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Airway sonography fails to detect difficult laryngoscopy in an adult Veteran surgical population

Justin S. Fulkerson [a, *], Heather M. Moore [b], Robert F. Lowe Jr. [c], Tristan S. Anderson [d], Lisa L. Lucas [b], Jonathan W. Reed [b]

[a] Veterans Health Administration Medical Center, Minneapolis, MN, USA
[b] Veterans Health Administration Medical Center, Memphis, TN, USA
[c] Veterans Health Administration Medical Center, Togus, ME, USA
[d] Veterans Health Administration Medical Center, Temple, TX, USA

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ABSTRACT

Objective: To evaluate ultrasound's utility to detect difficult laryngoscopy in a preoperative setting.
Methods: This single-site, prospective, cross-sectional, within-subjects study was performed at a Veterans Affairs Medical Center with 144 subjects. The sonographic independent variables included sonographic hyomental distance (HMD) and anterior neck thicknesses at the hyoid bone (HB), thyrohyoid membrane (THM), and vocal cords (VC). Additional independent variables were standard airway indicators of BMI, neck circumference, obstructive sleep apnea, snoring, abnormal upper teeth, jaw mobility, interincisor gap, Mallampati score, thyromental distance and neck range of motion. The outcome variable was the modified Cormack-Lehane Grade (CLG).
Results: There was no significance found among the four sonographic measurements or their derived ratios in predicting difficult laryngoscopy. Correlation analysis between the sonographic measurements did find significance of the HMD:HB ($p = 0.040$) and the HB:THM ($p = 0.44$) ratios. However these ratios had a weak correlation at −0.172 and −0.168 respectively. Standard airway indicators did not demonstrate significance in predicting the difficult airway, sans obese patient with neck circumference ($p = 0.016$).
Discussion: This study demonstrated ultrasonography in predicting difficult laryngoscopy lacked utility. Ultrasound utilization as an efficacious means of difficult airway assessment requires further research with a larger sample size. Further studies using sonography on those patients with known difficult airways may provide data to determine if ultrasound has utility in predicting difficult laryngoscopy.
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1. Introduction

Airway assessment and management are paramount skills among anesthesia, pulmonary, critical care, and emergency providers. Failure to optimize these abilities has obvious implications for patient survival in both emergent and elective settings. Positive "difficult airway" predictors allow providers to prepare additional potentially life-saving adjuncts and personnel. However, available difficult airway screening tests have limited sensitivity and specificity leading to false-negatives for difficult airway detection [1]. When these screening tests are used in combination detection does increase but remains suboptimal [2]. As such, the catastrophic "cannot intubate/cannot ventilate" (CICV) scenario still occurs in practice today most commonly from unanticipated difficult airways (false negatives on bedside screening tests) [1]. These failures to predict difficult airways may be in part because the term "difficult airway" is not a single entity, but rather a constellation of attributes related to provider competency, patient anatomy, and components of airway management - for example, ventilation, intubation, failed intubation, supraglottic device placement, and laryngoscopy [2].

There is emerging literature on the utility of ultrasonography in airway assessment and management [3–7]. Among imaging modalities, sonography is comparable to the gold standard of computed tomography in evaluating airway structures [8–10]. A variety of studies have emerged with increasing frequency over the

* Corresponding author. 1 Veterans Drive, Anesthesia Department, Minneapolis, MN, 55417, USA.
E-mail address: justin.fulkerson@va.gov (J.S. Fulkerson).

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last few years. The universal outcome measure among these studies is some variation of the Cormack-Lehane Grade (CLG) depicted in Fig. 1 [11]. The CLG is a laryngoscopic view that, while not the perfect outcome variable for all facets of the "difficult airway," is the most-commonly utilized measure of the twenty-two available studies [12–32]. In accordance with past literature, "difficult laryngoscopy" – and by extension "difficult intubation" – is defined as CLG views III and IV. The likelihood of a difficult intubation with a CLG grade III view approaches 90% [11]. "Easy laryngoscopy" is defined as CLG views I, IIa, and IIb.

While some investigators have found sonographic evidence for difficult laryngoscopy detection at varied points of the airway, other researchers have rebuked the utility of ultrasonography in this realm of airway management. These discrepancies are reflective of a heterogeneity of research methods, scanning protocols, and anatomic locations evaluated [33]. Of the measurement points, there has been statistical significance for detection of difficult laryngoscopy found at the sonographic hyomental distance [29], depth to anterior hyoid bone [14,18,30], and depth to anterior thyrohyoid membrane [14,15,24,30]. There is conflicting evidence at the vocal cords [12,14,15,15,19,30]. This prompted the following research questions:

1) In the Veteran population, how do sonographic measures of the anterior neck compare with standard physical assessment indicators for prediction of a difficult laryngoscopy?
2) Does the use of ultrasonography change the accuracy of detecting a difficult airway compared to standard difficult airway indicators?

The primary aim of this study was to evaluate which individual difficult airway predictors differ between easy and difficult laryngoscopy subjects. The secondary aim was to assess if sonographic measures and ratios correlate to the laryngoscopic Cormack-Lehane Grade.

2. Materials and methods

This single-site, prospective, cross-sectional, within-subjects study was conducted at the Memphis Veterans Affairs Medical Center from February 1st to June 4th, 2016. The study received Internal Review Board approval to recruit 200 patients. Before beginning the recruiting process, the sonographers performed a literature review [33] to develop a standardized scanning protocol and conducted a 3-h workshop to ensure consistent technique. The four sonographers were nurse anesthesia residents with at least 50 h of supervised ultrasound training. Reliability assessment was undertaken utilizing four staff volunteers.

Veterans ages 19–79 scheduled for elective surgical procedures were screened for eligibility as a convenience sample from the Anesthesia Preoperative Clinic. Inclusion criteria consisted of the projected need for endotracheal intubation using direct laryngoscopy, the ability to consent, and the ability to lay flat for approximately 5 min. Exclusion criteria consisted of pre-existing airway malformation or pathology, previous surgical alteration of sonographic landmarks in the anterior neck, contraindication to the sniffing position (i.e. cervical spine fracture), or a beard of sufficient size to limit image acquisition. Additionally, patients with a known history of difficult intubation were excluded. Difficult intubation was operationally defined as a history of three or more attempts to intubate by a single licensed provider, two or more licensed providers required to intubate, or a "Difficult Airway" medical record alert.

After providing education to the Anesthesia Department staff, the inclusion/exclusion criteria were posted for reference. Upon presentation to the Anesthesia Preoperative Clinic, all patients received a standard assessment by the anesthesia provider on duty and were screened for inclusion/exclusion criteria as listed above. Standard difficult airway indicators were obtained during the preoperative assessment. After inclusion criteria were met, a sonographer was notified, who then verified inclusion/exclusion criteria, obtained informed consent, and acquired sonographic measurements. Additionally, the sonographer recorded the data points listed in Fig. 2 (Parts I, II, and III), which included patient demographics, standard difficult airway predictors, sonographic measurements at four locations, and time to obtain sonographic measurements. An International Standards of Measurement-compliant goniometer was used to assess neck flexion and extension. Neck circumference was obtained for patients with a body mass index of $\geq$35 kg/m^2. After appropriate positioning in the supine sniffing position, sonographic measurements were obtained and timed using a ProCoach RS 013 stopwatch. A SonoSite S-Nerve ultrasound™ with a SonoSite HFL38X™ (6–13 MHz) linear probe was used to obtain the anterior neck tissue thickness at the hyoid bone (Fig. 3), pre-epiglottic space (Fig. 4), and the vocal cords (Fig. 5). A SonoSite C60X™ curvilinear probe was used to obtain the hyomental distance as it exceeded the linear probe footprint (Fig. 6). All sonographic measures were obtained to the 1/10th of a millimeter without pausing the timer. All sonographic measurements were recorded in a secure spreadsheet, and ratios of the measurements were calculated.

The main outcome variable, a modified CLG [11] (Fig. 1) was obtained the day of surgery under direct laryngoscopy without the use of adjuncts such as external laryngeal pressure. Subjects must have received neuromuscular blockade and undergone direct laryngoscopy. Difficult laryngoscopy was defined as CLG of III or IV in accordance with previous research. Each subject had a designated grading form with images of the modified CLG. The intubating provider circled which grade view they obtained during direct laryngoscopy and turned the form in to the same secure location as the anesthesia record. These forms were then collected and the data was entered by the sonographers into the secure spreadsheet daily. Only licensed providers and anesthesia personnel with at least 60 successful intubations were eligible to grade the view. This threshold was established based on anesthesia training literature, which estimates an average success rate of 90% after 50 intubations [34]. It would be unethical to blind airway practitioners to the standard difficult airway predictors but they

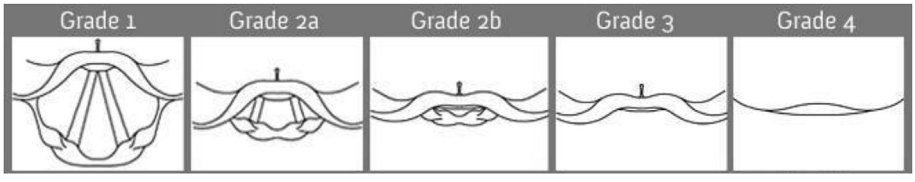
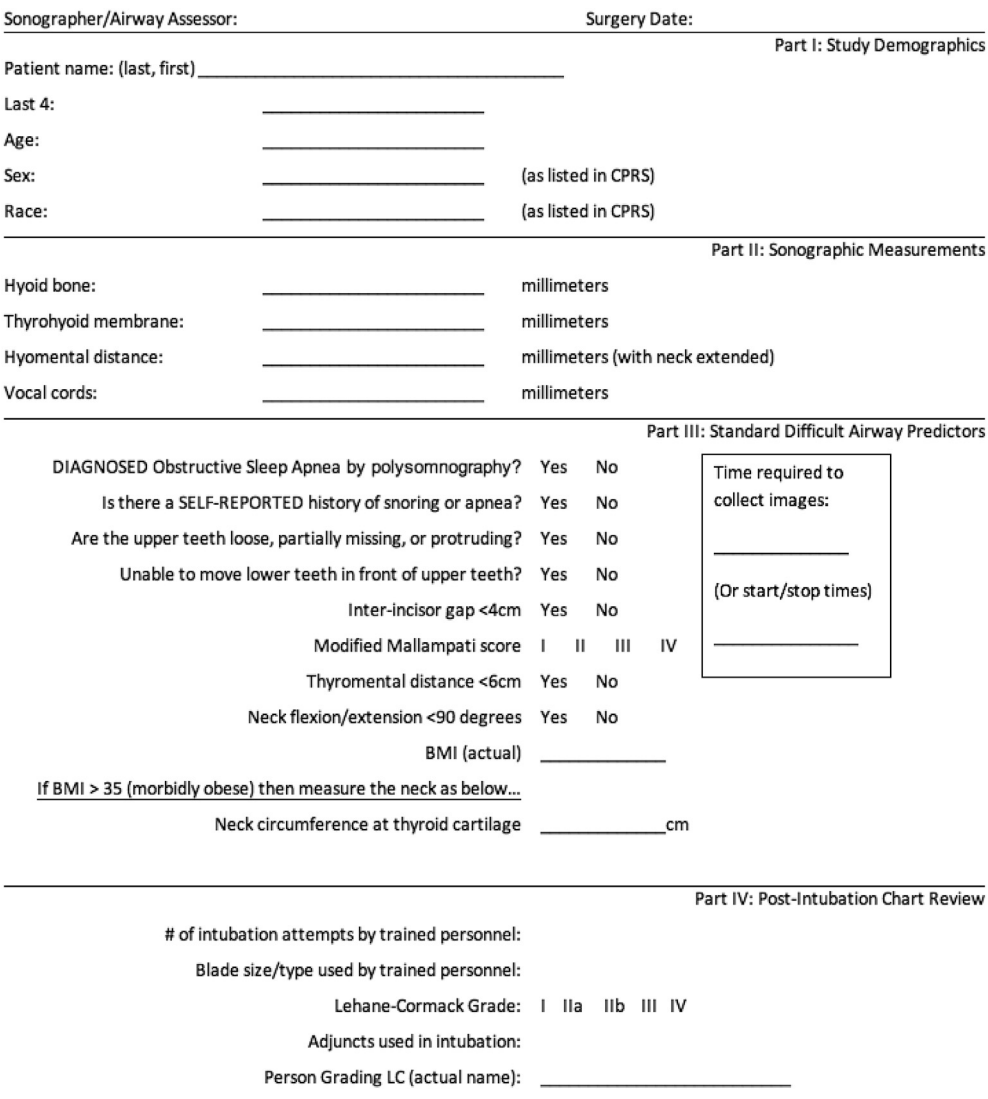


Fig. 1. Modified Cormack-Lehane Grade (Outcome Variable)
Reproduced with permission from Magaw Medical. http://copilotvl.com/blog/2011/01/09/Cormack-who. Published January 9, 2011. Accessed September 21, 2016.


Sonographer/Airway Assessor: Surgery Date:

Part I: Study Demographics

Patient name: (last, first) _____

Last 4: _____

Age: _____

Sex: _____ (as listed in CPRS)

Race: _____ (as listed in CPRS)

Part II: Sonographic Measurements

Hyoid bone: _____ millimeters

Thyrohyoid membrane: _____ millimeters

Hyomental distance: _____ millimeters (with neck extended)

Vocal cords: _____ millimeters

Part III: Standard Difficult Airway Predictors

DIAGNOSED Obstructive Sleep Apnea by polysomnography? Yes No

Is there a SELF-REPORTED history of snoring or apnea? Yes No

Are the upper teeth loose, partially missing, or protruding? Yes No

Unable to move lower teeth in front of upper teeth? Yes No

Inter-incisor gap <4cm Yes No

Modified Mallampati score I II III IV

Thyromental distance <6cm Yes No

Neck flexion/extension <90 degrees Yes No

BMI (actual) _____

If BMI > 35 (morbidly obese) then measure the neck as below...

Neck circumference at thyroid cartilage _____cm

Time required to collect images:

_____

(Or start/stop times)

_____

Part IV: Post-Intubation Chart Review

# of intubation attempts by trained personnel:

Blade size/type used by trained personnel:

Lehane-Cormack Grade: I IIa IIb III IV

Adjuncts used in intubation:

Person Grading LC (actual name): _____

Fig. 2. Data collected.

were blinded to the sonographic measurements. Similarly, the direct laryngoscopy was not performed by the same sonographer who obtained the subjects measurements.

2.1. Statistical analysis

Sample size was calculated with G*Power version 3.1 using a moderate effect size of 0.3, alpha of 0.05, and power of 80%. This resulted in n = 144 subjects required to power the study. All other analysis utilized IBM® SPSS® Statistics version 23. Statistical significance was set at $p < 0.05$.

Pearson R correlation was used to calculate, intra- and inter-class reliability among sonographers. Descriptive statistics for continuous data is reported as the mean with standard deviation, and for nominal data as percentage in Table 1. Table 2 reflects the purported predictors for difficult laryngoscopy, comparing the easy laryngoscopy group (CLG I, IIa, IIb) to difficult laryngoscopy group (CLG III & IV). Comparison analysis was performed using a two-tailed independent *t*-test for continuous data (age, sonographic measures, sonographic ratios, BMI, and neck circumference) after confirming homogeneity of variance with Levene's test. Standard indicators were considered nominal data and evaluated using the Chi-square or Fisher's Exact tests as appropriate for cell size. For correlation analysis, Spearman's correlation was used in order to test for relationships more rigorously than using the binary "difficult" vs. "easy" laryngoscopy.

3. Results

A total of 170 subjects were screened for the study, and 168 met inclusion criteria at the time of evaluation in the Anesthesia Preoperative Clinic. Surgery was cancelled or rescheduled for 13 subjects. A total of 155 subjects received anesthesia. Enrollment in the study did not mandate anesthesia management, so 11 patients were excluded on the day of surgery as the anesthesia providers utilized a plan that did not involve direct laryngoscopy (i.e regional anesthesia, laryngeal mask airway, monitored anesthesia care, or video laryngoscopy.) Fig. 7 outlines the subject selection and attrition process for a total of n = 144 subjects.

Table 1 contains the demographic distribution for the aggregate sample. 144 subjects (130 males and 14 females) with a mean age of 59.56 years were included in the analysis. 129 subjects had easy laryngoscopies (CLG I, IIa, IIb) while 15 were difficult (CLG III & IV). Table 2 reflects the comparison of these two groups. There was no

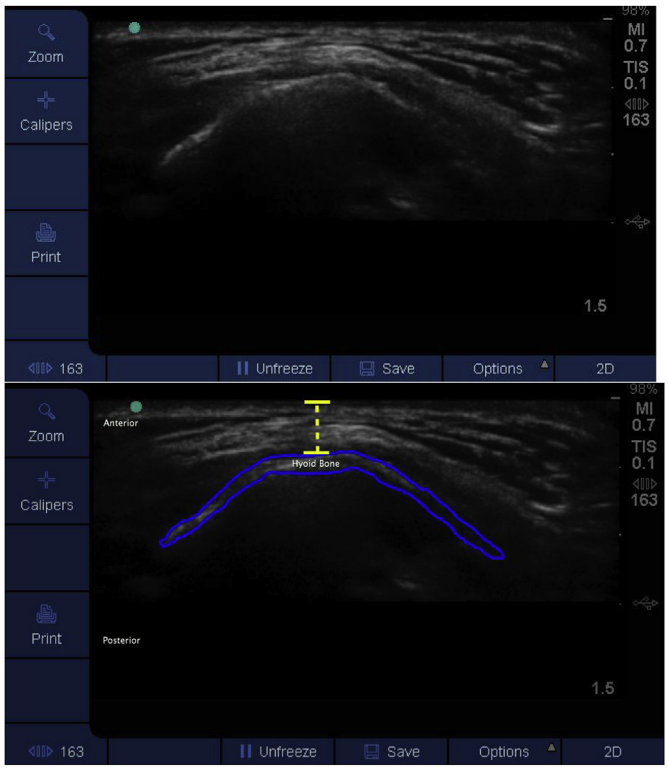


Fig. 3. Anterior neck thickness to hyoid bone.

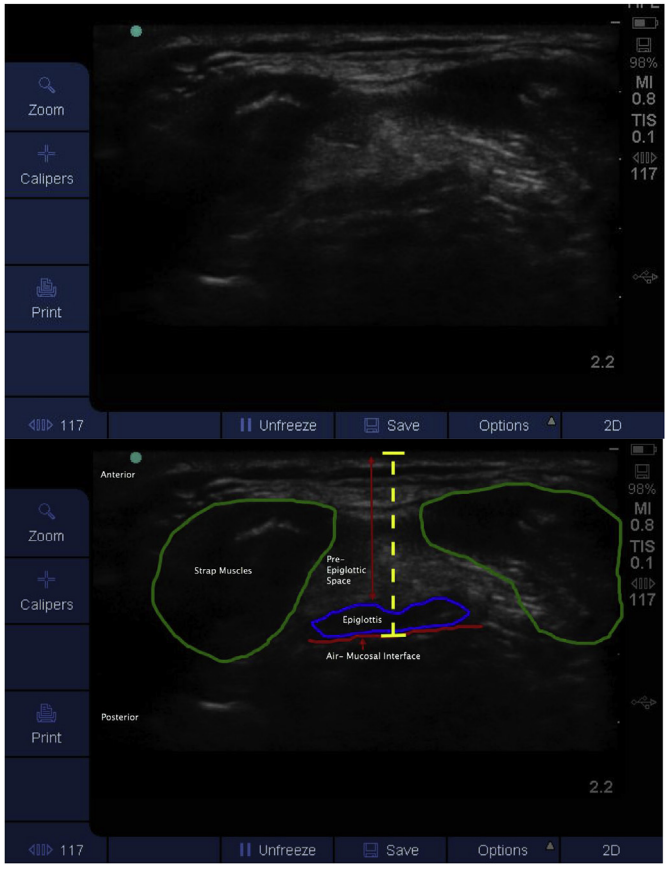


Fig. 4. Pre-epiglottic space at thyrohyoid membrane.

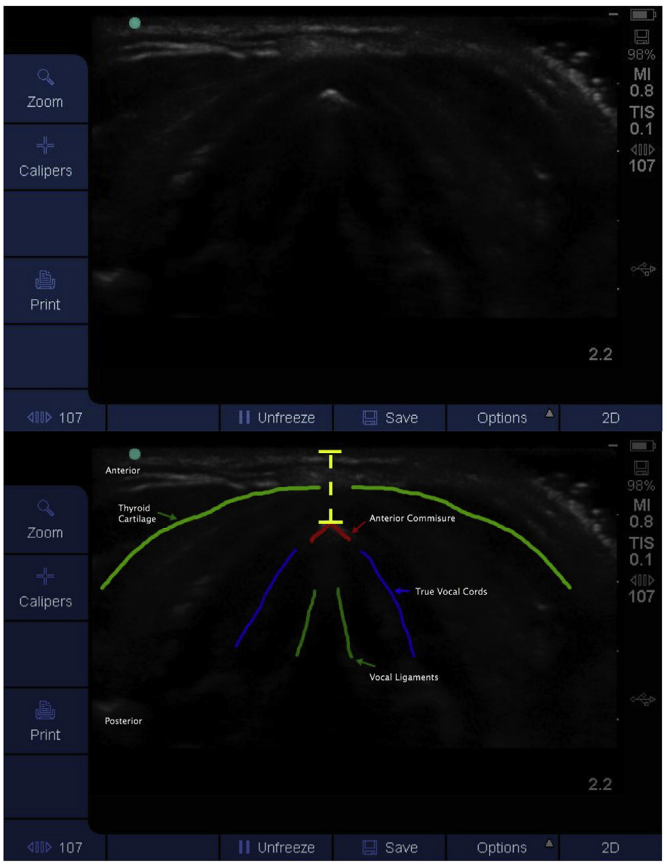


Fig. 5. Anterior neck thickness to vocal cords (anterior commissure).

statistically significant difference in sex, age, or BMI between easy and difficult groups. Two of the 15 subjects in the difficult laryngoscopy group had BMI >35 kg/m^2, with a statistically significant difference in neck circumference between groups ($p = 0.016$).

Intra-class correlation for sonographers was excellent as demonstrated by Pearson R correlation of 0.940–0.991 across all measurements. Interclass correlation was also excellent with $p = 0.000$ for the various sonographers. It appears from these findings and others [35] that with training, reproducibility of ultrasonic airway measure is possible and consistent. The time to acquisition of sonographic images – including caliper measurements and one probe change – ranged from 68 to 360 s, averaging 135 s (2.25 min).

Among the standard indicators for detection of difficult laryngoscopy, no predictor was significantly different between groups. For the continuous data, normal variance was assumed with Levene's test ranging from 0.160 to 0.881. Among the sonographic measurements, no indicator demonstrated significance. Finally, among the ratios of the four sonographic locations, no significant difference was found with any ratio.

Table 3 outlines the correlation analysis of the sonographic measures, finding statistically significant negative correlation between the hyomental to hyoid bone ratio (correlation coefficient −0.172, $p = 0.040$) and the hyoid bone to thyrohyoid membrane (correlation coefficient −0.168, $p = 0.044$). While statistically significant, the weak correlation implies minimal clinical significance.

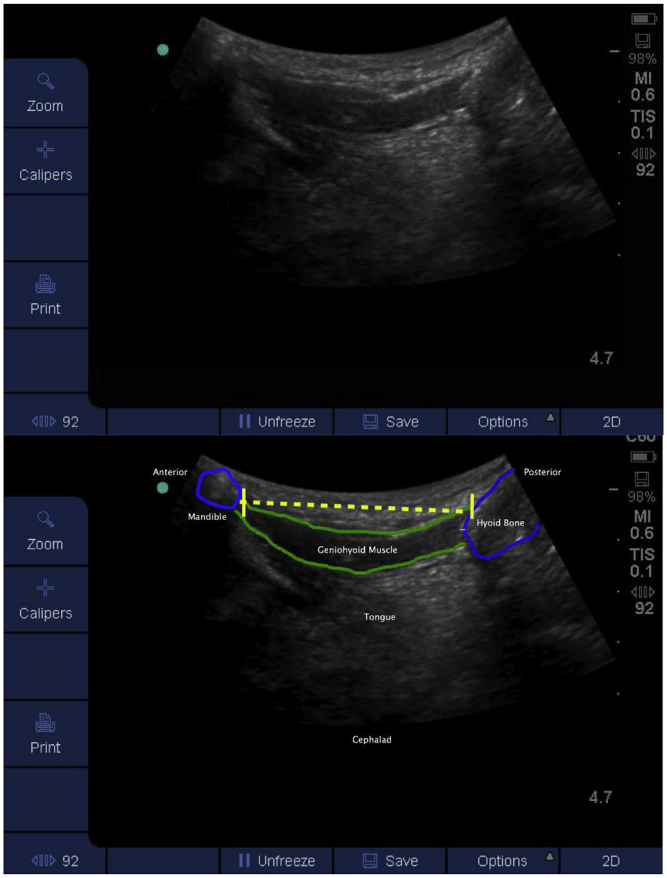


Fig. 6. Hyomental distance.

4. Discussion

This study validated the null hypothesis that sonographic measurements of airway anatomy do not perform differently than standard indicators for the prediction of difficult intubation.

The primary aim of this study was to evaluate which individual difficult airway predictors differ between easy and difficult laryngoscopy subjects. The secondary aim was to assess if sonographic measures and ratios correlate to the CLG. This study found no clinical significance in the utility of ultrasound as a predictive tool. These negative results are consistent with the same measures obtained using MRI as the measure of anterior neck thickness [36]. The difference in grading methods utilized may explain these results that contradict previous studies.

Correlation of sonographic measures to difficult CLG has been described [32]. Of these, distance to the hyoid bone was best with a Pearson Correlation index of 0.345 (0.215–0.463 95% CI). Our study did as well find a positive correlation (0.095) at this location, but this was non-significant ($p = 0.260$). This is a weak correlation by our and other's research and should make clinicians skeptical that it is clinically useful for individual patients [43].

The previous research is mixed on utilization of external laryngeal pressure (ELP) before CLG grading and in this study; the researchers did not elect to include it in the methods. ELP is known to improve the laryngoscopic grade and may therefore have implications in stratifying difficult from easy laryngoscopies [37,38]. As previously described in a systematic review of similar studies [33], the study design excluded use ELP in order to provide a more standardized approach to comparing results to like studies. Much of the research into sonographic ability to detect difficult laryngoscopy excludes patients that require ELP [12,19,22,24,25,39,40].

One potential limitation of this study is the seemingly-high number of difficult laryngoscopies the researchers encountered. As outlined in previous research [34] the researchers methodology required larygnoscopists with at least 60 intubations to obtain the CLG grade. These graders encountered a rate of 9.6% ($n = 15/144$) This actually compares well to the established 11% (6–19% [0–100%]) incidence of CLG grades III and IV, according to a recent Cochrane review on the subject [1]. However, given the non-use of ELP, there is potential that ultrasonography may have clinical utility in the population where ELP still yields a high-grade CLG. Future studies should standardize this methodology of CLG acquisition and potential compare with and without its use.

Future studies should look at utility in specific patient populations; for example various classifications of obesity or different ranges of neck circumference. In this study, the authors did not perform a sub-group analysis utilizing BMI. Some of the previous research focused specifically into obese populations and sonographic measures. These authors did not have a large enough sample population to derive appropriate conclusions from in the difficult laryngoscopy morbidly obese group ($n = 2$) to the non-difficult group ($n = 27$). Such sub-analysis would have provided numbers, but would have been underpowered and inappropriate for conclusive analysis.

All previous studies, sans one, evaluated significance levels at individual measurement sites. The “three axis alignment” theory for intubation as described by Bannister and Macbeth [42] is still prominently used in practice to maximize direct laryngoscopy grade. This suggests that a comparative ratio of measurements may be more predictive than individual measurements allow. This study is among the larger of its kind to compare individual sonographic

Table 1
Sample descriptive characteristics.

		Range/Number	Mean ± SD/Percent
Age		29–78	60 ± 10 years
Sex	Male	130	90.3%
	Female	14	9.7%
Race	Asian	1	0.7%
	Black	70	48.6%
	White	73	50.7%
BMI		17–46	30 ± 5
Neck Circumference		34–58 cm	48 ± 5 cm in BMI ≥35 subjects
CLG	I	59	41%
	IIa	45	31.3%
	IIb	25	17.4%
	III	9	6.3%
	IV	6	4.2%

Table 2
Difference between Easy vs. Difficult Laryngoscopy Groups.

Demographics		Easy Laryngoscopy (n = 129)	Difficult Laryngoscopy (n = 15)	*p* - value
Age		60 ± 11 years	57 ± 8 years	.398
Sex	Male	116 (81%)	14 (10%)	.673
	Female	13 (9%)	1 (1%)	
BMI		30 ± 5	30 ± 4	.818
Neck Circumference (n = 27)		49 ± 5 cm (n = 25)	40 ± 8 cm (n = 2)	**.016**
Standard Indicators				
Diagnosed OSA	No	94 (65%)	9 (6%)	.296
	Yes	35 (24%)	6 (4%)	
Snoring	No	55 (38%)	5 (4%)	.489
	Yes	74 (51%)	10 (7%)	
Upper Teeth Abnormal	No	104 (72%)	13 (9%)	.737
	Yes	25 (17%)	2 (1%)	
Jaw mobility Abnormal	No	127 (88%)	13 (9%)	.054
	Yes	2 (1%)	2 (1.4%)	
Interincisor Gap <4 cm	No	122 (85%)	12 (8%)	.071
	Yes	7 (5%)	3 (2%)	
Mallampati	1	47 (32.6%)	3 (2.1%)	.369
	2	73 (51%)	10 (7%)	
	3	9 (6%)	2 (1%)	
	4	0	0	
Thyromental distance <6 cm	No	11 (8%)	14 (10%)	0.615
	Yes	14 (9.7%)	1 (0.7%)	
Neck ROM < 90°	No	120 (83.3%)	14 (9.7%)	0.964
	Yes	9 (6%)	1 (1%)	
Sonographic Measures				
Hyomental distance (HMD)		5.28 ± 0.69 cm	5.10 ± 0.65 cm	.341
Hyoid Bone (HB)		0.97 ± 0.31 cm	0.93 ± 0.22 cm	.681
Thyrohyoid Membrane (THM)		2.14 ± 0.48 cm	2.00 ± 0.47 cm	.304
Vocal Cords (VC)		0.70 ± 0.23 cm	0.73 ± 0.15 cm	.631
Sonographic Ratios				
HMD:HB		6.12 ± 2.7	5.05 ± 1.73	.139
HMD:THM		2.62 ± 0.85	2.55 ± 1.03	.749
HMD:VC		8.25 ± 2.92	6.87 ± 2.62	.080
HB:THM		0.47 ± 0.17	0.49 ± 0.14	.606
HB:VC		1.47 ± 0.59	1.37 ± 0.46	.482
THM:VC		3.30 ± 1.24	2.85 ± 0.82	.174

airway measurements as well as ratios of measurements to assess predictive value for detection of the difficult airway. The authors performed an systematic literature review to evaluate and describe research designs and scanning protocols [33]. As such, the established a protocol that is an amalgam of several other studies and validated its reproducibility through a standardized workshop. Previous authors had discussed difficulties in obtaining measurements due to insufficient training [16]. As our high inter- and intra-class correlations demonstrate, 3 h of training for experienced sonographers is sufficient for high reproducibility for sonographic measurements and can easily overcome this shortcoming of evaluation.

Previous studies have limited samples to specific surgical populations (i.e obese or pregnant), while this study included all surgical specialties and comorbidities. While this reflects a realistic patient population at the Memphis Veterans Affairs Medical Center, it limited the ability to control for confounding variables. A convenience sample of participants from a Veterans Health Administration facility were used for data collection in this study. Patients in the Veterans Health Administration are known to have more males, higher rates of mental illness, higher rates of overuse and orthopedic injuries, more comorbidities, and lower income than the general population [41]. The authors did not intend to have these results generalizable to the non-Veterans Health Administration population and current evidence suggests much of Veterans Health Administration research is not generalizable to the non-Veterans Health Administration population except possibly elderly male Medicare patients [41]. This study in particular had a significantly higher rate of male than female participants, but no significant difference between the difficult and non-difficult groups. There is even some evidence that sonography may have higher sensitivity in females and higher specificity in males [15].

Furthermore, many veterans presenting for surgery have extensive medical records available for review. As opposed to the civilian population, when a Veteran's physical assessment indicates they may be a difficult intubation, the Veterans Health Administration likely will have anesthesia records denoting an easy intubation, which can sway airway providers and influence intubation method selection. This may have biased our study compared to others, as it is the only one known to be conducted in the Veteran population.

A limitation of this study was the number of airway providers involved. Approximately 20 providers were involved in the Anesthesia Preoperative Clinic evaluation and in the operating room, which may have introduced inconsistency into laryngoscopy methods and grading despite staff education on study protocol.

Direct laryngoscopy is performed with the end goal of tracheal intubation. Intubation is attempted with the corollary that easy laryngoscopy translates into easy endotracheal intubation. It should be acknowledged, however, that this is not always true in clinical practice. Instances occur when a CLG I or II is obtained but difficulty passing the endotracheal tube is encountered. Similarly, when a CLG III or IV is obtained it is sometimes still easy to accomplish intubation. This was the case for one patient in our

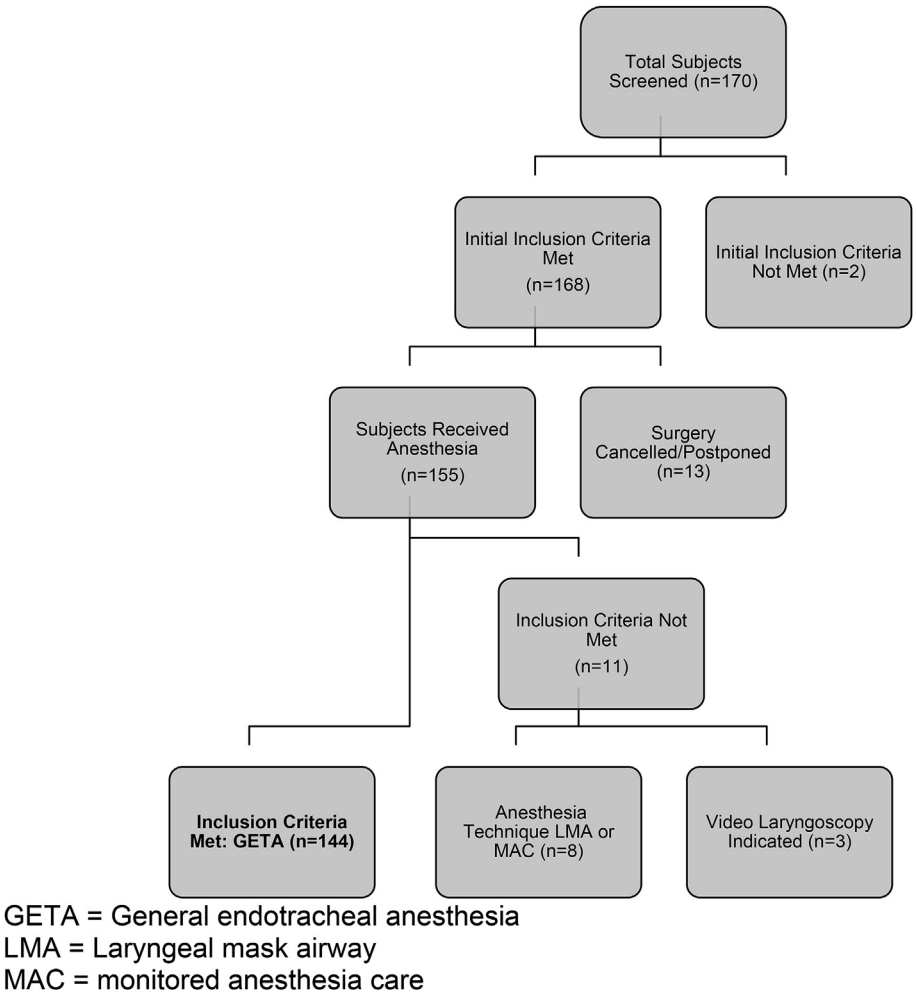


Fig. 7. Subject Selection Process
GETA = General endotracheal anesthesia
LMA = Laryngeal mask airway
MAC = monitored anesthesia care.

Table 3
Sonographic measure correlation to CLG.

	HMD	HB	THM	VC	HMB: HB	HMB: THMB	HMB: VC	HB: THM	HB: VC	THM: VC
Correlation coefficient	-.116	.095	-.061	.137	**-.172**	-.010	-.134	**.168**	.007	-.134
p - value	.168	.260	.470	.102	**.040**	.901	.108	**.044**	.934	.109

study, who had a CLG IV but demonstrated that difficult laryngoscopy did not correlate to difficult intubation. The definition of difficult intubation still lacks consensus [44,45] but is commonly derived from laryngoscopy endpoints like the CLG or the Intubation Difficulty Score (IDS) [46]. The CLG has become a standard for defining difficult laryngoscopy for research purposes in anesthesia. To further obscure matters, research describes variable criteria for the number of trained airway personnel required to truly denote "difficult" airway [44]. Because of the lack of stringent and consistent definition, more studies are needed to determine or refute the utility of ultrasonography in the prediction of the difficult airway. Our study suggests that ultrasound is not clinically useful in predicting difficult laryngoscopy. Future research may find that ultrasound is useful for other aspects of airway management, such as detection of difficult mask ventilation. For example, sonographic anterior neck thickness to the hyoid bone may be an emerging indicator [32].

5. Conclusions

Anticipating the difficult airway is not always a simple process, and the anesthesia provider needs to integrate numerous factors to be fully prepared for challenging intubations. This study sought to determine if ultrasound could be a valuable tool in predicting a difficult laryngoscopy. The results of the Memphis Veterans Affairs Medical Center investigation indicated that using ultrasound to predict the difficult airway did not demonstrate statistical significance. While previous investigators did find significance with the hyomental distance [29], depth to anterior hyoid bone [14,18,30], and depth to anterior thyrohyoid [14,24,30] for detection of difficult laryngoscopy, this study was unable to replicate those results. Given the mixed results within the research, statistical significance

may be found with a larger sample size, and further research would help to validate findings. To this end, the Memphis Veterans Affairs Medical Center investigation study has provided a structured protocol applying ultrasonography in measuring airway anatomy, which can further research towards providing for the safety of our Veterans undergoing surgical procedures.

Competing interests

The authors state no potential conflicts of interest.

Other

This study is not funded. The authors have no conflicts of interest to declare.

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Conflict of interest

The authors declare no funding or conflict of interest for this article.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tacc.2019.07.003.

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