatocele</td>
<td>Prolonged procedure time</td>
</tr>
<tr>
<td>Serious, rare complications</td>
<td></td>
<td>Persistent stoma</td>
</tr>
<tr>
<td>Barotrauma (secondary to high airway pressures, more common with complete airway obstruction)</td>
<td>Pneumothorax</td>
<td>Persistent stoma</td>
</tr>
<tr>
<td>Pneumomediastinum (less occurrence if high airway pressures are avoided, and not performed with complete airway obstruction)</td>
<td>Mediastinal perforation</td>
<td>Persistent stoma</td>
</tr>
<tr>
<td>Dysphonia or voice changes (secondary to vocal cord injury, laryngeal fracture, or disruption of laryngeal cartilage)</td>
<td>Esophageal perforation</td>
<td>Persistent stoma</td>
</tr>
<tr>
<td>Potential or theoretical complications (not yet commonly associated with percutaneous translaryngeal jet ventilation, although reported with tracheostomy and other airway procedures)</td>
<td>Pneumatocele</td>
<td>Persistent stoma</td>
</tr>
<tr>
<td>Subglottic/glottic stenosis</td>
<td>Tracheoesophageal fistula</td>
<td>Subjective feeling of a “lump in the throat”</td>
</tr>
<tr>
<td>Tracheoesophageal fistula</td>
<td>Damage to laryngotracheal mucosa (such as tracheobronchitis)</td>
<td>Pneumatocele</td>
</tr>
<tr>
<td>Subglottic/glottic stenosis</td>
<td>Damage to laryngotracheal mucosa (such as tracheobronchitis)</td>
<td>Swallowing problems</td>
</tr>
</tbody>
</table>

**Figure 6–14** Homemade ventilation setup for transtracheal catheter ventilation using a ventilation bag, a standard endotracheal tube adapter, a 3-mL syringe, and a 14-gauge angiocath.

advantage of being relatively easy to use if the clinician is inexperienced with the technique of surgical cricothyrotomy and they may have fewer complications with regard to the actual insertion process. Unfortunately, most of these transtracheal hybrid kits contain small uncuffed catheters. Studies pertaining to these hybrid kits suggest that their small caliber may prevent adequate ventilation and the lack of a cuff permits insufflated air to escape through the oropharynx above. (Fig. 6–16; see also Fig. 16–15.)

Figure 6–16 Having a commercial kit for cricothyrotomy (Melker, Cook Critical Care) (A) and TTJK (ENK, Cook Critical Care) (B) prominently displayed in the resuscitation room or crash cart makes these techniques readily available in an emergency. (A and B, Courtesy of Cook Critical Care, Bloomington, IN.)