ORIGINAL RESEARCH

Improvised Cricothyrotomy Provides Reliable Airway Access in an Unembalmed Human Cadaver Model

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Objective.—Patients with injuries requiring surgical airway management occurring far from medical care might benefit from the availability of a simple, reliable, improvisational method of cricothyrotomy with materials available in a wilderness or prehospital setting. We evaluated an improvised cricothyrotomy device in an experimental, unembalmed human cadaver model.

Methods.—A high-flow intravenous spike and drip chamber was cut through the drip chamber and used as the sole apparatus for performing cricothyrotomy on unembalmed cadavers whose anterior neck surfaces and deep tissues were warmed to or near body temperature. Correct placement in the trachea and damage to the posterior wall of the trachea were assessed by either fiberoptic bronchoscopy or neck dissection. Video recordings were used to time each procedure. Each operator was responsible for both device insertion and bag valve mask attachment and ventilation, modeling as the sole care provider for the patient.

Results.—One physician and 3 emergency medicine residents, all without previous, specific instruction, performed 10 procedures on 5 female and 5 male unembalmed cadavers weighing a mean of 65 kg (range 45–110 kg). All 10 attempts at placement of the intravenous tubing spike through the cricothyroid membrane were successful. On 2 attempts, the initial placement of the device was incorrect, but the error was immediately identified on attempt to ventilate the patient. Repositioning of the device resulted in appropriate cannulation of the trachea in both attempts. The median time span from manual identification of the cricothyroid membrane to percutaneous access and connection of the bag valve mask with successful ventilation was 27.3 seconds. Violation of the posterior tracheal wall was not seen on any of the 5 procedures in which fiberoptic visualization was available or in the 5 procedures evaluated by neck dissection.

Conclusions.—Cricothyrotomy is the quickest and most effective method for obtaining airway access when nonsurgical methods of securing the airway are contraindicated or fail. Although frequently described, no improvised airway devices of this type have been tested in a systematic manner. We tested the reliability and utility of cricothyrotomy with a high-flow intravenous spike and drip chamber. Our results suggest that the spike and drip chamber is a plausible means of temporarily establishing airway access in patients with acute airway obstruction in a wilderness or prehospital environment.

Key words: surgical cricothyrotomy, airway obstruction, prehospital, improvised, intravenous spike

Introduction

Cricothyrotomy is a method of obtaining airway access by entering the trachea through the skin and membra-

nous tissue between the cricoid and thyroid cartilages. Cricothyrotomy is an uncommon procedure in the emergency department, with an estimated frequency of 1.7% to 2.7% of all tracheal intubations.^{1,2} Cricothyrotomy performed by prehospital providers in the trauma setting is more common, with reported rates ranging from 2.1% to 14.9%.^{3,4} Emergency cricothyrotomy is indicated in any patient who cannot be ventilated with a bag valve

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mask (BVM) or with orally or nasally inserted devices such as a laryngeal mask airway (LMA North America Inc, San Diego, CA), esophageal-tracheal double-lumen airway (Combitube, Kendall Company, Mansfield, MA), and conventional endotracheal tubes. Common scenarios requiring cricothyrotomy include severe facial trauma, clenched teeth, inaccessible airway, massive bleeding or emesis, and failure of oral or nasal endotracheal intubation.

Reported complication rates from emergency cricothyrotomy vary from 4% to 27%.^{1,2,5,6} Complications include failure to cannulate the trachea, esophageal intubation, damage to the posterior wall of the trachea, severe bleeding, and pneumothorax.^{7,8} The high rates of complications are thought to result from the difficulty of the procedure, the context in which the procedure is typically performed, and the lack of experience by most practitioners.

Several methods of cricothyrotomy have gained acceptance by emergency physicians and anesthesiologists: 1) surgical cricothyrotomy with a scalpel and endotracheal tube, 2) wire-guided Seldinger technique with dilation, 3) catheter-over-needle technique, and 4) transtracheal jet ventilation.⁸⁻¹⁰ Many prehospital providers favor small self-contained devices for performing cricothyrotomy; a number of such devices are commercially available.¹¹ A 2004 study by Fikkers et al¹² comparing 2 of the more popular devices on a pig larynx model found that the catheter-over-needle device known as the Quicktrach (Rusch Inc, Duluth, GA) was faster and had a higher success rate than the wire-guided device known as Minitrach (Smiths Medical Ltd, Kent, UK). The mean time from skin incision to the first artificial ventilation was 34 seconds with the catheter-over-needle device and 129 seconds with the wire-guided device. However, a study of paramedics by Keane et al⁹ found a shorter time to completion and a trend toward a higher rate of success by using a conventional surgical approach as opposed to a percutaneous method of cricothyrotomy.

Because cricothyrotomy is not usually anticipated and must be performed rapidly, considerable attention has focused on improvisational approaches that could be used in a wilderness or prehospital setting. Most of these methods involve the use of a makeshift tube that can either be forced through the cricothyroid membrane directly or be placed through an incision in the membrane. Tubes cut from tuberculin or 3-mm syringes, plastic pens, penlights, and nasopharyngeal airways have all been described, but there are no reports of their use in the literature. The use of a high-flow intravenous (IV) spike and drip chamber as a means of penetrating the cricothyroid membrane has been advocated, in part be-

cause the chamber fits well with the BVM commonly used to ventilate patients.¹⁰ There are no case reports, case series, or experimental data to support the use of these popularly described improvisational cricothyrotomy techniques.

Materials and methods

Ten consecutively obtained, unselected, unembalmed cadavers were obtained through the University of California, San Francisco, Willed Body Program, which approved our protocol. All cadavers made available were entered into the study, and all were adults who had died of medical illness.

For each cadaver, 1 of 4 individuals participating in this study performed a cricothyrotomy with a Baxter Clearlink System high-flow IV tubing spike and drip chamber modified by cutting the drip chamber in half with a pair of trauma shears (Figure 1A and B). This product has a round, synthetic spike without an integrated air vent, filter, or other mechanical obstruction. The internal diameter of the spike is 3.5 mm, the external diameter is 5 mm, and the length is 3 cm. The anterior neck area of each cadaver was warmed to at least 34°C before the procedure. The individuals performing the study included an American Board of Emergency Medicine-certified attending physician with 2 previous cricothyrotomies, 1 third-year emergency medicine resident with 4 previous cricothyrotomies, and 1 third-year emergency medicine resident and 1 second-year emergency medicine resident each with no previous cricothyrotomies. We defined the number of previous cricothyrotomies to include both emergency cricothyrotomies performed on live patients as well as practice cricothyrotomies performed on cadavers or dogs.

No specific instructions were provided to the individuals before performing the cricothyrotomy, though each observed the others as the experiment progressed. One of the participants had conceived of the study and had extensive knowledge of the procedure and possible complications (MRL). The attending physician and the residents with 4 previous cricothyrotomies each performed 3 procedures, and the resident with no previous cricothyrotomies performed 2 procedures. The number of procedures performed was determined only by cadaver availability and funds.

Direct visualization of the spike within the trachea by using fiberoptic bronchoscopy was used to confirm endotracheal placement in 5 experiments. In the remaining 5 experiments, bronchoscopy was not available and placement was confirmed by anterior neck dissection preceded by ventilation with the BVM to assess chest-wall expansion and stethoscope auscultation (Figure 1C

Figure 1. A, Cutting the drip chamber in half. B, Improvised cricothyrotomy device ready for use. C and D, Attachment of the bag valve mask. E, Evaluation of placement by bronchoscopy.

and D). Fiberoptic bronchoscopy and neck dissection were also used to assess for damage to the posterior wall of the trachea. Fiberoptic bronchoscopy was performed by placing the scope through an endotracheal tube inserted just past the vocal cords (Figure 1E). Significant chest expansion was achieved with manual occlusion of the cadaver's mouth and nose to achieve chest rise rather than simply pushing air out of the mouth; this step required the assistance of a second person. Time to perform the procedure was measured for each procedure from a video recording. Consistent with previous studies,^{9,12} performance time began after the equipment was ready, and the cricothyroid membrane was localized and ended with the first successful manual ventilation with the BVM. Each unembalmed cadaver was used only once.

The primary outcome variable was whether or not the

IV tubing spike entered the trachea. Secondary observations included time to complete the procedure and evidence of complications such as incorrect location of the spike (eg, inadvertent tracheostomy) and damage to the posterior wall of the trachea.

Results

The mean weight for the cadavers was 65 ± 19.4 kg (SD) with a range of 45 to 110 kg. All 10 cricothyrotomy attempts resulted in successful cannulation of the trachea. In 5 procedures, position was confirmed by direct visualization of the spike in the trachea by using fiberoptic bronchoscopy. In the 5 attempts in which bronchoscopy was not available, position was confirmed by lung auscultation, evidence of chest rise, and absence of subcutaneous air in the neck followed by neck dis-

Figure 2. Time to complete each procedure for the 1 attending physician and 3 emergency medicine residents in this study. The cadaver number of the attempt is provided next to each data point.

section. The median time from identification of the cricothyroid membrane until first manual ventilation was 27.3 seconds with a range of 14 to 49 seconds. There was a trend to shorter times to completion of the procedure in subsequent attempts for all 4 individuals (Figure 2). On no attempt did tissue get stuck in or obstruct the spike; once the spike was inside the trachea, BVM ventilation was instantaneous and without resistance.

In 2 cases, the spike was initially placed incorrectly, and the first attempt to bag the cadavers resulted in obvious subcutaneous air within 2 assisted breaths with the BVM. In both cases, the individual performing the procedure recognized the error, and relocation of the spike resulted in successful placement. The attending physician and the resident with no previous cricothyrotomies committed these 2 first-pass errors, which occurred on their first experience using the spike and drip chamber. In both cases, the time to correct the error was included in the measurement of the time to perform the procedure.

Discussion

The goal of this study was to determine whether cricothyrotomy with a high-flow IV tubing spike and drip chamber could reliably puncture the cricothyroid membrane and provide effective airway access in an unembalmed partially rewarmed cadaver. Our results indicate that the procedure can be successfully performed even by an inexperienced individual with no previous cricothyrotomies and with no specific instructions except for knowledge of the relevant neck anatomy and the goals of the procedure.

Although specific instructions were not provided to

any of the participants before attempting to cannulate the trachea, after completion of the study we agreed that the best technique seemed to be the following: The nondominant hand is used to stabilize the trachea and stretch the overlying skin to maximize tension over the cricothyroid membrane and maximize the cutting advantage of the IV spike's edge. The cricothyroid membrane should be palpated with the index finger of the dominant hand, and the improvised device is then introduced by puncturing the skin and cricothyroid membrane. Orientation of the spike perpendicular to the membrane or angled slightly caudally was thought to afford the least resistance for entry into the trachea. Once inserted, the device should be held firmly in place at all times and attached to the BVM for immediate ventilation. The 2 first-pass errors occurred because the spike entered soft tissue lateral to the trachea. The best way to avoid a first-pass error was thought to be proper stabilization of the trachea with the nondominant hand and insertion of the spike in the midline.

The force required for placement of the plastic spike into the trachea was minimized by stretching the overlying skin as tautly as possible. As an additional test, we performed a repeat cricothyrotomy on 1 cadaver with a scalpel to make a small vertical incision through the skin over the cricothyroid membrane similar to the first step in the performance of a surgical cricothyrotomy. Placing the spike into the trachea through this skin incision was thought to be significantly easier than without the skin incision. We designed the study to demonstrate that the spike and drip chamber could be used as the sole device for performing cricothyrotomy. After comparing the 2 techniques, we thought that if a scalpel were available, we would likely make a small skin incision first. The purpose of the skin incision would not be to expose and visualize the membrane but rather to reduce resistance to cutting when introducing the spike.

Limitations

Although we demonstrate that this method of improvised cricothyrotomy can be effective and reliable on warm unembalmed human cadavers, cadavers are different from patients encountered in the emergency setting. Bleeding, patient movement, and the stress created by the presence of a live patient with inadequate airway access may make the actual procedure more challenging than the procedure we studied. Additionally, whereas study participants had time before the procedure to examine both the neck of the cadaver and the spike and drip chamber, time for such preparation would be greatly reduced in an emergency. The effect of rigor mortis on stabilizing the musculature of the neck also may make

the procedure easier to perform on a cadaver than on a live patient. Although warming the neck may make the skin overlying the cricothyroid membrane more supple, warming probably does not change the characteristics of the cadaver musculature. Also, even though the 10 of 10 successful cannulations in our study are encouraging, the small number of procedures leaves open the possibility of a failure rate as high as 25.9% (95% CI 0%–25.9%).

Because the spike and drip chamber does not have a cuff, this device does not protect against aspiration. Furthermore, we found that significant chest rise was achieved only with manual obstruction of the mouth and nose, which required a second person for assistance. In a cadaver model, it is not possible to assess oxygenation. Because of the small internal diameter of the IV spike and drip chamber, it is possible that even if adequate oxygenation occurred, ventilation would be insufficient to prevent a gradual rise in PaCO_2 . To protect against aspiration and to ensure adequate ventilation, an exchange of the IV spike and drip chamber for a large-diameter airway with cuff would probably be necessary. Unlike the commercially available devices, the spike and drip chamber we used does not come with a simple means of attachment to the neck. Attachment with tape or with sutures placed through the rim of the device is plausible but not studied.

We remind readers that we tested the Baxter Clearlink System high-flow IV tubing spike and drip chamber. There are several other types of high-flow spike and drip chambers available with architecture different from the one we studied. We do not know if these other spike and drip chambers would be as effective for performing an improvised cricothyrotomy. The Baxter Clearlink System spike and drip chamber may be preferable to others because it has an unobstructed central lumen, which may allow for lower air resistance and, in theory, would allow one to exchange the device over a wire for a conventional endotracheal tube.

Other devices for performing an improvised cricothyrotomy were not tested on cadavers. We examined a typical plastic pen, a small-diameter (3 mL and tuberculin) syringe, and a nasopharyngeal airway and found that none is readily adapted to a conventional BVM. Although these devices may allow rapid airway access, air exchange with these devices may prove to be more difficult than with an IV spike and drip chamber. Also, though the individuals performing the experiments were not provided with specific instructions, all are emergency personnel familiar with the relevant neck anatomy for this procedure, and 1 had also conducted preliminary research on the subject. We were not able to evaluate long-term complications from cricothyrotomy such as tracheal stenosis and dysphonia.

Conclusions

Various methods of improvised cricothyrotomy have been described, but no studies of this procedure have been published. We demonstrate that individuals with knowledge of the relevant anatomy but without specific instructions could plausibly use an IV spike and drip chamber as a cricothyrotomy device in a human cadaver model.

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