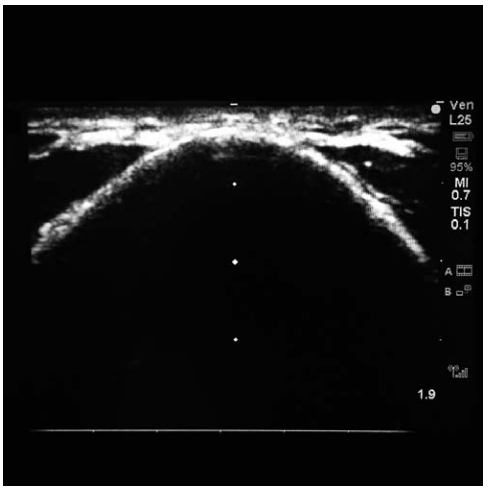
Emergency Cricothyrotomy

Toward a Safer and More Reliable Rescue Method in "Cannot Intubate, Cannot Oxygenate" Situation

Takashi Asai, M.D., Ph.D.

IF oxygenation is difficult due to failed tracheal intubation and difficult ventilation *via* a facemask after induction of anesthesia, all the major guidelines on "difficult airway management" recommend to insert a supraglottic airway, and if that is ineffective, to gain invasive access to the infraglottic airway (such as cricothyrotomy and tracheostomy) as the last resort.[1–3] Nevertheless, this invasive method as the last resort may also fail, rendering the current strategies for difficult airway management not ideal.[4] In this issue of Anesthesiology, Siddiqui *et al.*[5] have shown that emergency percutaneous cricothyrotomy may frequently produce another life-threatening complication (tear to the posterior tracheal wall) and that ultrasonography may drastically reduce this complication.



"Emergency percutaneous cricothyrotomy may frequently produce another life-threatening complication (tear to the posterior tracheal wall), and ultrasonography may drastically reduce this complication."

Key Findings

Siddiqui *et al.*[5] randomly allocated 47 anesthesia residents (with no experience in neck ultrasonography) to two groups, after giving didactic teaching and hands-on training of ultrasound-guided cricothyrotomy. In one group, residents performed percutaneous cricothyrotomy after locating the cricothyroid ligament by palpation, whereas in the other group, they did so under ultrasound guidance, in cadavers. The conventional palpation method was associated with a high incidence of moderate or severe injury to the larynx and trachea, and the incidence was 100% when palpation of the cricothyroid ligament was difficult. The use of ultrasound reduced the incidence to 33% in cadavers with difficult palpation of the cricothyroid ligament. In addition, the ultrasound guidance increased the success rate of correct insertion in cadavers with difficult and impossible palpation of the cricothyroid ligament although insertion time took longer.

What We Know and What We Do Not

So, what can we learn from the study by Siddiqui *et al.*[5] in cadavers, and what we still do not know? First, we now know that emergency percutaneous cricothyrotomy may frequently injure the posterior tracheal wall when performed by inexperienced staff, particularly when it is difficult to locate the puncture site by palpation. We do not know whether or not the incidence of the injury is also high when experienced anesthesiologists perform cricothyrotomy, but we should consider that the incidence is likely to be considerably high, because the most "experienced" anesthesiologists would not have expertise in performing the task in a hastily manner, in patients with difficult airways.

Second, Siddiqui *et al.*[5] used one type of cricothyrotomy device, and we do not know whether or not there are differences in the success rate of insertion and in the incidence of airway injury between different types of cricothyrotomy devices. In addition, although some systematic reviews indicate that emergency cricothyrotomy with a small-bore cannula may frequently be ineffective, evidence is still insufficient to conclude which method of gaining access to the infraglottic airway (such as cannula cricothyrotomy or surgical tracheostomy) is more reliable than another[6,7] in the "cannot intubate, cannot oxygenate" situation.

Image: J. P. Rathmell.

Corresponding article on page 1033.

Accepted for publication July 14, 2015. From the Department of Anesthesiology, Dokkyo Medical University Koshigaya Hospital, Koshigaya City, Saitama, Japan.

 Anesthesiology 2015; 123:995-6

Third, the study by Siddiqui *et al.*[5] has shown that ultrasonography may drastically reduce the incidence of airway injury, but compared with conventional cricothyrotomy, ultrasound-guided cricothyrotomy may take a longer insertion time (the mean time of > 3 min). Therefore, this result suggests that the use of ultrasound may be impractical in a dire situation where the patient would have become severely hypoxic after failed intubation and failed oxygenation. What we do not know is whether or not appropriate training shortens the time required to perform ultrasound-guided cricothyrotomy. Nor do we know whether or not location of the cricothyroid ligament using the ultrasound and marking on the puncture site before induction of anesthesia would increase the success rate of correct access to the infraglottic airway in a "cannot intubate, cannot oxygenate" situation, with a decreased incidence of airway injury. If so, it would be safer to routinely use the ultrasound to locate the puncture site before induction of anesthesia when difficult airway management is predicted. In addition, if airway management is predicted to be extremely difficult, a cannula may be inserted under ultrasound guidance before induction of anesthesia, so that if mask ventilation is difficult, a guidewire is inserted through the cannula, and a cricothyrotomy tube may be passed over the guidewire.

We also do not know how frequently it would be difficult to perform cricothyrotomy, and what are the causes of the difficulty. Routine use of preoperative ultrasound examination of the neck in patients with predicted difficult airway management would enable us to learn the incidence and possible causes of difficulty, such as blood vessels or a tumor at the puncture site, and deformation of the airway. We also do not know whether or not active use of preoperative ultrasound examination of the neck would increase the competence of anesthesiologists in performing emergency cricothyrotomy.

When the posterior membranous part of the trachea is injured, life-threatening tension pneumothorax, pneumomediastinum, mediastinitis, and progressive respiratory failure may occur. Siddiqui *et al.*[5] have shown that percutaneous cricothyrotomy may frequently damage the airway (even under ultrasound guidance), and thus we now know that the presence or absence of airway injury should be confirmed after establishing emergency cricothyrotomy, by the fiber-optic bronchoscopy, by the chest radiograph, and if necessary by the computed tomography. Surgical intervention is frequently required to repair the injury,[8] but this may be practically difficult if the patient has become hypoxia due to failed intubation and failed mask ventilation and received "rescue" percutaneous cricothyrotomy. Therefore, there is a real danger of death caused by this "rescue" procedure, and thus we should urgently establish reasonable diagnosis and treatment methods of iatrogenic airway injury.

Conclusions

Since the severity of adverse outcomes associated with airway management was recognized in early 1990s, efforts have been made to reduce the incidence of serious adverse outcomes. As a result of formulating reliable and practical guidelines about difficult airway management, together with development of new reliable airway devices and wide availability of oximetry and capnography, the incidence is likely to be decreased. Nevertheless, "cannot intubate, cannot oxygenate" situation does occur in a limited number of patients, and we still have insufficient knowledge about how most effectively we can save the patient's life by gaining access to the infraglottic airway. It is now time for us to elucidate the incidence of, and predisposing factors to, difficulties in gaining access to the infraglottic airway and to find suitable access methods. Only through studies (such as the one reported by Siddiqui *et al.*[5]), we can make this "rescue" method safer and more reliable in "cannot intubate, cannot oxygenate" situation.

Competing Interests

The author is not supported by, nor maintains any financial interest in, any commercial activity that may be associated with the topic of this article.

Correspondence

Address correspondence to Dr. Asai: asaita@dokkyomed.ac.jp

References

1. Apfelbaum JL, Hagberg CA, Caplan RA, Blitt CD, Connis RT, Nickinovich DG, Hagberg CA, Caplan RA, Benumof JL, Berry FA, Blitt CD, Bode RH, Cheney FW, Connis RT, Guidry OF, Nickinovich DG, Ovassapian A; American Society of Anesthesiologists Task Force on Management of the Difficult Airway: Practice guidelines for management of the difficult airway: An updated report by the American Society of Anesthesiologists Task Force on Management of the Difficult Airway. Anesthesiology 2013; 118:251–70
2. Henderson JJ, Popat MT, Latto IP, Pearce AC; Difficult Airway Society: Difficult Airway Society guidelines for management of the unanticipated difficult intubation. Anaesthesia 2004; 59:675–94
3. Japanese Society of Anesthesiologists: JSA airway management guideline 2014: To improve the safety of induction of anesthesia. J Anesth 2014; 28:482–93
4. Asai T: Strategies for difficult airway management—The current state is not ideal. J Anesth 2013; 27:157–60
5. Siddiqui N, Arzola C, Friedman Z, Guerina L, You-Ten KE: Ultrasound improves cricothyrotomy success in cadavers with poorly defined neck anatomy: A randomized control trial. Anesthesiology 2015; 123:1033–41
6. Hubble MW, Wilfong DA, Brown LH, Hertelendy A, Benner RW: A meta-analysis of prehospital airway control techniques part II: Alternative airway devices and cricothyrotomy success rates. Prehosp Emerg Care 2010; 14:515–30
7. Langvad S, Hyldmo PK, Nakstad AR, Vist GE, Sandberg M: Emergency cricothyrotomy—A systematic review. Scand J Trauma Resusc Emerg Med 2013; 21:43
8. Hofmann HS, Rettig G, Radke J, Neef H, Silber RE: Iatrogenic ruptures of the tracheobronchial tree. Eur J Cardiothorac Surg 2002; 21:649–52

Ultrasound Improves Cricothyrotomy Success in Cadavers with Poorly Defined Neck Anatomy

A Randomized Control Trial

Naveed Siddiqui, M.D., M.Sc., Cristian Arzola, M.D., M.Sc., Zeev Friedman, M.D., Laarni Guerina, M.D., Kong Eric You-Ten, M.D., F.R.C.P.C.

ABSTRACT

Background: Misidentification of the cricothyroid membrane in a "cannot intubate-cannot oxygenate" situation can lead to failures and serious complications. The authors hypothesized that preprocedure ultrasound-guided identification of the cricothyroid membrane would reduce complications associated with cricothyrotomy.

Methods: A group of 47 trainees were randomized to digital palpation (n = 23) and ultrasound (n = 24) groups. Cricothyrotomy was performed on human cadavers by using the Portex® device (Smiths Medical, USA). Anatomical landmarks of cadavers were graded as follows: grade 1—easy = visual landmarks; 2—moderate = requires light palpation of landmarks; 3—difficult = requires deep palpation of landmarks; and 4—impossible = landmarks not palpable. Primary outcome was the complication rate as measured by the severity of injuries. Secondary outcomes were correct device placement, failure to cannulate, and insertion time.

Results: Ultrasound guidance significantly decreased the incidence of injuries to the larynx and trachea (digital palpation: 17 of 23 = 74% *vs.* ultrasound: 6 of 24 = 25%; relative risk, 2.88; 95% CI, 1.39 to 5.94; $P = 0.001$) and increased the probability of correct insertion by 5.6 times ($P = 0.043$) in cadavers with difficult and impossible landmark palpation (digital palpation 8.3% *vs.* ultrasound 46.7%). Injuries were found in 100% of the grades 3 to 4 (difficult–impossible landmark palpation) cadavers by digital palpation compared with only 33% by ultrasound ($P < 0.001$). The mean (SD) insertion time was significantly longer with ultrasound than with digital palpation (196.1 s [60.6 s] *vs.* 110.5 s [46.9 s]; $P < 0.001$).

Conclusion: Preprocedure ultrasound guidance in cadavers with poorly defined neck anatomy significantly reduces complications and improves correct insertion of the airway device in the cricothyroid membrane. **(ANESTHESIOLOGY 2015; 123:1033-41)**

DIFFICULTY with tracheal intubation is the most common cause of serious adverse respiratory events for patients undergoing anesthesia.[1,2] Repeated attempts of difficult intubation can result in serious soft tissue injury and rapidly deteriorate into a "cannot intubate-cannot oxygenate" situation that requires a surgical cricothyrotomy as a potentially life-saving procedure. However, cricothyrotomy is an infrequently performed procedure[3,4] with complication rates ranging from 9 to 40%.[5,6] Accurate identification of the cricothyroid membrane is crucial for the success and minimal complications in performing a cricothyrotomy. The current practice to identify relevant anatomical landmarks has relied solely on digital palpation. However, inaccuracy in identifying the cricothyroid membrane using digital palpation is among one of the most common errors that have resulted in device misplacement, leading to failed cricothyrotomies and adverse outcomes.[7–9]

Ultrasonography of the airway is increasingly used in airway management.[10,11] Nicholls *et al.*[12] reported a standardized ultrasonography technique to identify the cricothyroid membrane and to evaluate the ability of emergency

What We Already Know about This Topic

- Cricothyrotomy is an effective procedure for a "cannot intubate-cannot oxygenate" situation, but misidentification of the cricothyroid membrane can lead to failures and serious complications
- Ultrasonography technique can easily identify the cricothyroid membrane

What This Article Tells Us That Is New

- This is the first study systematically assessing whether ultrasound guidance can reduce the complications associated with cricothyrotomy performed in human cadaver
- The incidence of injuries to the larynx and trachea during ultrasound-guided cricothyrotomy was significantly lower compared with conventional digital palpation technique (25 *vs.* 74%), whereas the insertion time was significantly longer with ultrasound than with digital palpation (196 *vs.* 110 s)
- Results of this study suggest that ultrasound guidance of the cricothyroid membrane and neck landmarks should be performed before airway management, particularly in patients with difficult palpable neck landmarks and difficult airways

This article is featured in "This Month in Anesthesiology," page 1A. Corresponding article on page 995.

Submitted for publication October 22, 2014. Accepted for publication July 14, 2015. From the Department of Anesthesia and Pain Management, Mount Sinai Hospital, University of Toronto, Toronto, Ontario, Canada.

physicians to apply this technique in a cohort of patients in the emergency department. The findings in this study suggest that the cricothyroid membrane and relevant structures can be quickly identified by emergency physicians by using ultrasonography technique. Furthermore, the use of ultrasonography in identification of the cricothyroid membrane has been described in detail in the study by Kristensen.[10] However, little is known on the outcomes in performing a cricothyrotomy with ultrasonography guidance. We hypothesized that ultrasound-guided identification of the cricothyroid membrane would reduce complications associated with cricothyrotomy. In this study, we aimed to determine the outcomes of cricothyrotomy performed on human cadavers by using ultrasound guidance, compared with conventional digital palpation, of anatomical landmarks. In particular, complication rates, failure to cannulate, correct placement of the device, and insertion time of cricothyrotomy were assessed.

Materials and Methods

Participants

This study was approved by the Research Ethics Board of Mount Sinai Hospital, Toronto, Ontario, Canada, and registered with ClinicalTrials.gov identifier: NCT01475487 (principal investigator: N.S.; date of registration: November 3, 2011). The clinical trial registry has been updated due to an oversight in the initial registration before data collection. We followed Consolidated Standards of Reporting Trials (CONSORT) checklist (appendix).

After written informed consent, 47 anesthesia residents in postgraduate years 1 to 5 and anesthesia fellows at the University of Toronto (Toronto, Ontario, Canada) were recruited in the study over a period of 12 months. Only participants with no previous experience in neck ultrasonography were recruited in the study. Their age, training grade, and years of practice were recorded. Participants who had performed a cricothyrotomy in the previous 6 months were excluded from the study.

Human Cadavers

The study was conducted on formalin-fixed human cadavers in the anatomy laboratory at the Department of Anatomy, University of Toronto. We used a total of 52 formalin-fixed human cadavers for the study assessment and teaching. To make reliable injury assessment, we used separate cadavers for each performance.

Two study investigators selected the cadavers based on preset criteria that included identification of anatomical landmarks visually and by palpation. The identification of the cricothyroid membrane by digital palpation was performed by using the index and third fingers of the nondominant hand. The thyroid cartilage was first palpated in the midline starting from cephalad and moving caudally until the cricoid cartilage is palpated. The cricothyroid membrane is the space between the inferior border of the thyroid cartilage and the superior border of the cricoid cartilage. The degree of difficulty in identifying the landmarks was graded according to a previously described grading system[12]: grade 1—easy = visual landmarks; 2—moderate = requires light palpation of landmarks; 3—difficult = requires deep palpation of landmarks; and 4—impossible = landmarks not palpable. Cadavers with a grade greater than 2 were recruited in the study.

Pretest Teaching of Ultrasonographic Identification of the Cricothyroid Membrane

A 15- to 10-mHz linear probe (MicroMaxx System; SonoSite Canada Inc., Canada) was used to obtain sonographic images of anatomical landmarks on cadaveric necks as described in the study by Kristensen.[10]

The participants held the linear high-frequency transducer in their nondominant hand and placed themselves on the right side of the cadaver facing toward the head of the cadaver. Then they placed the ultrasound probe transversely over the cadaver's neck just above the suprasternal notch to visualize the trachea. The transducer was then moved laterally to the patient's right side until the right border of the transducer was superficial to the midline of the trachea. During this movement, it was ensured that the right end of the transducer was kept in the midline of the trachea while the left end of the transducer was rotated into the sagittal plane resulting in a longitudinal scan of the midline of the trachea.

All participants in the study received a 10-min didactic lecture on cricothyrotomy using the Portex® cricothyrotomy kit (Smiths Medical, USA) followed by a 3-min video demonstration of ultrasonographic and conventional digital palpation technique to identify the anatomical landmarks and the cricothyroid membrane. All participants were then given hands-on training at least five times with ultrasound using the Portex® cricothyrotomy device on human cadavers.

Test Session

After the teaching session, participants were randomized by computer-generated number tables to one of two groups: digital palpation group (n = 23), participants in this group performed cricothyrotomy using the Portex® device with conventional digital palpation of the cricothyroid membrane, and ultrasound group (n = 24), participants in this group performed cricothyrotomy using the Portex® device with ultrasonographic identification of the cricothyroid membrane. Only cadavers with grades 2 to 4 landmarks were used in the test session.

Outcome Measures. All cricothyrotomy procedures were video recorded for analysis. After termination of each cricothyrotomy, two anesthesiologists who were blinded to group allocation assessed the cadaver's neck. The assessments were done first with a fiber-optic bronchoscope and then followed with dissection of the neck to assess for device position, complications, and severity of any injuries.

The primary outcome measure was the complication rate as assessed by the severity of injuries, defined as the incidence and severity of posterior laryngeal and tracheal wall injuries, as graded by two anesthesiologists using the grading system described by Murphy *et al.*[13] (none [no injury]; mild [< 5-mm laceration]; moderate [> 5-mm laceration or partial puncture]; and severe [> 10-mm laceration or full puncture]). The secondary outcomes included (1) insertion time, measured in seconds from the time of palpation of the skin to insertion of the Portex® device in the trachea; (2) failure, with a "failure" defined as any attempt in which the trachea was not cannulated or which required more than 300 s to perform; and (3) correct landmarking, defined as having the Portex® device inserted *via* the cricothyroid membrane. In this study, the scale was dichotomized to none–mild and moderate–severe injuries. An injury of none–mild severity would likely have little clinical adverse outcomes, whereas a moderate–severe injury could lead to significant adverse outcomes.

Sample Size Calculation

We calculated the sample size based on complication rate as primary outcome. This calculation was based on our pilot cases with the use of ultrasound and review of the literature, to give us an α error of 0.05 and 80% power.[14] A sample size of 21 participants per group was required to detect a 40% absolute difference in the complication rate between digital palpation and ultrasonography-guided techniques assuming a 45% complication rate in the digital palpation (control) group and using the Fisher exact test for the comparison of independent proportions. The sample size was increased by 10% to compensate for potential withdrawals and incompletion. Therefore, a total of 23 and 24 participants were recruited in the digital palpation and ultrasonography group, respectively.

Data Analysis

All the recorded variables were entered into a Microsoft Excel (Microsoft Corp., USA) spreadsheet and were analyzed using SAS version 9.01 (SAS Institute, Inc., USA) statistical software. Descriptive statistics including measures of central tendency, dispersion, and 95% CIs were calculated. We reported relative risk (RR) to compare injuries between the two groups. This is a randomized, controlled trial where the exposure precedes the outcome. It is therefore preferable to refer to the risk of an event occurring given exposure (and thus RR as a ratio of risks). The independent-samples Student *t* test and Fisher exact test were used to compare group means. Categorical data including injuries were compared using chi-square test. A two-tailed *P* value of less than 0.05 was considered statistically significant for all analyses.

Results

We enrolled 47 participants who completed the training and procedural assessments: 23 procedures under digital palpation group and 24 under ultrasonography group (fig. 1). Although the participants included anesthesia residents and clinical anesthesia fellows, the distribution of residents at different training level (first year through fifth year in the residency program) and fellows was similar among groups ($P = 0.70$). We analyzed 39 procedures performed by residents and 8 by fellows. The cadavers' sex, 28 (59.6%) feminine and 19 (40.4%) masculine, was equally distributed among groups ($P = 0.14$). The anatomical difficulty represented by the cadaver's neck circumference (overall mean [SD] 21.45 [1.82] cm; $P = 0.72$) and grading system (overall grade 2, 3, and 4: 20, 16, and 11; $P = 0.70$) was also similar among study groups. Table 1 demonstrates the characteristics of participants and human cadavers, that is, sex, level of training of residents, cadavers' sex, grade, and neck size.

The cricothyrotomy outcomes between digital palpation and ultrasonography groups are presented in table 2. The incidence of moderate–severe injury rate was almost three times greater in the digital palpation group than in the ultrasonography group (17 of 23 = 74% *vs.* 6 of 24 = 25.0%; $P = 0.001$) with an RR of 2.88 (95% CI, 1.39 to 5.94). The frequency of distribution for injuries according to original grade classification is presented in table 3.

The mean (SD) insertion time in the ultrasonography group was significantly longer than that in the digital palpation group (196.1 s [60.6 s] *vs.* 110.5 s [46.9 s]; $P < 0.001$). The majority of participants in both groups inserted the Portex® device on the first attempt with nonsignificant difference (digital palpation: 20 of 23 = 87% *vs.* ultrasound: 19 of 24 = 79%; $P = 0.701$). However, a greater, but not significant, number of participants in the ultrasonography group, compared with the digital palpation group, inserted the device correctly *via* the cricothyroid membrane (15 of 24 = 63 *vs.* 9 of 23 = 39%; $P = 0.148$).

When cricothyrotomy procedures were stratified to cadaver subjects with grade 3 (difficult) and grade 4 (impossible) landmarks, ultrasonography guided, compared with digital palpation, increased the probability of correct device insertion by 5.6 times ($P = 0.043$) and significantly reduced the incidence of moderate–severe injuries by three-fold (ultrasound group 5 of 15 = 33.3% *vs.* digital palpation group 12 of 12 = 100%; $P < 0.001$; table 4).

Discussion

This study aimed to assess the impact of ultrasonographic identification of the cricothyroid membrane on cricothyrotomies performed on human cadavers. The most significant findings of our study demonstrate that ultrasonography compared with conventional digital palpation increased the probability of correct insertion of the Portex® cricothyrotomy device *via* the cricothyroid membrane by 5.6 times

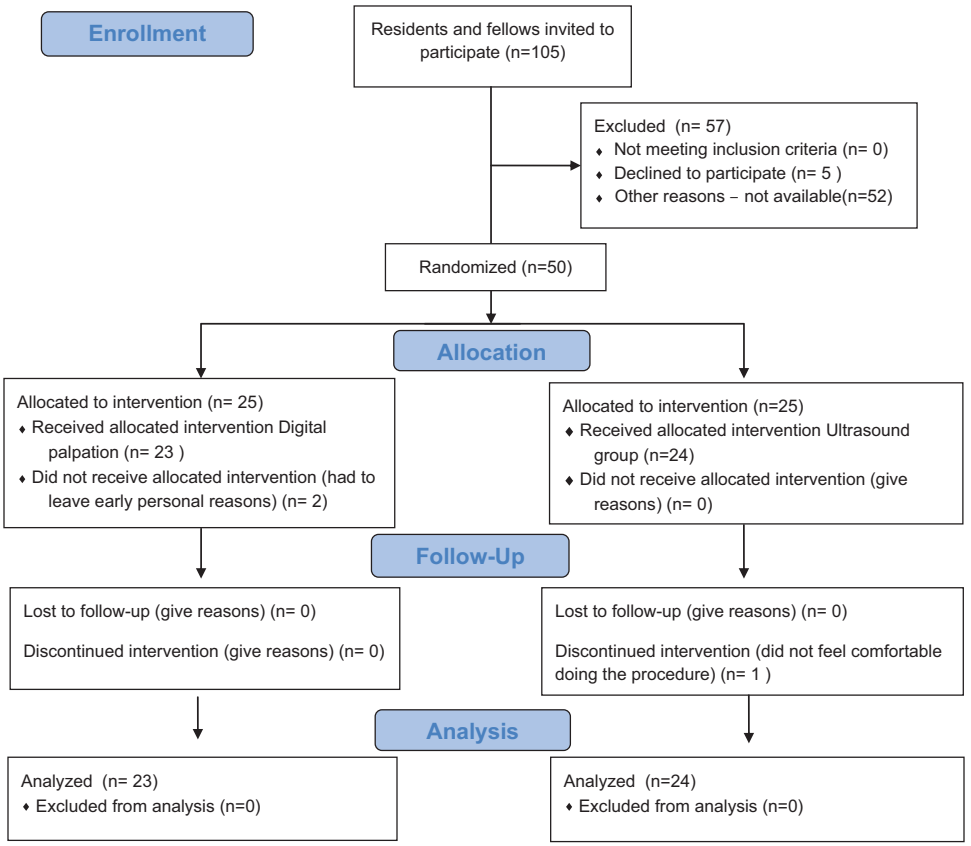


Fig. 1. Consolidated Standards of Reporting Trials (CONSORT) flow diagram (www.consort-statement.org) for patient participation.

and decreased the incidence of moderate–severe injuries by three-fold in cadavers with difficult or impossible to palpate anatomical landmarks. These results imply that ultrasound-guided identification of cricothyroid membrane significantly improves the success rate and decreases the severity of injuries in performing cricothyrotomy with the Portex® device on human cadavers.

The accurate identification of the cricothyroid membrane plays a crucial role when performing a surgical cricothyrotomy for correctly inserting the airway device *via* the

Table 1. Characteristics of Participants and Human Cadavers

Characteristics	Overall (n = 47)	Digital Palpation (n = 23)	Ultrasound (n = 24)	*P* Value*
Level, n (%)				0.709
PGY-1	11 (23.4)	4 (17.4)	7 (29.2)	
PGY-2	11 (23.4)	7 (30.4)	4 (16.7)	
PGY-3	6 (12.8)	4 (17.4)	2 (8.3)	
PGY-4	5 (10.6)	2 (8.7)	3 (12.5)	
PGY-5	6 (12.8)	2 (8.7)	4 (16.7)	
Fellows	8 (17.0)	4 (17.4)	4 (16.7)	
Sex of cadaver				0.143
Female	28 (59.6)	11 (47.8)	17 (70.8)	
Male	19 (40.4)	12 (52.2)	7 (29.2)	
Neck circumference, mean (SD)	21.45 (1.82)	21.35 (1.92)	21.54 (1.74)	0.719
Landmark grade				0.699
Grade 2	20 (42.6)	11 (47.8)	9 (37.5)	
Grade 3	16 (34.0)	8 (34.8)	8 (33.3)	
Grade 4	11 (23.4)	4 (17.4)	7 (29.2)	

All respondents reported training on Portex® (Smiths Medical, USA) and ultrasound.

* Fisher exact test for categorical characteristics and Student *t* test for continuous factors.

PGY = postgraduate year.

Table 2. Comparison of Cricothyrotomy Outcomes between Digital Palpation and Ultrasound Group

Characteristics	Overall (n = 47)	Digital Palpation (n = 23)	Ultrasound (n = 24)	*P* Value*	RR (95% CI)†
Number of attempts				0.701	0.91 (0.12–2.72) (RR for one attempt)
1	39 (83.0)	20 (87.0)	19 (79.2)		
2	8 (17.0)	3 (13.0)	5 (20.8)		
Total time (s)				< 0.001	
Mean (SD)	154.21 (69.03)	110.48 (46.94)	196.13 (60.64)		
Median (IQR)	166 (90–192)	95 (69–171)	188.5 (165.5–232.0)		
Correct landmarking, n (%)				0.148	1.60 (0.88–2.90) (for correct landmarking)
Yes	24 (51.1)	9 (39.1)	15 (62.5)		
No	23 (48.9)	14 (60.9)	9 (37.5)		
Injury to larynx or trachea, n (%)				0.001	2.88 (1.39–5.94)
None to mild	24 (51.1)	6 (26.1)	18 (75.0)		
Moderate to severe	23 (48.9)	17 (73.9)	6 (25.0)		

* Fisher exact test for categorical characteristics and Student *t* test for continuous factors. † Ultrasound relative to digital palpation group.
IQR = interquartile range; RR = relative risk.

Table 3. Distribution of Injury to Larynx or Trachea

Injury Grading, n (%)	Overall, n = 47	Digital Palpation, n = 23	Ultrasound, n = 24
None	22 (46.8)	6 (26.1)	16 (66.7)
Mild	2 (4.3)	0 (0.0)	2 (8.3)
Moderate	9 (19.2)	7 (30.4)	2 (8.3)
Severe	14 (29.8)	10 (43.5)	4 (16.7)

Values expressed as frequency counts (%).

Table 4. Cricothyrotomy Outcomes in Cadavers Graded with Grade 3 to 4 Neck Landmarks

	Overall (n = 27)	Digital Palpation (n = 12)	Ultrasound (n = 15)	*P* Value*	RR (95% CI)†
Correct landmarking, n (%)				0.043	5.60 (0.79–39.48) (for making a correct landmark)
Yes	8 (29.6)	1 (8.3)	7 (46.7)		
No	19 (70.4)	11 (91.7)	8 (53.3)		
Injury to larynx or trachea n (%)				< 0.001	‡
None to mild	10 (37.0)	0 (0.0)	10 (66.7)		
Moderate to severe	17 (63.0)	12 (100.0)	5 (33.3)		

* Fisher exact test for categorical characteristics. † Ultrasound relative to digital palpation group. ‡ Cannot calculate an RR here because of zero cell value.
RR = relative risk.

cricothyroid membrane.[5] The fourth National Audit Project on major airway complications reveals that 15 (52%) of the total 29 attempted cricothyrotomies resulted in failure. Of the 25 attempts made by anesthesiologists to establish an emergency surgical airway, only 9 (36%) were successful.[7] Device misplacement was reported as one of the most common errors resulting in failed cricothyrotomies. The findings in this study suggest that ultrasound-guided identification of cricothyroid membrane may improve correct device insertion and successful cricothyrotomy.

The updated American Society of Anesthesiologist Difficult Airway Algorithm has introduced an additional category of patients with possible difficult surgical airway access.[14] Although the specifics of this group of patients were not described, patients with large body mass index (BMI), previous radiation exposure, neck surgery, neck tumors, and large tissue flaps could potentially create a challenge for identifying landmarks for cricothyroid membrane localization. In this study, we had a subcohort of 27 cadavers with difficult or impossible to palpate landmarks due to various factors such as obesity and short necks. Eisma *et al.*[15] have demonstrated that formalin treatment of cadavers leads to distortion of skin and tissue and thus hampering tactile feedback for identifying anatomical landmarks. In the remaining 20 cadavers, the landmarks were superficially palpable.

The incidence rate of correctly inserting the Portex® device *via* the cricothyroid membrane in all cadavers studied was 62.5 and 39.1% by digital palpation and ultrasound, respectively. However, when stratified by the cadavers with difficult and impossible landmarks, conventional digital palpation resulted in only 8.3% of correct device insertion. In contrast, ultrasound guidance significantly increased correct device insertion by almost six-fold to 46.7%. Our findings are consistent with the literature showing that conventional digital palpation was inaccurate in identifying the cricothyroid membrane. Elliott *et al.*[16] demonstrated that only 30% of digital palpation by anesthesiologists correctly identified the cricothyroid membrane of patients with various BMI. Furthermore, Aslani *et al.*[17] highlighted inaccurate identification of the cricothyroid membrane in 14 of 15 obese patients (BMI > 30 kg/m^2). There is evidence that increased pretracheal soft tissue and greater neck circumference can be associated with difficult laryngoscopy.[18] These features could potentially lead to difficult palpable landmarks similar to the cadavers in our study.

Cricothyrotomies have been shown to lead to major complications such as esophageal perforation, subcutaneous emphysema, and hemorrhage due to improper device insertion.[3] In this study, 15 cadavers had difficult or impossible neck landmarks, and the incidence rate of moderate–severe injuries using ultrasound-guided cricothyrotomy was only 33%. This was statistically significant when compared with the 100% incidence of moderate–severe injuries in the 12 cadavers of the digital palpation group.

The mean (SD) insertion time in the ultrasound group (196.1 [60.6]) was significantly longer than that in the digital palpation group (110.5 [46.9]). A possible explanation might be that the ultrasound group participants were novices at the technique for ultrasound-guided identification of the cricothyroid membrane. In addition, they only had one didactic and hands-on teaching session. A study performed by Nicholls *et al.*[12] demonstrated a mean time of less than 30 s (24.3 s [20.2 s]) to visualize the cricothyroid membrane using ultrasound on patients with a variety of neck circumference and BMI. The physician participants in the study by Nicholls *et al.* who scanned the patients were not formally trained in this technique but regularly attended monthly didactic ultrasound teaching sessions and used ultrasound in their daily practice. Thus, it can be suggested that with routine practice and teaching, there may be room for improvement in this technique. An interesting finding of this previous study was the shorter time to visualization of the cricothyroid membrane in patients with higher BMI and difficult palpable neck landmarks. The justification suggested by these authors was similar to that provided by Aslani *et al.*.[17]; that is, the additional tissue overlying the membrane could improve focus of the ultrasound beam to provide a better postimage acquisition resolution.

This study has some limitations. Percutaneous cricothyrotomy can be performed using a variety of techniques. In this study, we used only the trocar-over-needle technique with the Portex® device, which appears to be more traumatic than other surgical airway techniques such as the Seldinger or scapel.[13] Future studies comparing ultrasound guided *versus* conventional digital palpation on cricothyrotomy performances using different techniques merit further research. The formalin-fixed cadavers used in this study have firm pallid tissues, are not pliable, and do not reflect normal tissue handling characteristics. These changes could have made digital palpation of landmarks more difficult and challenging in comparison with ultrasound guidance. Fresh cadavers with normal tissue characteristics are ideal models for research; however, they are not readily available and cannot be preserved for longer duration. The limited sample size prevented potentially important findings, such as the greater than 20% difference in correct landmarking that could not be concluded as statistically different. Although this difference was large and probably clinically relevant, sample size was not large enough to be conclusive. It may be argued that, in a cohort of patients with difficult palpable landmarks, ultrasound guidance may lead to faster localization, increased accuracy, and less injuries when performing a cricothyrotomy in an emergency situation. It should be emphasized that we are not proposing to use of ultrasound guidance of the cricothyroid membrane in emergency airway crisis situations but rather to localize the cricothyroid membrane before airway management in patients with difficult airways and neck anatomy landmarks that are not well defined.

In conclusion, ultrasound guidance of the cricothyroid membrane improves correct device insertion and reduces the severity of injuries when performing cricothyrotomy using the Portex® device on human cadavers. We propose that ultrasound guidance of the cricothyroid membrane and neck landmarks should be performed before airway management, particularly in patients with difficult palpable neck landmarks and difficult airways. There may be scope for studies in real-life patients who present with risk factors for accessing the cricothyroid membrane in an emergency although there might be challenges for adequately powering the study and an ethical aspect.

Acknowledgments

Support was provided solely from institutional and/or departmental sources.

Competing Interests

The authors declare no competing interests.

Reproducible Science

Raw data and full protocol are not available.

Correspondence

Address correspondence to Dr. Siddiqui: Department of Anesthesia and Pain Management, Mount Sinai Hospital, University of Toronto, 600 University Avenue, Toronto M5G1X5, Ontario, Canada. naveed.siddiqui@uhn.ca. This article may

References

1. Caplan RA, Posner KL, Ward RJ, Cheney FW: Adverse respiratory events in anesthesia: A closed claims analysis. Anesthesiology 1990; 72:828–33
2. Domino KB, Posner KL, Caplan RA, Cheney FW: Airway injury during anesthesia: A closed claims analysis. Anesthesiology 1999; 91:1703–11
3. Mori M, Fujimoto J, Iwasaka H, Noguchi T: Emergency percutaneous dilatational cricothyroidotomy after failed intubation. Anaesth Intensive Care 2002; 30:101–2
4. Griggs WM, Myburgh JA, Worthley LI: Urgent airway access—An indication for percutaneous tracheostomy? Anaesth Intensive Care 1991; 19:586–7
5. Bair AE, Panacek EA, Wisner DH, Bales R, Sakles JC: Cricothyrotomy: A 5-year experience at one institution. J Emerg Med 2003; 24:151–6
6. McGill J, Clinton JE, Ruiz E: Cricothyrotomy in the emergency department. Ann Emerg Med 1982; 11:361–4
7. Cook TM, Woodall N, Frerk C; Fourth National Audit Project: Major complications of airway management in the UK: Results of the Fourth National Audit Project of the Royal College of Anaesthetists and the Difficult Airway Society. Part 1: Anaesthesia. Br J Anaesth 2011; 106:617–31
8. Shibasaki M, Nakajima Y, Ishii S, Shimizu F, Shime N, Sessler DI: Prediction of pediatric endotracheal tube size by ultrasonography. Anesthesiology 2010; 113:819–24
9. Erlandson MJ, Clinton JE, Ruiz E, Cohen J: Cricothyrotomy in the emergency department revisited. J Emerg Med 1989; 7:115–8
10. Kristensen MS: Ultrasonography in the management of the airway. Acta Anaesthesiol Scand 2011; 55:1155–73
11. Sustić A, Zupan Z, Antoncić I: Ultrasound-guided percutaneous dilatational tracheostomy with laryngeal mask airway control in a morbidly obese patient. J Clin Anesth 2004; 16:121–3
12. Nicholls SE, Sweeney TW, Ferre RM, Strout TD: Bedside sonography by emergency physicians for the rapid identification of landmarks relevant to cricothyrotomy. Am J Emerg Med 2008; 26:852–6
13. Murphy C, Rooney SJ, Maharaj CH, Laffey JG, Harte BH: Comparison of three cuffed emergency percutaneous cricothyroidotomy devices to conventional surgical cricothyroidotomy in a porcine model. Br J Anaesth 2011; 106:57–64
14. Apfelbaum JL, Hagberg CA, Caplan RA, Blitt CD, Connis RT, Nickinovich DG, Hagberg CA, Caplan RA, Benumof JL, Berry FA, Blitt CD, Bode RH, Cheney FW, Connis RT, Guidry OF, Nickinovich DG, Ovassapian A; American Society of Anesthesiologists Task Force on Management of the Difficult Airway: Practice guidelines for management of the difficult airway: An updated report by the American Society of Anesthesiologists Task Force on Management of the Difficult Airway. Anesthesiology 2013; 118:251–70
15. Eisma R, Mahendran S, Majumdar S, Smith D, Soames RW: A comparison of Thiel and formalin embalmed cadavers for thyroid surgery training. Surgeon 2011; 9:142–6
16. Elliott DS, Baker PA, Scott MR, Birch CW, Thompson JM: Accuracy of surface landmark identification for cannula cricothyroidotomy. Anaesthesia 2010; 65:889–94
17. Aslani A, Ng SC, Hurley M, McCarthy KF, McNicholas M, McCaul CL: Accuracy of identification of the cricothyroid membrane in female subjects using palpation: An observational study. Anesth Analg 2012; 114:987–92
18. Ezri T, Gewürtz G, Sessler DI, Medalion B, Szmuk P, Hagberg C, Susmallian S: Prediction of difficult laryngoscopy in obese patients by ultrasound quantification of anterior neck soft tissue. Anaesthesia 2003; 58:1111–4

Appendix: CONSORT Checklist

Section/Topic	Item No.	Checklist Item	Reported on Page No.
Title and abstract			
	1a	Identification as a randomized trial in the title	1
	1b	Structured summary of trial design, methods, results, and conclusions (for specific guidance, see CONSORT for abstracts)	1
Introduction			
Background and objectives	2a	Scientific background and explanation of rationale	2
	2b	Specific objectives or hypotheses	2
Methods			
Trial design	3a	Description of trial design (such as parallel or factorial) including allocation ratio	2
	3b	Important changes to methods after trial commencement (such as eligibility criteria), with reasons	2,3
Participants	4a	Eligibility criteria for participants	2
	4b	Settings and locations where the data were collected	2
Interventions	5	The interventions for each group with sufficient details to allow replication, including how and when they were actually administered	2,3
Outcomes	6a	Completely defined prespecified primary and secondary outcome measures, including how and when they were assessed	2,3
	6b	Any changes to trial outcomes after the trial commenced, with reasons	None
Sample size	7a	How sample size was determined	3
	7b	When applicable, explanation of any interim analyses and stopping guidelines	N/A
Randomization			
Sequence generation	8a	Method used to generate the random allocation sequence	2
	8b	Type of randomization; details of any restriction (such as blocking and block size)	2
Allocation concealment mechanism	9	Mechanism used to implement the random allocation sequence (such as sequentially numbered containers), describing any steps taken to conceal the sequence until interventions were assigned	2,3
Implementation	10	Who generated the random allocation sequence, who enrolled participants, and who assigned participants to interventions	3
Blinding	11a	If done, who was blinded after assignment to interventions (*e.g.*, participants, care providers, and those assessing outcomes) and how	3
	11b	If relevant, description of the similarity of interventions	Nil
Statistical methods	12a	Statistical methods used to compare groups for primary and secondary outcomes	3
	12b	Methods for additional analyses, such as subgroup analyses and adjusted analyses	3
Results			
Participant flow (a diagram is strongly recommended)	13a	For each group, the numbers of participants who were randomly assigned, received intended treatment, and were analyzed for the primary outcome	Flow diagram figure 1
	13b	For each group, losses and exclusions after randomization, together with reasons	Flow diagram figure 1
Recruitment	14a	Dates defining the periods of recruitment and follow-up	3
	14b	Why the trial ended or was stopped	3
Baseline data	15	A table showing baseline demographic and clinical characteristics for each group	Table 1
Numbers analyzed	16	For each group, number of participants (denominator) included in each analysis and whether the analysis was by original assigned groups	3
Outcomes and estimation	17a	For each primary and secondary outcome, results for each group, and the estimated effect size and its precision (such as 95% CI)	3
	17b	For binary outcomes, presentation of both absolute and relative effect sizes is recommended	3
Ancillary analyses	18	Results of any other analyses performed, including subgroup analyses and adjusted analyses, distinguishing prespecified from exploratory	3
Harms	19	All important harms or unintended effects in each group (for specific guidance, see CONSORT for harms)	None (cadaver study)

(*Continued*)

Appendix: (*Continued*)

Section/Topic	Item No.	Checklist Item	Reported on Page No.
Discussion			
Limitations	20	Trial limitations, addressing sources of potential bias, imprecision, and, if relevant, multiplicity of analyses	6
Generalizability	21	Generalizability (external validity, applicability) of the trial findings	3–6
Interpretation	22	Interpretation consistent with results, balancing benefits and harms, and considering other relevant evidence	3–6
Other information			
Registration	23	Registration number and name of trial registry	2
Protocol	24	Where the full trial protocol can be accessed, if available	2
Funding	25	Sources of funding and other support (such as supply of drugs), role of funders	6

Available at: www.consort-statement.org. Accessed July 14, 2015.

CONSORT = Consolidated Standards of Reporting Trials.