Practice of Ultrasound-Guided Palpation of Neck Landmarks Improves Accuracy of External Palpation of the Cricothyroid Membrane

Kong Eric You-Ten, MD, PhD,*† David T. Wong, MD,*‡ Xiang Y. Ye, Msc,§ Cristian Arzola, MD,*† Atoosa Zand, MD,*† and Naveed Siddiqui, MD, MSc*†

BACKGROUND: Ultrasonography can accurately identify the cricothyroid membrane; however, its impact on the subsequent accuracy of external palpation is not known. In this study, we tested the ability of anesthesia participants to identify the midpoint of the cricothyroid membrane using external palpation with and without ultrasound (US)-guided practice.

METHODS: Following institutional ethics approval and informed consent, anesthesia participants consisting of anesthesia residents, fellows, and practicing anesthesia assistants underwent didactic teaching on neck landmarks. The participants were then randomized to practice palpation of neck landmarks with US guidance (US group) or without ultrasonography (non-US [NUS] group). After the practice session, each participant identified the cricothyroid membrane using external palpation on the neck of 10 volunteers and marked the anticipated entry point for device insertion (palpation point [PT]). The midpoint of the cricothyroid membrane of each volunteer had been premarked with invisible ink using ultrasonography (US point) by a separate member of the research team. The primary outcome was the accuracy rate defined as the percentage of the attempts with the distance ≤5 mm measured from the PT to US point for the participant. The primary outcome was compared between NUS and US groups using Wilcoxon rank sum test. A mixed-effect logistic regression or mixed-effect linear model was also conducted for outcomes accounting for the clustering and adjusting for potential confounders.

RESULTS: Fifteen anesthesia participants were randomized to US (n = 8) and NUS (n = 7) groups. A total of 80 and 61 attempts were performed by the US and NUS groups, respectively. The median accuracy rate in the US group was higher than the NUS group (65% vs 30%; $P = .025$), and the median PT-US distance in the US group was shorter than in the NUS group (4.0 vs 8.0 mm; $P = .04$). The adjusted mean PT-US distance in the US group was shorter compared to the NUS group (adjusted mean [95% CI], 3.6 [2.9–4.6] vs 6.8 [5.2–8.9] mm; $P < .001$).

CONCLUSIONS: Anesthesia participants exposed to practice with US-guided palpation of the cricothyroid membrane location were better able to identify the cricothyroid membrane using only blind palpation than participants without US-guided practice. Practice with US-guided palpation of neck landmarks improves subsequent blind localization of the cricothyroid membrane using palpation alone. (Anesth Analg XXX;XXX:00–00)

KEY POINTS

- **Question:** Does practice with ultrasound-guided palpation of neck landmarks improve the subsequent accuracy of blind localization of the cricothyroid membrane?
- **Findings:** Practice with ultrasound-guided palpation improved the accuracy of localizing the cricothyroid membrane using external palpation alone.
- **Meaning:** Ultrasound-guided palpation practice of neck landmarks improves the subsequent palpation accuracy of the cricothyroid membrane using external palpation.

Accurate localization of the cricothyroid membrane is the first and critical step when performing an emergency cricothyrotomy. Misidentification of the cricothyroid membrane is a major cause of tube misplacements, cricothyrotomy failures, and complications.[1,2] However, external palpation of the cricothyroid membrane by clinicians may be inaccurate, even under elective conditions.[3]

Current evidence suggests that ultrasonography of neck landmarks improves the accuracy of cricothyroid membrane localization.[3–8] Furthermore, when compared to external palpation alone, ultrasonography of the neck of human cadavers increased the success rate of cricothyrotomies and reduced complications.[9] Ultrasonography of the cricothyroid membrane has been suggested before airway manipulation during nonemergency situations in anticipation of difficult airways.[10,11] However, little evidence to date supports ultrasound (US) use during a "can't intubate, can't oxygenate" airway crisis.[12] US use can delay emergency surgical access to the airway. In an airway crisis requiring

From the *Department of Anesthesia and Pain Management and †Mount Sinai Hospital, Sinai Health System, Toronto, Ontario, Canada; ‡Toronto Western Hospital, University Health Network, Toronto, Ontario, Canada; and §Micare Research Centre, Toronto, Ontario, Canada.

Accepted for publication May 21, 2018.

Funding: Departmental.

The authors declare no conflicts of interest.

This report was previously presented in part at the Faculty Education Day, Department of Anesthesia, University of Toronto on November 11, 2016.

Reprints will not be available from the authors.

Address correspondence to Kong Eric You-Ten, MD, PhD, Department of Anesthesia and Pain Management, Mount Sinai Hospital, Sinai Health System, 600 University Ave, Rm 19–104, Toronto, ON M5G 1X5, Canada. Address e-mail to eric.you-ten@sinaihealthsystem.ca.

DOI: 10.1213/ANE.0000000000003604

an emergency cricothyrotomy, external palpation of the cricothyroid membrane remains the standard of practice. Whereas external palpation of the cricothyroid membrane is a blind technique, ultrasonography provides direct visualization of neck landmarks and accurately identifies the cricothyroid membrane.[3–9,12–14]

Currently, little is known about the impact of ultrasonography on the accuracy of external palpation of the cricothyroid membrane. We hypothesized that practice with US-guided palpation of the cricothyroid membrane would improve subsequent blind localization of the cricothyroid membrane without US. To test our hypothesis, we compared the effects of practice with US- and NUS-guided palpation of neck landmarks on the subsequent accuracy of cricothyroid membrane localization using external palpation.

METHODS

Participants and Volunteers

The Mount Sinai Hospital Research Ethics Board (Toronto, ON, Canada) approved the study, and written informed consent was obtained from all participants and volunteers. Participants were anesthesia residents in postgraduate years 1 and 2, anesthesia fellows, and practicing anesthesia assistants from the Department of Anesthesia at Mount Sinai Hospital, Sinai Health System. Volunteer models for cricothyroid membrane localization were males and females ≥18 years of age without a previous history of neck surgery, neck irradiation, and known neck deformity or abnormality. Volunteer demographics (age, weight, height) and neck circumference were recorded.

Teaching Intervention and Randomization

All participants recruited in the study first underwent a 15-minute didactic PowerPoint presentation on the anatomy of the neck, landmarks, and cricothyroid membrane. After the teaching intervention, the participants were randomized to 1 of 2 groups: US or NUS. Randomization was performed by asking each participant to choose blindly a piece of paper from an opaque bag labeled US or NUS.

Practice Session

US Group. After the didactic presentation, participants in the US group practiced US-guided palpation on each other to identify the neck landmarks. Ultrasonography of the neck was performed as previously reported[7,9] using the approach described by Kristensen et al.[12,13] A portable US system with a 10–5 MHz linear-array transducer (Zonare Medical Systems, Inc, Mountain View, CA) was used for the US scans. The participants being scanned were positioned supine with the neck in a neutral position. An instructor experienced in neck US demonstrated the scan using the longitudinal and transverse approaches[3,14] (Figure). Thereafter, participants practiced palpation of the neck landmarks with US guidance. Each participant would palpate and confirm visually with US guidance the neck landmarks, including the tracheal rings, cricoid cartilage, thyroid cartilage, and cricothyroid membrane. Each participant would practice palpation with US guidance until the neck landmarks and cricothyroid membrane were correctly localized in ≥5 attempts. The total duration of the practice session was 1 hour.

NUS Group. After the didactic presentation, participants in the NUS group practiced on each other to palpate the neck landmarks and cricothyroid membrane without the use of ultrasonography. Each participant practiced palpating the neck landmarks and cricothyroid membrane until their ability to localize the neck landmarks and cricothyroid membrane was confirmed a minimum of 5 times by a staff anesthesiologist using external palpation. The duration of this practice session was 1 hour. US was not used during this period to confirm localization of the cricothyroid membrane.

Assessment

After the practice interventions, each participant in both groups was asked to identify the cricothyroid membrane of 10 healthy volunteers using external palpation and to mark the anticipated entry point (palpation point [PT]) of a cricothyrotomy device using a water-soluble marker. The volunteers were in a supine position with the neck in a neutral position. Before the assessment, a study investigator trained in upper airway US scanned the neck of each volunteer with ultrasonography in the longitudinal and transverse axes. The midpoint of the longitudinal axis of the cricothyroid membrane was identified and premarked with an alcohol-erasable ultraviolet invisible marker (US point). The PT point marked with a water-soluble marker was erased with a wet towel after each assessment was measured. The US point marked with an alcohol-erasable marker was not erased by the wet towel.

Outcome Measures

The primary outcome was the accuracy rate of localization for each participant, defined as the number of attempts with distance ≤5 mm[15,16] from the PT to US point divided by the total number of attempts by the participant expressed as a percentage. Secondary outcomes were (1) the PT-US distance defined as the median of the PT-US distances for the participant, (2) the accuracy rate at attempt level defined as the PT-US distance ≤5 mm at the attempt, and (3) the PT-US distance (mm) at attempt level. The outcomes at attempt level were outcomes measured at each attempt, whereas the outcomes at participant level were outcomes measured for all attempts of a participant.

Statistical Analysis

Data Analysis. The study population was summarized. Participant characteristics were compared descriptively between NUS and US groups. Accuracy rate and PT-US distance at participant level were compared between the 2 groups using Wilcoxon rank sum test. To compare the accuracy or PT-US distance at attempt level between the 2 groups, a mixed-effect logistic regression model or mixed-effect linear model was conducted, adjusting for volunteers' age, gender, body mass index, and neck circumference and participants' level of clinical experience and previous airway US training. To account for the clustering within each volunteer and participant, the compound symmetric and autoregressive (AR(1)) covariance structures were applied, respectively. The odds ratios for binary outcome (or means for continuous one) were determined based on the final model derived by backward variables selection procedures

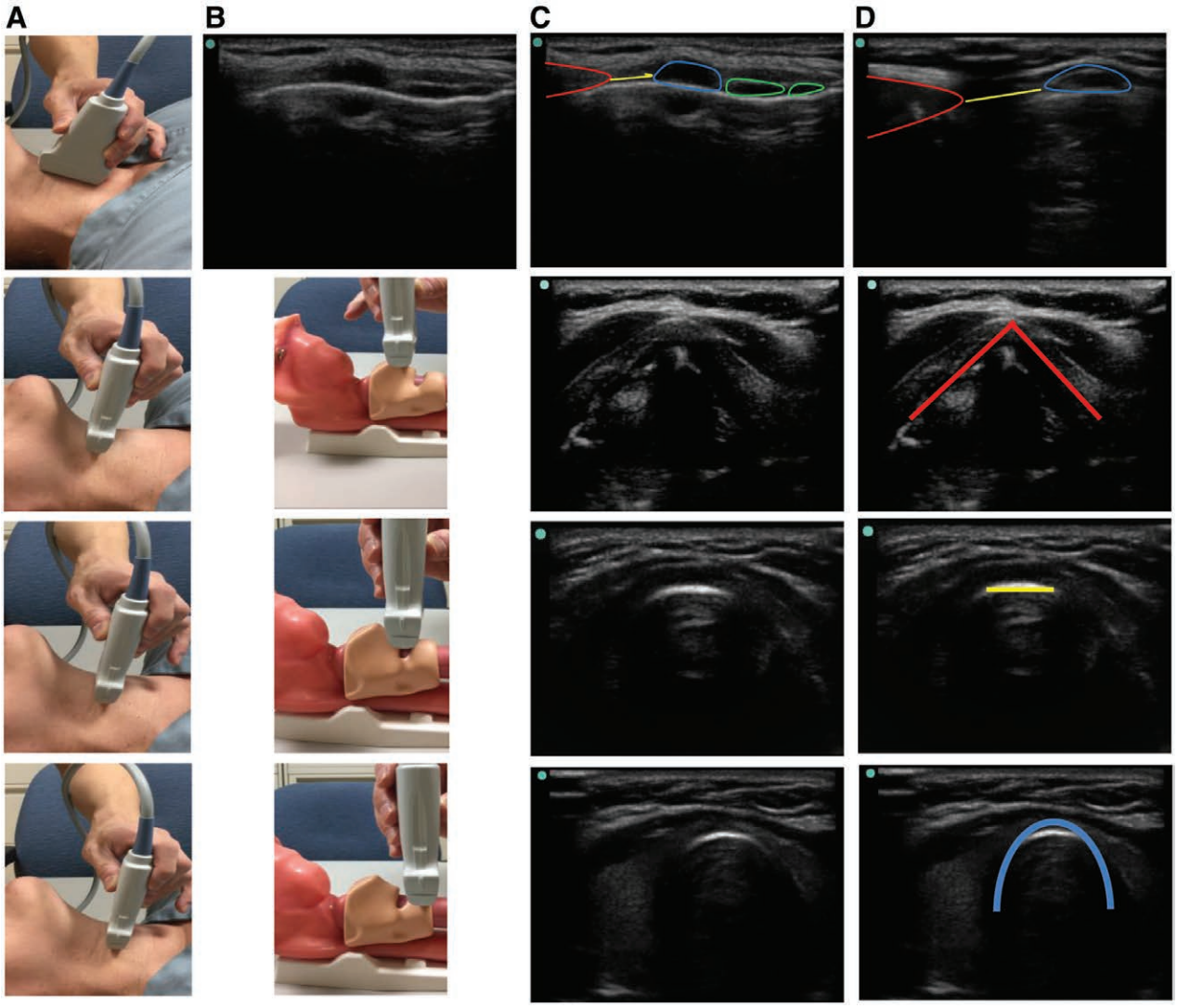

Figure. Ultrasound (US) identification of neck landmarks. First row: Longitudinal view of neck landmarks. Column A, The US probe was placed on the longitudinal axis in the midline of a volunteer's neck with the probe indicator in the cephalad position. Column B, The US image showing the cartilages as hypoechoic structures. The white hyperechoic line is the tissue-air artifact with the lumen of the trachea below as reverberation artifacts. Column C, The US image depicting the thyroid cartilage (in red), cricothyroid membrane (in yellow), cricoid cartilage (in blue), and tracheal rings (in green). The cricoid cartilage (in blue) is identified as an anterior and a larger hypoechoic structure compared to the tracheal rings (in green). Column D, A straightened paper clip was slid cephalad to caudal between the probe and the neck. The paper clip produces a hypoechoic shadow over the cricothyroid membrane (in yellow) located between the thyroid cartilage (in red) and cricoid cartilage (in blue). Second row: Transverse view of thyroid cartilage. Columns A and B, The US probe was placed over the thyroid cartilage in the transverse axis on the volunteer's neck and on the plastic neck model. Columns C and D, US images showing the thyroid cartilage as a hypoechoic triangle-shaped structure outlined in red. Third row: Transverse view of the cricothyroid membrane. Columns A and B, The US probe was moved caudally below the thyroid cartilage in the transverse axis until the cricothyroid membrane was identified on the volunteer's neck and on the plastic model. Columns C and D, US images showing the cricothyroid membrane as a hyperechoic tissue-air line artifact outlined in yellow. Fourth row: Transverse view of the cricoid cartilage. Columns A and B, The US probe was moved caudally below the cricothyroid membrane in the transverse axis until the cricoid cartilage was identified on the volunteer's neck and on the plastic neck model. Columns C and D, US images showing the cricoid cartilage as a hypoechoic horseshoe structure outlined in blue.

with stay criterion of $P < .05$. The data management and all statistical analyses were performed using SAS 9.4 (SAS Institute, Inc, Cary, NC). A 2-sided P value of <.05 was used to determine statistical significance.

Sample Size Calculation. Sample size calculation was based on our primary outcome. From our previous study,[7] the successful palpation rate was 71% in nonobese female volunteers. Therefore, we assumed the mean primary outcome of 0.7 in the palpation (NUS) group and expected that US practice would improve the mean primary outcome to 0.91 (a relative 30% increase). We estimated that 15 participants (8 for US and 7 for NUS group) would achieve ≥80% power to detect the difference of 0.21 (0.7 × 30%) in the primary outcome between the 2 groups (US versus NUS), with a pooled standard deviation of 1.2 at the significance level of .05. The Wilcoxon rank sum test was used to estimate the sample size[17,18] using 300 Monte Carlo samples from assumed normal distributions (PASS software, NCSS LLC, www.ncss.com).

RESULTS

Fifteen anesthesia participants were randomized to US (n = 8) and NUS (n = 7) groups. After palpation practice, each participant from both groups was assessed for localization of the cricothyroid membrane using external palpation on the necks of 10 healthy volunteers for a total of 10 attempts each. Thus, the US group (n = 8) made 80 palpation attempts. Due to scheduling conflicts, 2 participants in the NUS group (n = 7) palpated the necks of 5 and 6 volunteers each, resulting in 61 attempts in the NUS group.

Table 1 showed the characteristics of the participants for the level of clinical anesthesia and airway US experience. Eighteen adult volunteers were recruited in the study (Table 1). Sixteen were female and 2 were male. The age, body mass index, and neck circumference (mean ± standard deviation) of the volunteers were 48.2 ± 8.0, 27.3 ± 4.8, and 35.2 ± 4.1, respectively.

Accuracy and distance results are shown in Table 2. The median accuracy rate in the US group was higher compared to the NUS group (65% vs 30%; $P = .025$), and the median PT-US distance in the US group was shorter compared to the NUS group (4.0 vs 8.0 mm; $P = .043$). Furthermore, analyses of the outcomes at attempt level showed that the adjusted odds of accuracy rate was 5 times greater (adjusted odds ratio [95% CI], 5.01 [2.64–9.49]), and the mean PT-US distance was shorter (adjusted mean [95% CI], 3.6 [2.9–4.6] vs 6.8 [5.2–8.9] mm; $P < .001$) in the US compared to the NUS group.

Table 1. Characteristics of Participants and Volunteers

	NUS Group (N = 7)	US Group (N = 8)
Participants' characteristics		
Clinical experience		
Anesthesia assistant	1	1
Postgraduate year 1 resident	1	0
Postgraduate year 2 resident	1	2
Anesthesia fellow	4	5
Previous session in airway US training	3	2
Volunteers' characteristics		
Total number	18	
Female (n)	16	
Age[a] (y)	48.3 ± 8.9	
Body mass index[a] (kg·m^{-2})	27.3 ± 4.8	
Neck circumference[a] (cm)	35.2 ± 4.1	

Abbreviations: NUS, non-ultrasound; US, ultrasound.
[a]Data are presented as mean ± standard deviation.

DISCUSSION

In this prospective randomized trial, we found that anesthesia participants who practiced US-guided palpation of neck landmarks were more accurate in subsequently localizing the cricothyroid membrane without US than participants practicing without US guidance. These findings suggest that practicing US-guided cricothyroid membrane palpation improves the ability to identify the cricothyroid membrane without US assistance.

Our results are congruent with limited studies showing the advantage of US as an adjunct teaching tool in palpation accuracy.[19–21] Medical students learning to palpate liver size with the addition of US, compared to those without US, demonstrated greater accuracy in measuring liver size using palpation.[19] Ahn et al[20] reported that medical students taught with US supplementing traditional physical examination palpated the femoral artery more accurately than those taught without US. A recent study of physiatry residents showed improved accuracy of palpation of the long head of the biceps tendon in the bicipital groove after palpation practice with US.[21] Our findings add further to current literature that palpation practice of the cricothyroid membrane with US guidance enhances palpation accuracy. This finding might have important implications in an emergency cricothyrotomy, where accurate cricothyroid membrane location is critical to the success of this procedure.[1,2]

Accurate identification of the cricothyroid membrane using external palpation is often more difficult than anticipated, even under elective conditions.[4–8] This study found

Table 2. Comparison of Outcomes Between US and NUS Groups

	Outcome at Participant Level			
	NUS (n = 7)	US (n = 8)	*P* Value	Differences (95% CI)[a] US Versus NUS Group
Accuracy rate (%), median (quartiles)	30 (20–40)	65 (50–80)	.025[b]	35 (16.6–63.5)
PT-US distance (mm), median (quartiles)	8.0 (7.5–11.0)	4.0 (3.5–5.8)	.043[b]	−4.0 (−6.9 to −1.1)
	Outcome at Attempt Level			
	NUS (Attempts = 61)	US (Attempts = 80)		Adjusted Ratio[c] (95% CI) US Versus NUS Group
PT-US distance (mm), mean (95% CI)	6.8 (5.2–8.9)	3.6 (2.9–4.6)	<.001[d]	0.48 (0.34–0.69)
	NUS (Attempts = 61)	US (Attempts = 80)		Adjusted OR[c] (95% CI) US Versus NUS Group
Accuracy rate, % (95% CI)	34.4 (21.1–47.7)	65.0 (52.0–78.0)	<.001[d]	5.01 (2.64–9.49)

Outcomes at participant level were measured for all attempts of a participant. Outcomes at attempt level were measured at each attempt.
Abbreviations: NUS, non-ultrasound; PT, palpation point; US, ultrasound.
[a]Differences between the US and NUS groups were estimated using quartile regression.
[b]The *P* values were based on the comparison between the 2 groups using Wilcoxon rank sum test. The *P* values based on Mood's median test were .015 and .006, respectively.
[c]Adjusted ratio: adjusted ratio of the mean PT distance (US versus NUS). Adjusted OR: adjusted odds ratio of accuracy rate between US and NUS group. Both adjusted measures were based on the models mentioned previously adjusted for participant training level and previous airway US training.
[d]The outcome measures were based on the mixed-effect generalized linear models, taking into account both the clustering within volunteer and participant.

that the cricothyroid membrane accuracy rate in the NUS group was 30% in the predominantly female volunteers (n = 16/18). Our findings are in keeping with other investigators.[5,6,22,23] Lamb et al[6] also demonstrated a success rate of 29.7% by anesthesiologist staff and trainees in female volunteers. In another study, Aslani et al[5] reported success rates of 24.4% and 29.3% in nonobese women with the neck placed in the neutral and extended positions, respectively. Furthermore, trauma surgeons with experience in surgical airways had a similar success rate of 26% in female volunteers.[22,23]

We defined "accurate" identification of the cricothyroid membrane as ≤5 mm of the US-identified midpoint of the cricothyroid membrane. This value was based on the known dimensions of the cricothyroid membrane in cadavers with an average horizontal width of 8.2 mm with an upper limit of 11.0 mm and an average vertical height of 10.4 mm with an upper limit of 13.0 mm.[15] This value is based on empirical data[6,15] and is clinically relevant because a puncture within this limit is likely to occur at the recommended site of placement of cricothyrotomy devices to avoid injuries to the vocal cords.[16]

Participants in the US group practiced palpation with US guidance to directly visualize and confirm neck landmarks, including the tracheal rings, thyroid cartilage, cricoid cartilage, and cricothyroid membrane. US-guided palpation training facilitates visual and tactile feedback of underlying neck landmarks that improves the accuracy of localizing the cricothyroid membrane with external palpation.

In our study, we recruited mostly female volunteers (n = 16/18) because females, compared to males, have less prominent neck landmarks. A more prominent thyroid cartilage in males makes the cricothyroid membrane easier to localize by palpation.[6,24] We also excluded volunteers with easy landmarks who were predominantly males because the greater ease of blind palpation in male volunteers with easy landmarks may have negated the impact of US-guided palpation practice.

There is an increasing role of ultrasonography in airway management.[14] Several difficult airway guidelines advocate the use of preprocedure US to identify the neck landmarks and cricothyroid membrane in nonemergency situations before airway manipulation in patients with difficult airways.[10,11] However, evidence on the role of ultrasonography in emergent surgical airway management is lacking because preparation of the US equipment can delay an emergent cricothyrotomy. Correctly and rapidly identifying the cricothyroid membrane with external palpation is the first critical step to performing a cricothyrotomy in a "can't intubate, can't oxygenate" situation. Our findings suggest a potential role of ultrasonography in improving the accuracy of external palpation. We found that practicing palpation of the neck landmarks with US guidance improves the localization of the cricothyroid membrane using external palpation in an emergency surgical airway. Moreover, in light of the evidence of a high failure rate of the needle technique,[25] an open cricothyrotomy with a vertical incision is recommended.[11] The size of the incision depends on the operator's accuracy of the neck landmarks and the patient's neck anatomy. An accurate localization of the cricothyroid membrane might lead to a smaller incision size with less bleeding and complications. The training for US identification of the cricothyroid membrane is relatively short,[26] and ultrasonography should be considered in palpation practice of the neck landmarks to localize the cricothyroid membrane.

Our study has several limitations. Palpation practice in the NUS group was conducted without US guidance. It is possible that due to the inaccuracies of blind palpation, the instructors did not always accurately identify the cricothyroid membrane during practice. In contrast to the US group, accuracy to localize the cricothyroid membrane was not confirmed during palpation practice in the NUS group, and the NUS group may only have located the cricothyroid membrane ≤50%[5,6,22] of the time during practice. However, palpation practice without US guidance is the current standard in localizing the cricothyroid membrane. The midpoint of the cricothyroid membrane was premarked with an invisible ultraviolet marker on volunteers in the neutral neck position. Location of the cricothyroid membrane is variable depending on the position of the neck.[5] A less than ideal neutral neck position could have affected the accuracy of the cricothyroid membrane. However, a donut-shaped pillow was used to minimize head movement and maintain the neck in a neutral position. Assessment of the participants was performed on the same day after the practice sessions. However, we did not assess for retention of skills at different time intervals. The scheduling of having both the same participants and volunteers at another time interval was a significant limitation to study the retention of skills. The assessment was performed on normal necks, and therefore our findings may not be extrapolated to the general population or in patients with distorted neck anatomy, including previous neck surgery, irradiation, and/or neck mass.

In conclusion, anesthesia participants practicing US-guided compared to NUS-guided palpation of the neck landmarks more accurately identified the cricothyroid membrane using external palpation. US-guided palpation practice of neck landmarks improves subsequent accuracy of localizing the cricothyroid membrane of human subjects using external palpation. Ultrasonography should be considered in the training of airway management, particularly when teaching external palpation of the neck landmarks to localize the cricothyroid membrane.

ACKNOWLEDGMENTS

The authors thank the anesthesia residents, anesthesia fellows, anesthesia assistants, and adult volunteers who participated in the study.

DISCLOSURES

Name: Kong Eric You-Ten, MD, PhD.
Contribution: This author helped design the study, conduct the study, analyze the data, and write and compose the manuscript.
Name: David T. Wong, MD.
Contribution: This author helped design the study, conduct the study, analyze the data, and write and compose the manuscript.
Name: Xiang Y. Ye, Msc.
Contribution: This author helped analyze the data, and write and compose the manuscript.
Name: Cristian Arzola, MD.
Contribution: This author helped design the study, conduct the study, analyze the data, and write and compose the manuscript.
Name: Atoosa Zand, MD.
Contribution: This author helped conduct the study, collect and analyze the data, and compose the manuscript.

Name: Naveed Siddiqui, MD, MSc.
Contribution: This author helped design the study, conduct the study, analyze the data, and write and compose the manuscript.
This manuscript was handled by: Avery Tung, MD, FCCM.

REFERENCES

1. Bair AE, Panacek EA, Wisner DH, Bales R, Sakles JC. Cricothyrotomy: a 5-year experience at one institution. *J Emerg Med*. 2003;24:151–156.
2. McGill J, Clinton JE, Ruiz E. Cricothyrotomy in the emergency department. *Ann Emerg Med*. 1982;11:361–364.
3. Kristensen MS, Teoh WH, Rudolph SS. Ultrasonographic identification of the cricothyroid membrane: best evidence, techniques, and clinical impact. *Br J Anaesth*. 2016;117(suppl 1):i39–i48.
4. Elliott DS, Baker PA, Scott MR, Birch CW, Thompson JM. Accuracy of surface landmark identification for cannula cricothyroidotomy. *Anaesthesia*. 2010;65:889–894.
5. 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;114:987–992.
6. Lamb A, Zhang J, Hung O, et al. Accuracy of identifying the cricothyroid membrane by anesthesia trainees and staff in a Canadian institution. *Can J Anaesth*. 2015;62:495–503.
7. You-Ten KE, Desai D, Postonogova T, Siddiqui N. Accuracy of conventional digital palpation and ultrasound of the cricothyroid membrane in obese women in labour. *Anaesthesia*. 2015;70:1230–1234.
8. 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;26:852–856.
9. 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;123:1033–1041.
10. Law JA, Broemling N, Cooper RM, et al; Canadian Airway Focus Group. The difficult airway with recommendations for management: part 2: the anticipated difficult airway. *Can J Anaesth*. 2013;60:1119–1138.
11. Frerk C, Mitchell VS, McNarry AF, et al; Difficult Airway Society Intubation Guidelines Working Group. Difficult Airway Society 2015 guidelines for management of unanticipated difficult intubation in adults. *Br J Anaesth*. 2015;115:827–848.
12. Kristensen MS, Teoh WH, Graumann O, Laursen CB. Ultrasonography for clinical decision-making and intervention in airway management: from the mouth to the lungs and pleurae. *Insights Imaging*. 2014;5:253–279.
13. Kristensen MS, Teoh WH, Rudolph SS, Hesselfeldt R, Børglum J, Tvede MF. A randomised cross-over comparison of the transverse and longitudinal techniques for ultrasound-guided identification of the cricothyroid membrane in morbidly obese subjects. *Anaesthesia*. 2016;71:675–683.
14. You-Ten KE, Siddiqui N, Teoh WH, Kristensen MS. Point-of-care ultrasound (POCUS) of the upper airway. *Can J Anaesth*. 2018;65:473–484.
15. Dover K, Howdieshell TR, Colborn GL. The dimensions and vascular anatomy of the cricothyroid membrane: relevance to emergent surgical airway access. *Clin Anat*. 1996;9:291–295.
16. Boon JM, Abrahams PH, Meiring JH, Welch T. Cricothyroidotomy: a clinical anatomy review. *Clin Anat*. 2004; 17:478–486.
17. Chow SC, Shao J, Wang H. *Sample Size Calculations in Clinical Research*. New York, NY: Marcel Dekker; 2003.
18. Devroye, L. *Non-Uniform Random Variate Generation*. New York, NY: Springer-Verlag; 1986.
19. Barloon TJ, Brown BP, Abu-Yousef MM, et al. Teaching physical examination of the adult liver with use of real-time sonography. *Acad Radiol*. 1998;5:101–103.
20. Ahn JS, French AJ, Thiessen ME, et al. Using ultrasound to enhance medical students' femoral vascular physical examination skills. *J Ultrasound Med*. 2015;34:1771–1776.
21. Woods R, Wisniewski SJ, Lueders DR, Pittelkow TP, Larson DR, Finnoff JT. Can ultrasound be used to improve the palpation skills of physicians in training? A prospective study. *PM R*. 2017 December 7 [Epub ahead of print].
22. Hiller KN, Karni RJ, Cai C, Holcomb JB, Hagberg CA. Comparing success rates of anesthesia providers versus trauma surgeons in their use of palpation to identify the cricothyroid membrane in female subjects: a prospective observational study. *Can J Anaesth*. 2016;63:807–817.
23. Law JA. Deficiencies in locating the cricothyroid membrane by palpation: we can't and the surgeons can't, so what now for the emergency surgical airway? *Can J Anaesth*. 2016;63:791–796.
24. Campbell M, Shanahan H, Ash S, Royds J, Husarova V, McCaul C. The accuracy of locating the cricothyroid membrane by palpation: an intergender study. *BMC Anesthesiol*. 2014;14:108.
25. 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;106:617–631.
26. Oliveira KF, Arzola C, Ye XY, Clivatti J, Siddiqui N, You-Ten KE. Determining the amount of training needed for competency of anesthesia trainees in ultrasonographic identification of the cricothyroid membrane. *BMC Anesthesiol*. 2017;17:74.