Original Article

Development of a scoring system for predicting difficult intubation using ultrasonography

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Submitted: 30-Sep-2019
Revised: 02-Dec-2019
Accepted: 03-Feb-2020
Published: 11-Mar-2020

Access this article online

Website: www.ijaweb.org

DOI: 10.4103/ija.IJA_702_19

Quick response code

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ABSTRACT

Background and Aims: Ultrasound measurement of anterior neck soft tissue thickness by skin to epiglottis distance (SED) has been shown to predict difficult laryngoscopy. In this study, we developed an airway scoring system incorporating SED into three clinical predictors and assessed whether it would improve accuracy in prediction of difficult intubation. **Methods:** Mentohyoid distance, mandibular subluxation, head extension and ultrasound measurement of skin to epiglottis distance were measured a day before surgery in 310 adult patients. During direct laryngoscopy, Cormack–Lehane grading was noted (Grade 1 and 2 = Easy, Grade 3 and 4 = Difficult). We constructed a score named MSH, which included mentohyoid distance, mandibular subluxation and head extension. Then, SED was added to the MSH score to form another new score named U_{SED}-MSH. Student's *t*-test, Mann-Whitney U test and Chi-square test or Fisher exact tests were used. Both scoring systems were compared under the receiver-operating characteristic curve and area under the curve (AUC) were calculated. **Results:** Difficult intubation was observed in 62/310 patients (20%). The AUC for U_{SED}-MSH score was greater than the MSH score (0.93, 95% CI [0.89–0.97] vs 0.76, 95% CI [0.69–0.84], *P* value <0.001). U_{SED}-MSH score had higher sensitivity (93.6% vs 59.7%) and lower specificity (85.9% vs 91.1%) with similar positive predictive value (62.7% vs 62.4%) in comparison with MSH score. **Conclusion:** An airway scoring system using the ultrasound measurements of skin-to-epiglottis distance along with the clinical predictors would be helpful in the prediction of difficult intubation.

Key words: Airway ultrasound, difficult intubation, skin-to-epiglottis distance

INTRODUCTION

The individual difficult airway predictors such as mouth opening, Mallampati grading, atlanto-occipital extension etc., have poor sensitivity, specificity and positive predictive value.[1,2] The composite airway scoring systems also lack dependable sensitivity and specificity.[3,4] Preoperative airway assessment tests should be quick, cost-effective and easy to perform at the bedside with high sensitivity, specificity and positive predictive value. The search continues for a simple and non-invasive technique that would provide a more accurate assessment of the patient's airway. Pilot studies had been conducted on the utility of point-of-care ultrasound in the assessment of difficult airway.[5,6] Among the ultrasound measurements, the skin-to-epiglottis distance (SED) has been shown to be useful in predicting difficult intubation.[7,8] Since looking at any single parameter to predict the difficulty will always be deficient, thus this study was designed with a primary objective to develop a scoring system for predicting difficult intubation incorporating an ultrasound measurement (SED) to three clinical predictors, that is, mentohyoid distance,

How to cite this article: Daggupati H, Maurya I, Singh RD, Ravishankar M. Development of a scoring system for predicting difficult intubation using ultrasonography. Indian J Anaesth 2020;64:187-92.

mandibular subluxation and head extension, using Cormack–Lehane grading of glottis view as a guide. The secondary objective was to analyse whether the addition of an ultrasound measurement (SED) would improve accuracy in the prediction of difficult intubation.

METHODS

This prospective observational study was conducted between May 2018 and November 2018, after obtaining the institute research council and human ethical committee (PG/2017/02/33, dated 25/2/2017) approval and registration with a clinical trial registry of India. After written informed consent, a total 310 patients aged between 18 and 65 years, of either sex with American Society of Anesthesiologists (ASA) physical status 1 to 3 posted for elective surgery planned under general anaesthesia with tracheal intubation using Macintosh laryngoscope were included in this study by consecutive sampling method. Patients with anatomical airway abnormality, mouth opening <3 cm and those undergoing emergency surgery were excluded from the study.

All patients underwent a detailed preoperative evaluation as per department protocol. During pre-operative airway assessment, mentohyoid distance, mandibular subluxation and head extension were noted.[2-4,9] The mentohyoid distance was measured in the standard intubating position of neck flexion with full head extension as a distance between mentum and hyoid bone using a measuring scale in centimetres. Mandibular subluxation was assessed by upper lip bite test. It was graded as grade +1: lower incisors can bite the upper lip above the vermilion line, grade 0: can bite the upper lip below the vermilion line, and grade −1: cannot bite the upper lip. For head extension, the patient was made to lie on a bed with a 7-cm pillow, asked to extend the head. It was measured as grade 3: the line of upper incisor less than a vertical line, grade 2: the line of the upper incisor in line with the vertical line and grade 1: the line of upper incisor beyond the vertical line. For SED measurement, all patients underwent a sub-mental ultrasound.[5-8] The examination was performed with a high-frequency linear probe (HFL 50xp) resonating at 15–6 MHz in the multi-beam mode (Sonosite Xporte, Fujifilm). Patients were made to lie in supine sniffing position with a pillow under the occiput to achieve optimum head extension and neck flexion. After applying a liberal amount of ultrasound gel, the probe was placed at the cricoid level in transverse axis and scanned cephalad till hyoid bone [Figure 1a]. The cricoid cartilage was seen as an oval hypoechoic structure with a bright air mucosal interface on the posterior surface of its anterior wall and reverberation artefact due to intraluminal air. At the level of the thyroid cartilage, the vocal cord was delineated medially by the hyperechoic vocal ligaments. Once the hyoid bone was visualised as a hyperechoic structure with posterior acoustic shadow, the probe was moved slightly caudal. The epiglottis was visualised as a hypoechoic curvilinear structure through the thyrohyoid membrane. Anteriorly, the epiglottis is demarcated by a hyperechoic structure, that is, pre-epiglottic space (PES), while it is bounded by a bright hyperechoic line, that is, air–mucosal interface. After freezing image at the midway between the hyoid bone and thyroid cartilage image, the measurement was obtained from skin to epiglottis [Figure 1b]. All preoperative airway parameters were recorded by an anaesthesiologist trained in airway ultrasound who did not take part further in the study.

All patients had fasted overnight and received premedication as per institutional protocol. On the day surgery, in operating room patients were connected with routine intra-operative monitors, including pulse oximetry, end-tidal capnography, non-invasive blood pressure and electrocardiography. Medications used for induction were left at the discretion of the OT anaesthesia consultant. All patients were positioned in an optimal 'sniffing' position when external auditory meatus and the sternal notch was at the same horizontal plane. The choice of intravenous induction agent and inhalational agents were as per the anaesthesiologist choice. All patients received injection vecuronium bromide 0.1 mg/kg for muscle relaxation. After 3 min, the attending anaesthesiologist blinded from the preoperative measurement values, who had a minimum of 2 years of experience performed laryngoscopy using appropriate size curved Macintosh

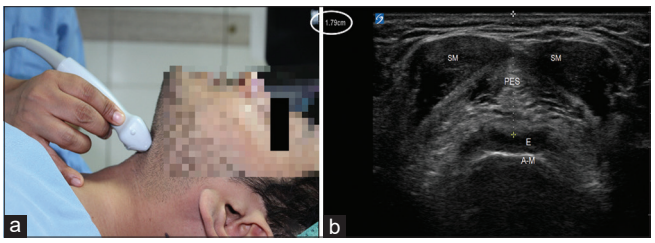

Figure 1: (a) Probe position, (b) transverse ultrasound image at midway between the hyoid bone and thyroid cartilage. SM: strap muscles, PES: pre-epiglottic space, E: epiglottis, A-M: air mucosal interface. In this image, skin to epiglottis distance is 1.79 cm

Blade. The glottis view obtained on first attempt without using any external laryngeal manoeuvre was graded and noted according to the Cormack and Lehane classification (Grade 1: complete visualisation of the vocal cords; Grade 2: Visualisation of the posterior portion of the glottis; Grade 3: Visualisation of only the epiglottis and Grade 4: Non-visualisation of epiglottis). The glottis view obtained on direct laryngoscopy was regarded as a surrogate for intubation difficulty; with grades 3 and 4 classified as difficult and grades 1 and 2 as easy. Difficult airway cart was always kept ready in case of an emergency. Patients were intubated with an appropriate-sized endotracheal tube and anaesthesia was continued as per attending anaesthesiologist plan.

PS, Power and Sample Size Calculation Software (version 3.0, January 2009, licensed under Creative Commons Attribution Non-commercial – Noderivs 3.0 United States license) was used for sample size calculation. Based on previous study by Reddy *et al*.,[5] considering the incidence of difficult intubation of 14%, we calculated sample size of 290 patients using formula sample size = $Z^2_{1-\alpha/2} P(1 - P)/d^2$ (margin of error (d) = 0.04, level of confidence = 95%). We targeted a total of 320 patients for the study assuming 10% dropouts from the study. SPSS for window 19.0 (SPSS Inc, Chicago) was used for statistical analysis. Data that were normally distributed are presented as mean (SD or 95% CI), and data that were not normally distributed as median (interquartile range [IQR]). Categorical data are described as a frequency, n (%). For continuous variables, student's *t*-test or Mann-Whitney U test was used and for categorical variables, Chi-square test or Fisher exact test was used. To determine the cut-off for SED, receiver-operating characteristic (ROC) analysis was done and the area under the curve (AUC) with 95% CI was calculated. The sensitivity, specificity, positive predictive value and negative predictive value were calculated for both scoring systems. The predictive accuracy of the scoring systems was compared on ROC curve measuring the AUC. All comparisons were two-tailed. $P < 0.05$ was considered significant.

RESULTS

A total of 346 patients were screened for eligibility. A total of 310 patients completed the study and included for analysis [Figure 2]. The demographic profile and airway variable of the study population are shown in Table 1. The incidence of difficult intubation was 20% (n = 62). The patients with difficult intubation (n = 62) had significantly lower mentohyoid distance (3.7, 95% CI [3.5–3.9] vs. 4.72, 95% CI [4.63–4.80] cm; *P* value <0.001), lower mandibular subluxation grade (*P* value <0.001), higher head extension grade (*P* value <0.001) and higher mean skin to epiglottis distance (2.17, 95% CI [2.12–2.22] cm vs 1.68, 95% CI [1.65–1.70] cm; *P* value <0.001) in comparison to easy intubation (n = 248). A measurement of 2.1 cm (after round off 2.09 cm) was taken as cut-off (based on 'The Closest to [0, 1] Criteria') for SED with the sensitivity of 82%, the specificity of 95% AUC of 0.934 (95% CI [0.889–0.980]) [Figure 3]. We assigned point values 1 or 2 to each of individual parameters (mentohyoid distance, mandibular subluxation and head extension) as shown in Table 2, and named MSH score (Minimum score: 3 and Maximum score: 6). Arbitrary, MSH score of 3 was predicted as easy intubation while scoring >3 as difficult intubation. Then we added ultrasound measurement (SED) in MSH score to make new score named as U_{SED}-MSH score (minimum score: 4, maximum score: 8) [Table 2]. Arbitrary, U_{SED}-MSH score of 4 was predicted as easy intubation while scoring >4 as difficult intubation. U_{SED}-MSH score had higher sensitivity (93.6% vs 59.7%) and slightly lower specificity (85.9% vs 91.1%) with similar positive predictive value (62.7% vs 62.4%) and a higher false-negative value (98.2% vs 90.0%) in comparison with MSH score. Both scoring systems were compared on the ROC curve. The AUC for U_{SED}-MSH score was greater than the MSH score (0.93, 95% CI [0.89–0.97] vs 0.76, 95% CI [0.69–0.84], *P* value <0.001) [Figure 4].

DISCUSSION

In this observational study, we incorporated an ultrasound measurement (skin to epiglottis distance) and clinical screening tests (mentohyoid distance, mandibular subluxation, head extension) to develop a

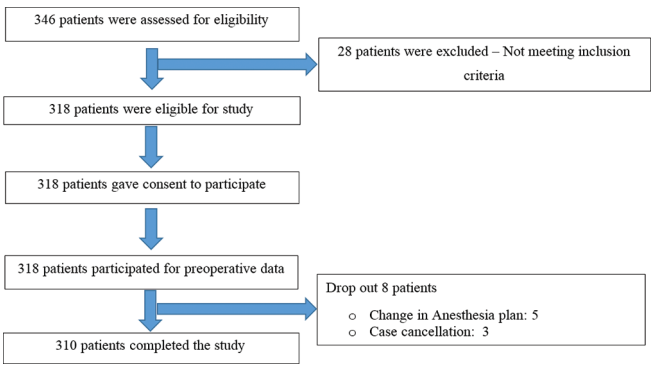

Figure 2: Study flowchart

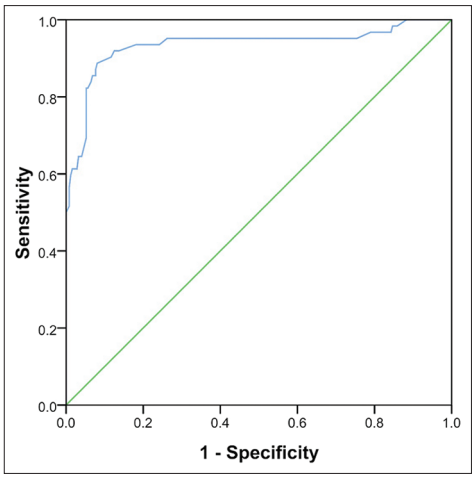

Figure 3: Skin to epiglottis distance (receiver operating characteristic curve and area under the curve)

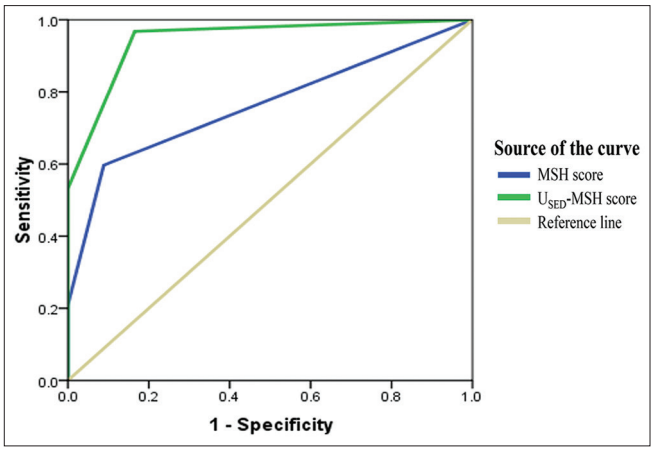

Figure 4: MSH vs U_{SED}-MSH score (receiver operating characteristic curve [Area under the curve])

score for predicting difficult intubation and to assess if it would improve the predictive accuracy. This study was performed on patients planned for surgery under general anaesthesia with tracheal intubation using Macintosh laryngoscope.

The direct laryngoscopy procedure is best described by separating into a static and dynamic phase.[10,11] The static phase requires appropriate head and neck positioning to align oral, pharyngeal and laryngeal axes to facilitate easy laryngoscopy and intubation. Thus, the range of head extension has a direct impact on the static phase of direct laryngoscopy. While the dynamic phase involves the introduction of a laryngoscope blade tip in the vallecula and lifting the epiglottis after displacing the soft tissue in the submandibular space. Increase in pre epiglottis space depth corresponding to vallecula implies an increase in difficulty to lift epiglottis. Ultrasound measurement of SED has an impact on epiglottis angulation.[10,11] More the SED means more the angulation hence poor glottis view. Thus, the dynamic phase of direct laryngoscopy is affected by temporomandibular joints movement, angulation of the epiglottis, compliance and volume of the submandibular space. The assessment of temporomandibular joints includes inter-incisor distance and anterior subluxation. But there is no objective method to measure submandibular space volume and compliance. The assessment of angulation of epiglottis includes measuring skin to epiglottis distance. As per the above-described model for direct laryngoscopy, we decided to include mentohyoid distance, mandibular subluxation and head extension for a new clinical scoring system (MSH score). Also, these three individual clinical predictors showed to have better predictive accuracy.[2,3] Vasudevan *et al*. have shown that restricted head extension and decreased mentohyoid distance have a significant association with poor glottis view.[9] Upper Lip bite

Table 1: Demographic and airway variables of the study population

Variables	Study population (*n*=310)
1. Age (years), mean (SD)	33 (13)
2. Body mass index (kg/m^2), mean (SD)	25.48 (2.10)
3. Gender (female/male), *n*	125/185
4. ASA physical status (I/II/III), *n*	179/121/10
6. Mentohyoid distance (cm), Mean (SD)	4.54 (0.83)
7. Mandibular subluxation grade (−1/0/1), *n*	17/98/195
8. Neck extension grade (1/2/3), *n*	281/29/0
9. Skin to epiglottis distance (cm), Mean (SD)	1.78 (0.30)
10. Cormack-Lehane Grade (1/2/3/4), *n*	131/117/56/6

*Categorical data are presented as a frequency (*n*), while continuous data as mean (SD)

Table 2: Airway scoring systems

Scoring system	Parameters		Grading	Score
MSH	Mentohyoid distance, cm	>=4	E	1
		<4	D	2
	Mandibular subluxation, Grade	+1 or 0	E	1
		−1	D	2
	Head extension, Grade	1 or 2	E	1
		3	D	2
U_{SED}-MSH	USG measurement (SED), cm	<2.1	E	1
		>=2.1	D	2
	Mentohyoid distance, cm	>=4	E	1
		<4	D	2
	Mandibular subluxation, grade	+1 or 0	E	1
		-1	D	2
	Head extension, grade	1 or 2	E	1
		3	D	2

*E: easy; D: difficult; MSH score-Minimum 3 and Maximum 6. MSH score of 3 was predicted as easy, and >3 as a difficult airway. U_{SED}-MSH score-Minimum 4, Maximum 8. U_{SED}-MSH score of 4 was predicted as easy, and >4 as difficult airway

test for mandibular subluxation show to have a higher sensitivity and specificity of 80% and 96.25%, respectively than other clinical predictors.[2,4]

Ultrasound imaging is a novel, non-invasive and portable tool for airway management such as preoperative evaluation for difficult airway, confirmations of endotracheal tube position etc.[5-8] Various ultrasound measurements for difficult intubation have been described such as tongue volume, the volume of the floor of the mouth, anterior neck soft tissue thicknesses measured at the hyoid bone/thyrohyoid membrane and anterior commissure levels.[7,8,12] There is a link between the presence of abundant neck soft tissue with that of difficult intubation.[11,13] As described by Greenland's model for direct laryngoscopy measuring SED might have an impact on epiglottis angulation thus difficult dynamic phase of direct laryngoscopy.[10,11] Aruna *et al*.[8] found out that SED was most sensitive (75%) and specific (63.6%) than other ultrasound measurements, for predicting difficult glottis view. A pilot study by Adhikari *et al*.[6] demonstrated that SED can be used to distinguish difficult and easy glottis view. Based on the above observations, we included the skin to epiglottic measurement in MSH score and framed another airway scoring system U_{SED}-MSH score.

Traditional individual predictors have poor sensitivity, specificity and positive predictive value.[1,2] Numerous group scores, for example, Arne's, Wilson's etc., have been designed for predicting difficult intubation but none of them is 100% sensitive and specific.[3,4,14,15] The Wilson's and Arne's scoring systems have a sensitivity of 75–94%, but low positive predictive value 9–42%.[3,4] The Naguib model was found to be 82.5% sensitive, 85.6% specific but a positive predictive value 15.3%.[14] The predictive accuracy of any scoring system has varied greatly as a result of differences in criteria, study population characteristics, different clinical test and its cut off. Still, the best possible combination of individual predictors needs to be established. The ideal score for the prediction of difficult intubation should have high sensitivity and specificity, with low false positives and negatives. Low false-negative rate is very important as predicting difficult intubation as easy intubation can be life-threatening. The aim of any score is to detect as many patients as possible with difficult intubation to minimise the subsequent deleterious sequel. Therefore, a group score with the highest sensitivity, positive predictive value and negative predictive value is desirable. But, it's difficult to improve the positive predictive value as the prevalence of difficult intubation in the general population is low.[1,2]

The AUC in ROC for U_{SED}-MSH score was 0.928 and closer to 1, indicating that they have high validity than MSH Score (AUC = 0.763) ($p = <0.001$). This finding is supported by the observation made by Aruna *et al*.[8] They also showed that combining a USG measurement (skin to epiglottis distance) to a clinical predictor (modified Mallampati classification) improved predictive accuracy. The cut-off value for the SED varied in previous studies. It was 1.78–2.8 cm with varied sensitivity and specificity.[6,8] This difference could be due to sampling size and ethnicity of the study population.

The limitation of our study was that only one USG measurement (skin to epiglottis distance) and three clinical predictors (mentohyoid distance, mandibular subluxation and head extension) were taken for airway scoring system. We didn't consider previously established airway scoring system such as LEMON, Wilson risk score etc. Nonetheless, comparison with the gold standard tool would have further validated the findings of the study. The most common cause of difficult intubation is difficult glottis view on direct laryngoscopy.[16] Thus, our diagnostic criteria for difficult intubation were based on Cormack–Lehane grade, as a guide.[1,5,8] We didn't consider external laryngeal manoeuvre, the attempt of intubation, use of ancillary device etc., while defining difficult intubation. This could be the probable cause for overestimation of incidence of difficult laryngoscopy (20%) in our study. This study was conducted in the south Indian population, may not be applicable to other populations because of variations due to ethnicity. Further research is needed to validate our data, including patients with known factors for difficult intubation such as obesity, pregnancy etc., and to get precise cut-off value for 'SED' need to be established using larger sample size.

Thus, we concluded that an airway scoring system using the ultrasound measurements of SED along with the clinical predictors would be helpful in the prediction of difficult intubation.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to

be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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