Brazilian Journal of Anesthesiology 2023;73(5): 570—577

Sociedade Brasileira de Anestesiologia

Brazilian Journal of ANESTHESIOLOGY

ORIGINAL INVESTIGATION

Upper airway angle and glottic height: a prospective cohort to evaluate two new features for airway prediction

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Received 3 November 2021; accepted 29 April 2022
Available online 13 May 2022

KEYWORDS
Airway management;
Laryngoscopy;
Predictive values of tests;
Sensitivity and specificity

Abstract
Background: Predicting difficult direct laryngoscopies remains challenging and improvements are needed in preoperative airway assessment. We conceived two new tests (the upper airway angle and the glottic height) and assessed their association with difficult direct laryngoscopies as well as their predictive performance.
Methods: A prospective cohort was conducted with 211 patients undergoing general anesthesia for surgical procedures. We assessed the association between difficult laryngoscopies and modified Mallampati Test (MMT), Upper Lip Bite Test (ULBT), Mandibular Length (ML), Neck Circumference (NC), Mouth Opening (MO), Sternomental Distance (SMD), Thyromental Distance (TMD), Upper Airway Angle (UAA), and Glottic Height (GH). We also estimated their predictive values.
Results: Difficult laryngoscopy was presented by 12 patients (5.7%). Six tests were significantly associated with difficult laryngoscopies and their area under the ROC curve, and 95% CIs were as follows: UAA = 88.82 (81.86—95.78); GH = 86.43 (72.67—100); ML = 83.75 (72.77—94.74); NC = 79.17 (64.98—93.36); MO = 65.58 (45.13—86.02); and MMT = 77.89 (68.37—87.41).
Conclusion: We have found two new features (the UAA and the GH) to be significantly associated with the occurrence of difficult direct laryngoscopies. They also presented the best predictive performance amongst the nine evaluated tests in our cohort of patients. We cannot ensure, however, these tests to be superior to other regularly used bedside tests based on our estimated 95% CIs.

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https://doi.org/10.1016/j.bjane.2022.04.004

Introduction

Problems with tracheal intubation are the main cause of major airway-related complications during anesthesia and may unfold some life-threatening conditions.[1-3] Much effort has then been made to find out a way of anticipating its occurrence in order to prepare a suitable strategy to tackle this scenario.[4] However, despite the several bedside tests for airway assessment described so far, none of them have high accuracy to segregate easy and difficult intubations.[4-11]

This poor ability we currently have to identify difficult airways leads some anesthesiologists and researchers to question the actual utility of undertaking a preoperative airway assessment.[6] Notwithstanding, most airway guidelines recommend preoperative airway assessments.[12-15]

However, there is currently no consensus on what predictor or combination of tests we should rely on. It is also problematic to figure whether an airway will be difficult to manage when the patient holds predictors of ease and difficulty simultaneously. These are some issues that along with the inaccurate diagnostic performance of the available predictors highlight the need for seeking new approaches to improve preoperative airway assessment.

As such, we conceived the Upper Airway Angle (UAA) to predict difficult Direct Laryngoscopies (DLs). Since DLs may be defined as the impossibility to see glottic structures during laryngoscopy and it comes from our inability to line up the oral and the pharyngeal axes, we may assume that the more acute the angle between the oral axis and the pharyngeal axis with the patient already in intubating position, the more difficult the laryngoscopy tends to be.[3,16-18] For the sake of clinical applicability, we may also assume the line linking the mentum to the mandibular angle (line 1) as being representative of the oral axis, while the line linking the mandibular angle to the anterior border of the thyroid cartilage (line 2) as being representative of the pharyngeal axis. Therefore, the angle between lines 1 and 2 – the UAA (Fig. 1) – might be associated with difficult direct laryngoscopies.

Furthermore, as it seems well accepted that many different factors may influence the unfold of a difficult airway,[7] it is also reasonable to accept that we might benefit from predictors carrying information from different parts of the upper airway. Accordingly, we regard the UAA as a more comprehensive test, since it encompasses information on multiple features, as follows: mandibular shape – it changes line 1 and mandibular angle; thyromental and sternomental distances – they are expected to maintain correlation with the UAA see Figure 1; glottic height – it moves line 2 and hence changes the UAA; neck mobility – it is also assumed to be directly correlated with the UAA; and others still.

We also conceived an extra test: the glottic height (GH – the height from the mandibular angle to the prominence of the thyroid cartilage [Fig. 1]). We developed this test based on the rationale that the antero-posterior glottic position plays a prominent role in airway assessment – as inferred by a recent systematic review with meta-analysis[19] evaluating the thyromental height test – the height between the anterior border of the thyroid cartilage and the anterior border of the mentum.[20]

Based on the aforementioned, we primarily aimed to evaluate whether difficult direct laryngoscopies would be associated with both the UAA and the GH. Alternatively, we assessed the predictive performances of these new features and compared them with those of other widely used bedside tests.

Methods

Ethics

Ethical approval for this study (n° 3.738.989) was provided by the Ethical Committee of the Federal University of Pernambuco's Teaching Hospital (Chairperson: José Ângelo Rizzo) on December 2, 2019.

This prospective study was performed at the surgical theater of the Federal University of Pernambuco's Teaching Hospital between December 2019 and July 2021. The study started only after Ethical Committee approval, and patients were only included if they agreed to participate and signed the informed consent form or the informed assent form in the case of patients under 18 years of age.

We included patients scheduled for surgery under general anesthesia, aged > 15 years, and in a consecutive series. We excluded patients submitted to awake laryngoscopy and patients not submitted to direct laryngoscopy with a Macintosh blade, but no patient met the exclusion criteria. The variables evaluated were age; sex; height; weight; Body Mass Index (BMI); American Society of Anesthesiologists (ASA) physical status; Modified Mallampati Test (MMT); Mouth Opening (MO); Mandibular Length (ML); Neck Circumference (NC); Sternomental Distance (SMD); Thyromental Distance (TMD); Upper Lip Bite Test (ULBT); Upper Airway Angle (UAA); Glottic Height (GH); and difficult laryngoscopy.

Laryngoscopy was described as difficult when the anesthesiologist, using direct laryngoscopy with the Macintosh blade (Smiths Medical France Sas, 3–5 rue du Pont des Halles, 94656 Rungis, France), classified the patient as grade 3 or 4 according to the Cormack and Lehane classification system.[21]

A preanesthesia evaluation was performed just before surgeries assessing the predictors of difficult airways as follows:

MMT: Determined with patient seated; examiner's eyes at the level of patient's mouth; and patient with her/his mouth opened as widely as possible without phonation. The individual was then classified as Mallampati 1, 2, 3 or 4.[22]

SMD: Distance in centimeters between the superior border of the manubrium sterni and the bony point of the mentum, measured by a millimeter ruler with the patient in supine position, mouth closed, and head fully extended.

TMD: Distance in centimeters between the thyroid prominence and the most anterior part of the mental prominence of the mandible, measured by a millimeter ruler with the patient in supine position, mouth closed, and head fully extended.

ULBT: Patients were asked to bite upper lip as high as possible with the lower incisors. Then, they were classified as class I, lower incisors could bite the upper lip above the vermilion line; class II, lower incisors could bite the upper lip bellow the vermilion line; and class III, lower incisors could not bite the upper lip.

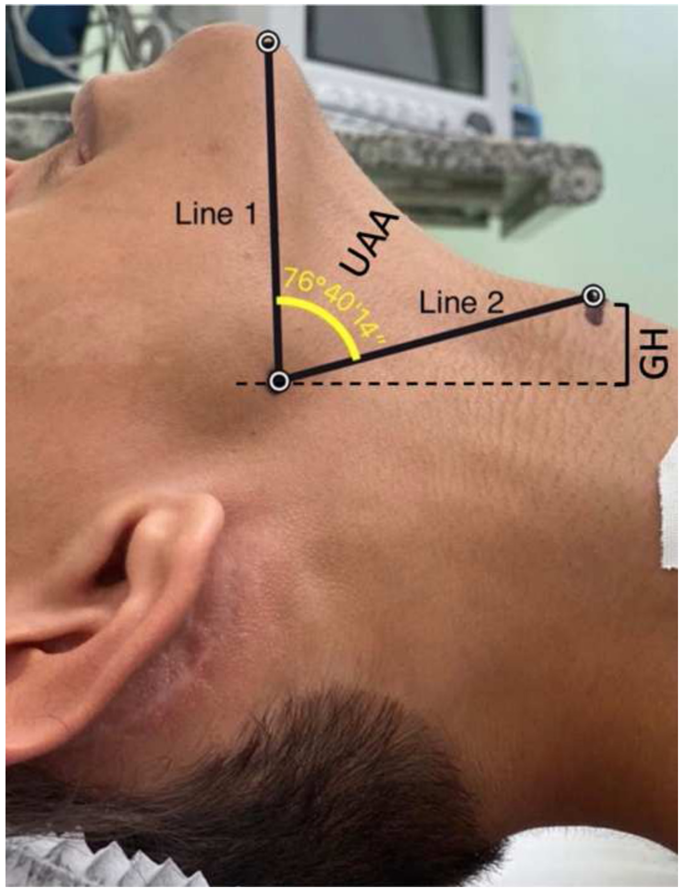

Figure 1 Upper Airway Angle (UAA) and Glottic Height (GH). While patient lies supine with head fully extended and performing the upper lip bite test, the angle made by lines 1 and 2 is the UAA and the height between the mandibular angle and the tip of the thyroid cartilage is the GH.

NC: Cervical perimeter measured with a ruler at the level of the thyroid cartilage.

MO: Distance between the upper and the lower incisors measured by a ruler with the mouth fully opened.

UAA: Angle formed by lines 1 and 2 (Fig. 1). Patients were put in supine position, head fully extended without pads under their occiputs, and performing the upper lip bite test. The anatomic landmarks were assessed by physical exam and discriminated on the skin surface by pen marks for posterior measurement of the UAA. A side photo of the patient's face and neck was then taken by the back camera of an Apple iPhone 11 Pro Max, model A2218 (Foxconn, Zhengzhou, China). The camera was placed at 30 cm from patient's head, 90 degrees with its bed — both measures ensured by appropriate rulers. Later, the angle was measured from the photo by Fiji, a free software program.[23] The angle measurements of all photos were performed by the first author (CC), who also performed a second measurement for 50 random patients eight weeks after the first assessment. We invited a person not involved in any way with the research to perform a third independent measure of the 50 randomly chosen participants. These multiple measures were for assessment of intra and inter-observer reliability. CC did not take part of neither the pre-anesthetic assessment nor the upper airway manipulations.

GH: Height between the mandibular angle and the thyroid prominence with patients in the same position as for the measurement of the UAA (Fig. 1). The GH was also taken from the patients' pictures with the aid of the Fiji software. Multiple independent measures were also taken for assessment of intra and inter-observer reliability as for the UAA.

ML: Length between the mentum and the mandibular angle. This measure was also taken from photos through the Fiji software.

The preanesthetic evaluation, including skin marks and photo captures, was performed by the second author (DdaS) and the third author (ML), who were not involved in induction of anesthesia or laryngoscopies.

Following intravenous access and routine monitoring (i. e., ECG, pulse oximetry, and non-invasive blood pressure), the patients were put in sniffing position and pre-oxygenated for 3—5 minutes. General anesthesia was induced according to the clinical judgment of the attending anesthesiologist — no standard protocol. After neuromuscular blockade, a manual facemask ventilation was performed for 3 minutes if the patient was not submitted to rapid sequence intubation. The laryngoscopies and the tracheal intubations were then carried out using the appropriate Macintosh blade by one of the residents or attending anesthesiologists, who were not aware of the preanesthetic evaluation.

Statistical analysis

Data analysis was performed using the R project software program.[24] First, a descriptive analysis was performed, with percentages and measures of central tendency and dispersion (means and standard deviation, SD) being calculated. For categorical variables, the chi-square and Fisher's exact tests were used. Student's *t*-test was used for quantitative variables with normal distribution, while the Wilcoxon test was applied for those quantitative variables with non-normal distribution. We also evaluated the presence of correlation between the Cormack and Lehane classification and both the UAA and the GH by the Spearman method.

We built nine different univariable models and their ROC curves and defined their AUC and further predictive values.

For sample size calculation, we first conducted a pilot study with 50 patients. The OpenEpi[25], version 3 − a free and open-source software program for epidemiological statistics − was used for estimations with both confidence interval and power of 95%.[26] We considered a frequency of difficult laryngoscopy of 11%[26] and employed data from the pilot study as follows: UAA for easy laryngoscopy (mean = 63; SD = 11.9); UAA for difficult laryngoscopy (mean = 46; SD = 3.6). The sample size was then estimated in 14 patients (12 easy and 2 difficult laryngoscopies). As the pilot study had already surpassed the estimated sample for the primary objective, we decided to collect data to evaluate the secondary objective: predictive performance of the UAA. We assumed MMT sensitivity to be 50% and specificity to be 80%.[26] A sample of 12 positive outcomes would then be needed to catch a sensitivity of 90% for the UAA, at the same MMT specificity, for a *p*-value of 0.039 and a power of 0.889.[27]

Results

A total of 211 patients were enrolled for the study without any exclusion (Fig. 2). Difficult laryngoscopy was present in 12 patients (5.7%). Age ranged from 15 to 84 years; weight from 33 to 164 Kg; height from 130 to 188 cm; and BMI from 13.6 to 61.7 $kg.m^{-2}$. Additional descriptive analysis is summarized in Table 1.

Intubators' experience ranged from less than one month (novice residents) up to 32 years (experienced anesthetists).

The observer variability for the UAA assessed by the intraclass correlation coefficient was as follows: intra-observer variability (ICC = 0.88; 95% CI: 0.80 to 0.93; $p < 0.001$) and inter-observer variability (ICC = 0.96; 95% CI: 0.92 to 0.97; $p < 0.001$). For the GH, we had the following values: intra-observer variability (ICC = 0.92; 95% CI: 0.86 to 0.95; $p < 0.001$) and inter-observer variability (ICC = 0.98; 95% CI: 0.96 to 0.99; $p < 0.001$).

The results from the bivariate analyses for difficult laryngoscopy are displayed in Tables 1 and 2.

The Cormack and Lehane classification was negatively correlated with the UAA (r = -0.22; p = 0.001) and positively correlated with the GH (r = 0.14; p = 0.036).

We built nine univariable predictive models for difficult laryngoscopy: one for UAA; one for GH; one for ML; one for NC; one for MMT; one for ULBT; one for MO; one for SMD; and one for TMD. We also plotted the ROC curves (Fig. 3) and estimated the Area Under the ROC Curve (AUC) for each model (Table 2). The Youden index was used to determine the cut-off values for categorization of each feature in two classes: predictive of ease or difficulty. Forest plots with the estimated AUC, sensitivity, and specificity as well as their 95% CIs for each predictor are displayed in Figure 4. The predictive values calculated from these cut-offs are presented in Table 3.

The UAA was negatively correlated with the number of intubation attempts (r = -0.22; p = 0.002). The GH did not reach statistically significant correlation with this outcome (r = 0.09; p = 0.213).

All the results presented in this paper as well as further results may be checked in the published analysis code: https://rpubs.com/clistenescarvalho/UAAandGH.

Our data set can also be checked in the Mendeley Data (DOI: 10.17632/vvkx4hjmp3.1).[28]

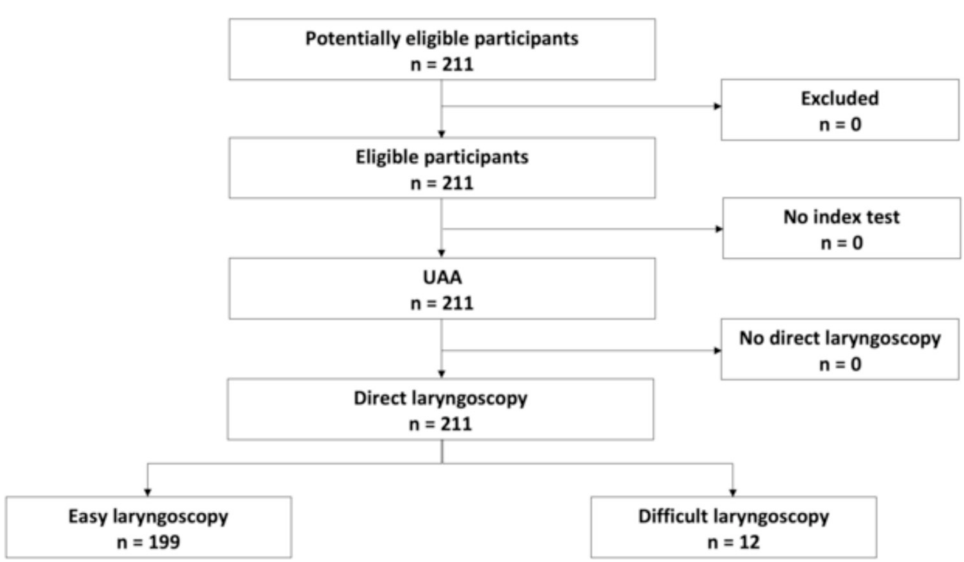

Figure 2 Diagram with the flow of participants through the study.

Table 1 Demographic data and ASA physical status. Values are mean (SD) or n (%).

Characteristics	Laryngoscopy			*p*-value
	Total n = 211	Easy n = 116	Difficult n = 9	
Age; years	47.7 (16.3)	47.2 (16.2)	56.6 (15.1)	0.063
Height; cm	162.2 (10)	162 (9.8)	164.4 (12.3)	0.661
Weight; kg	72.2 (18.4)	71.8 (18.4)	79.6 (17)	0.094
BMI; kg.m^{-2}	27.4 (6.5)	27.3 (6.6)	29.3 (4.9)	0.138
Sex				0.077
Female	130 (61.6)	126 (63.3)	4 (33.3)	
Male	81 (38.4)	73 (36.7)	8 (66.7)	
ASA Classification				0.206
I	82 (39.4)	80 (40.8)	2 (16.7)	
II	97 (46.6)	90 (45.9)	7 (58.3)	
III	29 (14)	26 (13.3)	3 (25)	
IV	0 (0.0)	0 (0.0)	-	

SD, Standard Deviation; ASA classification, physical status classification according to the American Society of Anesthesiology system; BMI, Body Mass Index; < Less; ≥ Greater or equal.

Discussion

The present study has revealed a significant association between difficult laryngoscopies and two new measures, the Upper Airway Angle (UAA) and the Glottic Height (GH). These two tests presented the best predictive values amongst the nine investigated tests (Table 3). However, when accounting for the uncertainty from the analyses (Fig. 4), we cannot ensure these tests to have higher accuracy than regularly used bedside tests. To overcome such flaw, further research with a larger sample size would be necessary.

Although our results have not demonstrated the UAA and the GH to ideally segregate easy and difficult laryngoscopies, these two features could somewhat improve what we currently have to predict difficult airways. The threshold of 60 degrees for the UAA had a sensitivity of 100%. Having an UAA < 60° might then indicate the use of a videolaryngoscope from the first attempt, as an example.

Table 2 Distribution of the patients according to different predictive tests in the bivariate analysis as a function of whether laryngoscopy was easy or difficult. Rows displaying significant associations are highlighted in grey.

Variable		Laryngoscopy		Bivariate analysis	
		Easy (n = 199) (n = 116)	Difficult (n = 12)	Odds ratio Fisher (95 CI)	Chi-square (*p*-value)
UAA	Easy	125	0	Inf (4.49–Inf)	< 0.001
	Difficult	74	12		
GH	Easy	18	2	51.06 (9.79–514.41)	< 0.001
	Difficult	17	10		
ML	Easy	128	2	9.05 (1.85–87.35)	0.001
	Difficult	70	10		
NC	Easy	159	5	5.79 (1.49–24.48)	0.005
	Difficult	38	7		
MMT	Easy	146	4	5.46 (1.39–25.80)	0.006
	Difficult	53	8		
MO	Easy	188	9	5.61 (0.86–27.18)	0.036
	Difficult	11	3		
ULBT	Easy	134	10	0.41 (0.04–2.02)	0.346
	Difficult	65	2		
SMD	Easy	161	8	2.12 (0.44–8.38)	0.262
	Difficult	38	4		
TMD	Easy	103	4	2.14 (0.55–10.02)	0.247
	Difficult	96	8		

UAA, Upper Airway Angle (easy ≥ 60°; difficult < 60°); GH, Glottic Height (easy ≤ 3.5 cm; difficult > 3.5 cm); ML, Mandibular Length (easy ≤ 9 cm; difficult > 9 cm); NC, Neck Circumference (easy ≤ 40 cm; difficult > 40 cm); MMT, Modified Mallampati Test (easy = I,II; difficult = III, IV); MO, Mouth Opening (easy ≥ 4 cm; difficult <4 cm); ULBT, Upper Lip Bite Test (easy = I; difficult = II, III); SMD, Sternomental Distance (easy ≥ 15 cm; difficult < 15 cm);TMD, Thyromental Distance (easy ≥ 8.5 cm; difficult < 8.5 cm); 95% CI, 95% Confidence Interval.

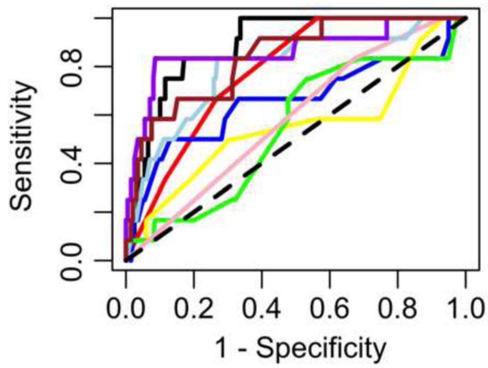

Figure 3 Receiver operating characteristic curve of different tests for prediction of difficult laryngoscopies. Black line: upper airway angle; purple: glottic height; brown: mandibular length; light blue: neck circumference; red: Modified Mallampati Test; blue: mouth opening; pink: upper lip bite test; yellow: sternomental distance; green: thyromental distance. The black dashed line represents an AUC of 50%, corresponding to classifying every patient as easy or everyone as difficult.

The GH also presented a prominent performance amongst the evaluated tests with the highest overall and balanced accuracies as well as the highest positive predictive value. It may highlight the important role of the antero-posterior glottic position on the unfold of a difficult airway — what was also inferred from a recent systematic review evaluating the predictive performance of the thyromental height for difficult laryngoscopies 19]. However, although the GH has more properly segregated the easy and the difficult laryngoscopies in our cohort of patients as compared to the UAA, the highest sensitivity (100%) of this latter test may be more clinically useful as the focus of the airway assessment is supposed to lie on the difficult airways. We should bear in mind, however, this estimated sensitivity needs to be more precisely defined by future research with a larger sample size.

An alternative approach might include multivariable models or composite scores with these two features — what we did not evaluate due to our limited number of positive outcomes — 12 events. We assume such approaches would overcome their individual performance as it has been demonstrated to happen with other predictors — an expected behavior since we have a multitude of factors potentially influencing the appearance of difficult airways.[7,8]

Regardless of the diagnostic performance presented by the evaluated tests, we should keep in mind that they are still valuable tools throughout airway management.[7,12-15] We may sometimes be disappointed by test errors, but it may be due to how we face the problem. Airway managers might avoid looking at these tests purely as diagnostic and try to see them also as risk factors, which augment the chances of having a difficult airway when present. Difficult laryngoscopies are relatively infrequent occurrences and even with the presence of a GH > 3.5 cm, which enhances the odds of having a difficult laryngoscopy by 51 times, the unfold of an actual difficult laryngoscopy will still be less likely than that of an easy laryngoscopy. We should not neglect such increased odds, however.

Although our results for the clinically used tests cannot be directly compared to those of recent meta-analyses[26,29] — because we have determined our own optimal thresholds and they differed from those regularly used, we could see an unexpected poor predictive performance of the ULBT. This result drew our attention to concerns about representativeness of our sample and consequently about the external validity of our results — a concern to be addressed by further research.

Readers should have in mind some limitations of the present work when interpreting our results. Apart from what was already discussed such as the uncertainty related to our analyses and the concern about external validity, as the first attempt to evaluate the UAA and the GH, we did not have appropriate tools to draw these measures directly from patients. We consequently extracted them from pictures, which is not ideal for clinical practice and may have influenced the accuracy of these measures. The same is valid for the ML, which was also extracted from pictures. Therefore, further studies might try to directly draw these measures. Additionally, as the predictors' performance were tested in

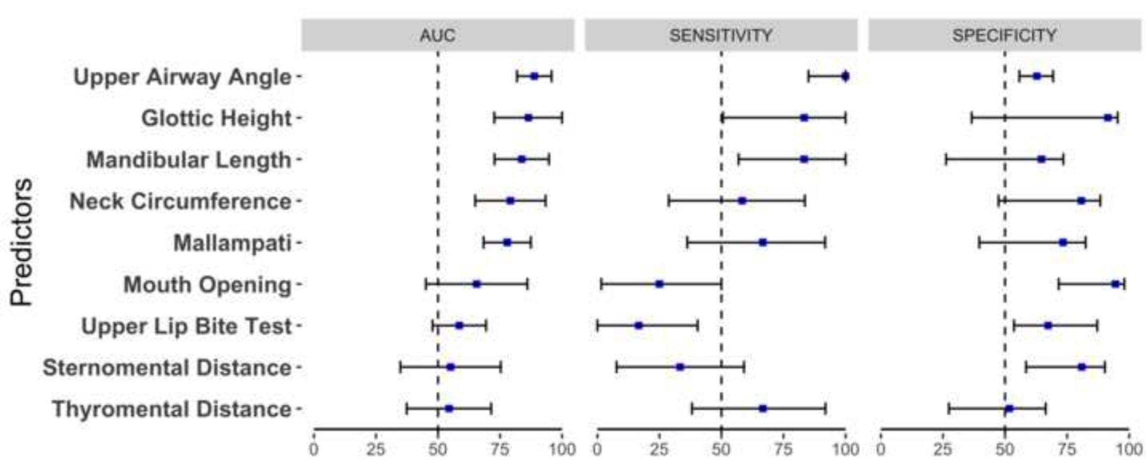

Figure 4 Forest plot with the predictive values of different tests for difficult direct laryngoscopy. The blue squares represent the results of the Area Under the ROC Curve (AUC) as well as the sensitivity and the specificity for the optimal thresholds. The bars represent the estimated 95% CIs. The dashed vertical line in the AUC facet represents the lack of diagnostic performance. The dashed lines in the sensitivity and the specificity facets are only to support comparisons amongst the tests. The data is sorted by descending AUC.

Table 3 Predictive values of different tests for difficult direct laryngoscopy. Data is sorted by descending AUC.

Features	AUC (95% CI)	Acc (95% CI)	Bal Acc	Sens	PPV	Spec	NPV
UAA	88.82 (81.86–95.78)	64.93 (58.1.5–71.4)	81.4	100	14	62.8	100
GH	86.43 (72.67–100)	91 (86.2–94.5)	87.4	83.3	37	91.4	98.9
ML	83.75 (72.77–94.74)	65.7 (58.9–72.1)	74	83.3	12.5	64.6	98.5
NC	79.17 (64.98–93.36)	79.4 (73.3–84.7)	69.5	58.3	15.6	80.7	97
MMT	77.89 (68.37–87.41)	73 (66.5–78.9)	70	66.7	13.1	73.4	97.3
MO	65.58 (45.13–86.02)	90.5 (85.7–94.1)	59.7	25	21.4	94.5	95.4
ULBT	58.58 (47.80–69.37)	64.5 (57.6–70.9)	42	16.7	3	67.3	93.1
SMD	55.07 (34.84–75.29)	78.2 (72–83.6)	57.1	33.3	9.5	80.9	95.3
TMD	54.42 (37.39–71.44)	52.6 (45.6–59.5)	59.2	66.7	7.7	51.8	96.3

UAA, Upper Airway Angle; GH, Glottic Height; ML, Mandibular Length; NC, Neck Circumference; MMT, Modified Mallampati Test; MO, Mouth Opening; ULBT, Upper Lip Bite Test; SMD, Sternomental Distance; TMD, Thyromental Distance; Sens, Sensitivity; PPV, Positive Predictive Value; Spec, Specificity; NPV, Negative Predictive Value; Acc, overall accuracy; Bal Acc, Balanced Accuracy; AUC, Area Under the ROC Curve.

the same set of data from which we estimated the thresholds, we may have had some overfitting and consequently some overestimated performance. Also, we did not evaluate head extension and consequently we cannot ensure the performance of the UAA is not only a reflex of this feature. Besides, the airway managers' experience varied too much, and it may have had some influence over our results, even though the 12 difficult laryngoscopies were checked and confirmed by an experienced anesthesiologist with at least 5 years of experience after failure by the resident. A further concern is related to the lack of a drug protocol for anesthesia induction, with different patients being submitted to different combinations of inductors, opioids, and neuromuscular blocking agents. This way, patients may have been managed under different conditions of hypnosis and neuromuscular blockade.

In conclusion, we have found two new measures (the UAA and the GH) to be significantly associated with the occurrence of difficult direct laryngoscopies. These two tests also held the best predictive performances amongst the nine evaluated tests in our cohort of patients. However, we cannot ensure their superiority as compared to regularly used bedside tests due to the amount of uncertainty present in our analyses.

Conflicts of interest

The authors declare no conflicts of interest.

Acknowledgments

The authors are grateful to the Hospital das Clínicas da Universidade Federal de Pernambuco, Department of Anesthesiology, Recife, Pernambuco, Brazil, the institution where this study was conducted.

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