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Impaired ventilation and oxygenation following emergency cricothyrotomy: recommendations for the management of suboptimal invasive airway access

Matthew A. Warner, MD,

Resident, Department of Anesthesiology, Mayo Clinic, Rochester, MN

Hugh M. Smith, MD, PhD, and

Assistant Professor of Anesthesiology, Department of Anesthesiology, Mayo Clinic, Rochester, MN

Martin D. Zielinski, MD

Associate Professor of Surgery, Department of Surgery, Mayo Clinic, Rochester, MN

Abstract

Invasive airway access by emergent cricothyrotomy remains an essential treatment modality in “can’t intubate/can’t ventilate” scenarios. While numerous commercial devices are available, limited comparative data exists with regard to the ventilation and oxygenation parameters of these devices. We report a case of severely compromised respiratory function while using the *Quicktrach II*, a commercially-available emergency cricothyrotomy device. Due to oxygenation and ventilatory insufficiency, our patient required emergent removal of the device and surgical tracheostomy to improve respiratory function. When confronted with a difficult airway, anesthesiologists and surgeons should be aware of commonly encountered cricothyrotomy devices and their potential limitations.

Introduction

In the American Society of Anesthesiologists’ (ASA) difficult airway algorithm and the Difficult Airway Society’s (DAS) guidelines for management of unanticipated difficult airway, the final treatment option is invasive airway access by tracheostomy or cricothyrotomy.(1,2) While the gold-standard remains surgical access to the airway, several percutaneous cricothyrotomy devices have been developed to simplify and facilitate invasive airway access. Percutaneous cricothyrotomy is often performed outside of operating environments by non-anesthesia providers including emergency medicine personnel, paramedics, and surgeons in patients who typically require further stabilization and/or operative management.(3)

Corresponding Author: Matthew A. Warner, MD, Mayo Clinic, Rochester, MN, 200 1st Street S.W., Rochester, MN 55905, warner.matthew@mayo.edu, Phone: 507-254-0925, Fax: 507-255-4267.

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While studies have compared placement speed and efficacy of various cricothyrotomy devices, there are limited data regarding the adequacy of controlled or spontaneous ventilation. Moreover, to our knowledge, there are no investigations of *in vivo* ventilation adequacy. In this manuscript, we report a case of severely compromised respiratory function in a patient with percutaneous cricothyrotomy using a commercially-available device (*Quicktrach II*, 4.0 mm internal diameter with cuff, VBM Medical). Moreover, we offer recommendations for definitive airway management in patients with pre-existing percutaneous cricothyrotomy. Written informed consent for this case report was obtained directly from the patient. In addition, the authors of this manuscript were directly involved in the patient's perioperative care.

Case Description

A previously healthy 35 year-old male (BMI 27 kg/m²) suffered a non-helmeted motorcycle-versus-deer collision at highway speeds. At the scene, he had a large occipital laceration and was conscious but agitated with a Glasgow Coma Scale (GCS) score of 12. In the local emergency department his mental status deteriorated and the decision was made to perform endotracheal intubation. Following administration of etomidate and rocuronium, intubation was unsuccessful despite nine attempts using direct laryngoscopy, indirect videolaryngoscopy, and direct laryngoscopy using gum elastic bougie. Intubation attempts were made by emergency medicine personnel, flight paramedics, and a nurse anesthetist. Bag mask ventilation with an oropharyngeal airway was maintained between attempts but ventilation became increasingly difficult. A King-LTS (King Systems) supraglottic airway was placed but promptly removed due to inadequate ventilation.

Given the unsecured, threatened airway, percutaneous cricothyrotomy was performed using a *Quicktrach II*. Despite successful placement, ventilation and oxygenation remained severely impaired as evidenced by oxygen saturation (SpO₂) of 80% and elevated airway pressures. The patient was administered 10 mg of intravenous vecuronium in an effort to improve respiratory function prior to transport to a tertiary care facility.

Upon arrival, SpO₂ readings ranged between 80–85% on 100% FiO₂ via portable ventilator. A cervical collar was in place, and the patient had a large occipital laceration with ongoing hemorrhage and moderate lip and oral trauma secondary to intubation attempts. Attempts to suction through the cricothyrotomy device were unsuccessful. The patient was switched to bag-valve ventilation with very high airway resistance noted on bag compression. Breath sounds, though distant, were confirmed bilaterally and colorimetric end-tidal CO₂ was present. Transport personnel were unable to report what type of cricothyrotomy device had been used, only that it was placed after numerous failed intubation attempts. During fiberoptic bronchoscopy to assess for airway obstruction, there appeared to be an extraneous object with a small lumen embedded within the device itself and the scope was unable to be advanced beyond this point and into the trachea (Figure 1a). Given concerns that a foreign body was impeding ventilation, the patient was transferred emergently to the operating room (OR) for definitive airway management.

In the OR, an initial arterial blood gas (ABG) obtained 1 hour after cricothyrotomy revealed pH of 7.01, partial pressure of CO₂ (PaCO₂) >100 mmHg, and bicarbonate of 29 mmol L⁻¹ (normal 22 – 25 mmol/L). He was placed on mechanical ventilation with a rate of 24 breaths per minute and PEEP of 5 cm H₂O, requiring peak airway pressures greater than 55 cm H₂O to maintain tidal volumes of 200–250 ml for a dynamic compliance of approximately 5 ml cm⁻¹ H₂O (normal > 30 ml cm⁻¹ H₂O). He was prepped and draped for surgical tracheostomy placement. Prior to proceeding, however, fiberoptic bronchoscopy with an adult flexible scope (PortaView® LF-GP, 4.1 mm external diameter, Olympus) was attempted but the scope was unable to pass through the device lumen. A wire was advanced through the side-port of the scope and into the small lumen of the cricothyrotomy device (Figure 1b). The wire acted as a conduit to the trachea for exchanging the device with a 7.0 cuffed tracheostomy tube (Bivona Adult TTS, Portex).

Following placement of the tracheostomy tube, ventilation immediately improved with tidal volumes greater than 400 ml and peak airway pressures of approximately 36 cm H₂O with PEEP of 12 cm H₂O (dynamic compliance of 17 ml cm⁻¹ H₂O). Repeat ABG obtained 10 minutes later showed improving hypercapnia and respiratory acidosis with pH of 7.19 and PaCO₂ of 90 mmHg. SpO₂ increased to 92%. Repeat bronchoscopy showed blood-stained bilious secretions throughout the right-sided bronchial tree consistent with aspiration. Portable chest radiography revealed right upper and lower lobe collapse. Following endobronchial suctioning, serial recruitment maneuvers were performed and FiO₂ was weaned to 80% within 1 hour of tracheostomy placement with ABG revealing pH of 7.28, PaCO₂ of 57 mmHg, and PaO₂ of 70 mmHg. He was weaned off the ventilator by the 5th postoperative day and his tracheostomy was decannulated on postoperative day number 7.

Closer inspection of the cricothyrotomy device revealed that the small internal lumen viewed during bronchoscopy was not a foreign object but rather part of the original device design. There were no apparent defects in the device and the cuff remained intact (Figure 1b).

Discussion

Surgical or percutaneous cricothyrotomy remains the last line of therapy in management of failed intubation/failed ventilation scenarios. Several commercially-available percutaneous devices are intended to assist providers with limited surgical airway experience in the performance of emergent cricothyrotomy, and the majority of these devices fall into two categories. The first relies on puncture of the cricothyroid membrane with a needle, followed by guidewire placement through the needle, and then placement of a specially-designed endotracheal tube over the wire after tract dilation using the Seldinger technique. Devices employing this technique include the *Arndt emergency cricothyrotomy catheter set* (Cook Medical), the *Melker emergency cricothyrotomy* (Cook Medical), and the *Minitrache II* (Smiths Medical). The second category does not rely on the use of a guidewire. Rather, these kits contain a cutting device that creates a passage large enough to directly accommodate an endotracheal tube unique to the kit. Devices placed with this technique include the *Airfree coniotomy set* (FRC Medizintechnik), the *Portex cricothyrotomy kit* (Smiths Medical), the *Quicktrach I* and *Quicktrach II* (VBM Medical), the *TracheoQuick emergency coniotomy set* (Teleflex Medical), and the *Pertrach kit* (Pulmodyne). Unfortunately, there is limited data

available to directly compare these devices. Theoretically, kits utilizing the Seldinger-based technique may be more familiar for anesthesia providers, while the wireless technique may be advantageous in that it requires fewer steps for placement. Similarly, there is limited evidence comparing cricothyrotomy kits with the gold standard of surgical cricothyrotomy, but overall rates of successful placement seem to be similar.(4) The amount of time required for placement varies between studies and may be device and operator-dependent. Regardless of technique, internal diameter sizes for cricothyrotomy tubes typically range from 4.0 – 6.0 mm, and devices may be cuffed or uncuffed based upon the manufacturer. In addition, there are several devices available which can be used to facilitate either open surgical cricothyrotomy or needle-based cricothyrotomy, thereby allowing temporary oxygenation and ventilation (i.e. via jet ventilation).

In this case, a *Quicktrach II* cuffed cricothyrotomy catheter with 4.0 mm internal diameter was utilized. This device consists of a cuffed cannula preloaded over a needle that allows airway access in a single “cannula-over-needle” technique. The device has a stopper that prevents the needle from being inserted too deeply, thereby reducing the risk of tracheal wall perforation. At our institution, the Seldinger technique-based *Melker emergency cricothyrotomy kit* with a 5.0 mm internal diameter is available in every emergency airway cart.

To date, there are limited data regarding the adequacy of oxygenation and ventilation through percutaneous cricothyrotomy devices, and no studies have examined *in vivo* performance. Michalek-Sauberer and colleagues used a model lung to assess respiratory mechanics during ventilation with seven cricothyrotomy devices at varying levels of compliance and resistance.(5) They concluded that the *Quicktrach II*, like other cuffed devices with an internal diameter of at least 4.0 mm, provided adequate tidal volumes during controlled ventilation at physiologic airway pressures regardless of model lung compliance or resistance. In a simulated human lung model with arterial oxygen saturation of 80%, Vadodaria and colleagues found that an uncuffed *Quicktrach I* device could be placed by an anesthetist in a median time of 51 seconds and allowed for attainment of a $\text{PaO}_2 > 100$ mmHg in 58 seconds.(6) Major limitations to the aforementioned studies are related to simulated airway models and uncertain applicability to human subjects. Notably, there are no prior investigations of ventilatory and oxygenation adequacy through cricothyrotomy devices in humans, particularly in patients with altered pulmonary mechanics. Clearly, the performance of cricothyrotomy devices may be significantly limited in the presence of pulmonary pathology such as atelectasis, inflammation, bleeding, and pneumothorax.

In this case, a *Quicktrach II* enabled airway access following multiple failed endotracheal intubation attempts, though ventilation and oxygenation remained severely compromised until surgical tracheostomy was performed. While acute lung injury, in the setting of atelectasis and aspiration, were contributing to respiratory dysfunction, the cricothyrotomy device was incapable of ameliorating life-threatening respiratory compromise. This may have been due, in part, to an inability to adequately recruit collapsed alveolar segments through the device. Fortunately, the patient was young and without significant comorbid disease, which likely allowed him to tolerate severe cardiopulmonary compromise without suffering acute arrest or permanent injury. However, in a patient with significant

cardiopulmonary disease, the ability of the device to prevent impending arrest and prolong further resuscitative efforts is uncertain. Additionally, the device did not allow for passage of adult-sized suction catheters or a fiberoptic bronchoscope, interventions which may be critical in the patient with impaired respiratory mechanics. Theoretically, a device with a larger internal diameter (e.g. 5.0 mm) may have allowed for these interventions and resulted in improved ventilatory mechanics.

Surprisingly, there is little evidence available regarding definitive airway management in patients with emergently-placed invasive airway devices. Acute complications including bleeding, tube misplacement, damage to surrounding structures including the posterior tracheal wall and glottic apparatus, and pneumothorax are common in emergent cricothyrotomy, with an estimated rate of up to 15%.(7) With regards to long-term consequences, traditional surgical teaching recommends conversion of cricothyrotomy to tracheotomy within 72 hours of placement in order to decrease the risk of subglottic stenosis. However, rates of subglottic stenosis vary widely in the existing literature. A review of 20 published series of cricothyrotomy found an overall rate of chronic subglottic stenosis of only 2.2%, leading the authors to question the mandatory replacement of cricothyrotomy within 72 hours of placement.(4) However, rates of 30% have been reported, especially when following prior attempts at endotracheal intubation.(8) In the absence of well-designed prospective investigations assessing long-term sequelae of cricothyrotomy maintenance and the potentially increased risk of subglottic stenosis with longer duration, we suggest that further management be determined by 3 parameters: 1) adequacy of ventilation and oxygenation, as evidenced by parameters such as near-normal pH (> 7.3) in the absence of significant metabolic acidosis and arterial oxygen saturation > 90%; 2) need for prolonged mechanical ventilation (e.g. multiple OR trips, extensive in-hospital transport, any out-of-hospital transport, or pathology precluding safe extubation); and 3) feasibility of exchange to another device. If ventilation and oxygenation are adequate, and long-term airway access is not required, the device may be safely maintained in the acute setting with the ultimate goal of removal or replacement when clinically feasible. When ventilation and oxygenation are adequate but long-term airway access is required, the device should be replaced. This may be performed with a variety of approaches including surgical tracheostomy with or without fiberoptic assistance, wire-exchange techniques, or additional oral or nasal intubation attempts including novel approaches such as combined indirect laryngoscopy and fiberoptic intubation. If ventilation and oxygenation are inadequate, secondary causes must be assessed and rectified. Such causes may include pneumothorax, low cardiac output, inadequate sedation or muscle relaxation, and mechanical obstruction among others. If ventilation and oxygenation remain inadequate, the device requires rapid replacement. In our case, mechanical obstruction was related to the 4.0 mm internal diameter, which proved insufficient to meet the patient's respiratory demands.

In summary, emergent cricothyrotomy with commercially-available devices may prolong resuscitative efforts; however there may be significant limitations in ventilation and oxygenation that require rapid evaluation and treatment by expert airway personnel.

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Figure 1.

a) View looking caudally through the cricothyrotomy device. Note the smaller lumen within the device itself (*), which was originally thought to represent an extraneous object embedded within the cricothyrotomy device. b) Guidewire placement via fiberoptic guidance through the lumen of the cricothyrotomy device to facilitate exchange for a formal cuffed tracheostomy tube using the Seldinger technique.