Rev Bras Anestesiol. 2020;70(2):125-133

Brazilian Journal of ANESTHESIOLOGY
Revista Brasileira de Anestesiologia

Sociedade Brasileira de Anestesiologia

CLINICAL RESEARCH

Evaluation of bedside tests and proposal of a model for predicting difficult laryngoscopy: an observational prospective study☆☆

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Received 14 August 2019; accepted 8 February 2020
Available online 17 May 2020

KEYWORDS
Airway assessment;
Difficult laryngoscopy;
Predictive tests;
Predictive multivariate model;
Sensitivity and specificity

Abstract
Background and objectives: The prediction of difficult laryngoscopy is based on tests that assess anatomic characteristics of face and neck. We aimed to identify the most accurate tests and propose a multivariate predictive model.
Methods: This prospective observational study included 1134 patients. Thyromental Distance (TMD), Sternomental Distance (STMD), Ratio of Height-to-Thyromental Distance (R-H/TMD), Neck Circumference (NC), Ratio of Neck Circumference-to-Thyromental Distance (R-NC/TMD), Hyomental Distance with head in Neutral Position (HMD-NP) and at Maximal Extension (HMD-HE), Ratio of Hyomental Distance at Maximal head extension-to-hyomental distance in neutral position (R-HMD), Mallampati Class (MLC), Upper Lip Bite Test (ULBT), Mouth Opening (MO) and Head Extension (HE) were assessed preoperatively. A Cormack-Lehane Grade ≥ 3 was defined as Difficult Laryngoscopy. Sensitivity, specificity, positive and negative predictive values were assessed for all tests. Multivariate analysis with logistic regression was used to create the predictive models.
Results: A model incorporating MLC, ULBT, HE, HMD-HE and R-NC/TMD showed high prognostic accuracy; $x^2(5) = 109.12$, $p < 0.001$, AUC = 0.86, $p < 0.001$). Its sensitivity, specificity and negative predictive value were 82.3%, 74.8% and 97.4%, respectively. A second model including two measurements not requiring patient's cooperation (R-NC/TMD and HMD-HE) exhibited good prognostic performance; $x^2(2) = 63.5$, $p < 0.001$, AUC = 0.77, $p < 0.001$. Among single tests, HE had the highest sensitivity (78.5%) and negative predictive value (96%).

☆ The study was carried out in two hospitals, General Hospital of Rethymno and George Papanikolaou General Hospital in Thessaloniki.
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https://doi.org/10.1016/j.bjane.2020.04.021
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Conclusions: A five-variable model incorporating MLC, ULBT, HE, HMD-HE and R-NC/TMD showed satisfyingly high predictive value for difficult laryngoscopy. A model including R-NC/TMD and HMD-HE could be useful in incapable patients. The most accurate single predictor was HE.
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PALAVRAS-CHAVE
Avaliação de via aérea;
Laringoscopia difícil;
Testes preditivos;
Modelo preditivo multivariado;
Sensibilidade e especificidade

Avaliação de testes à beira leito e proposta de modelo para prever laringoscopia difícil: estudo prospectivo observacional

Resumo
Justificativa e objetivos: A previsão de laringoscopia difícil se baseia em testes que avaliam as características anatômicas da face e pescoço. Nosso objetivo foi identificar os testes mais precisos e propor modelo preditivo multivariado.
Método: Estudo observacional prospectivo incluiu 1134 pacientes e avaliou no pré-operatório: Distância Tireomentoniana (DTM), Distância Esternomentoniana (DEM), razão Altura-Distância Tireomentoniana (A/DTM), Circunferência Cervical (CC), razão Circunferência Cervical-Distância Tireomentoniana (CC/DTM), Distância Hiomentoniana com a cabeça na Posição Neutra (DHM-PN) e em Extensão Máxima (DHM-EM), razão Distância Hiomentoniana com Cabeça em Extensão Máxima/Distância Hiomentoniana na posição Neutra (DHME/DHMN), Classe Mallampati (CML), Teste da Mordida do Lábio Superior (TMLS), Abertura da Boca (AB) e Extensão da Cabeça (EC). Grau Cormack-Lehane $\geq$ 3 foi definido como Laringoscopia Difícil. A sensibilidade, especificidade, valores preditivos positivo e negativo foram avaliados para todos os testes. A análise multivariada com regressão logística foi usada para criar modelos preditivos.
Resultados: Um modelo incorporando CML, TMLS, EC, DHM-EM e CC/DTM demonstrou alta precisão prognóstica ($x^2(5) = 109,12$, $p < 0,001$, AUC = 0,86, $p < 0,001$). A sensibilidade, especificidade e valor preditivo negativo foram 82,3%, 74,8% e 97,4%, respectivamente. Um segundo modelo incluindo duas medidas que não necessitavam da cooperação do paciente (CC/DTM e DHM-EM) demonstrou bom desempenho prognóstico (x^2 $(2) = 63,5$; $p < 0,001$; AUC = 0,77, $p < 0,001$). Entre os testes individuais, EC teve a maior sensibilidade (78,5%) e valor preditivo negativo (96%).
Conclusões: O modelo de cinco variáveis incorporando CML, TMLS, EC, DHM-EM e CC/DTM mostrou valor preditivo satisfatoriamente alto para laringoscopia difícil. Um modelo que incluísse CC/DTM e DHM-EM poderia ser útil em pacientes com incapacidade. O preditor individual mais preciso foi EC.
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Introduction

Difficult airway management is one of the main concerns of clinical anesthesiologists, as it may cause serious, even fatal, complications.[1] The reported incidence of difficult laryngoscopy – defined as direct laryngoscopic view of a Cormack-Lehane grade $\geq$ 3 – in surgical patients without known or obvious airway deformities is estimated to be 5.8%.[2] Although several predictive tests have been developed and used in clinical practice as bedside screening tests, no single predictor is considered to be sufficiently reliable.[2] Thus, anesthesiologists usually rely on the combination of multiple tests for the prediction of difficult airway.

The aim of the present study was to assess the predictive accuracy of anatomic measurements and bedside tests that are used as single predictors of difficult airway and develop a reliable multivariate predictive model.

Methods

One thousand one hundred and thirty four (1134) patients were included in this prospective open cohort study, which was approved by the Institutional Review Boards of the involved hospitals (General Hospital of Rethymno, Greece, 05/03/2013/nº 41, and George Papanikolaou General Hospital, Exohi, Thessaloniki, Greece, 20/09/2013/nº 878) and was registered on ClinicalTrials.gov (NCT02957084). The Strengthening the Reporting of Observational studies in Epidemiology (STROBE) guidelines were followed for the presentation of the study.

Adult patients, American Society of Anesthesiology (ASA) physical status I–II, scheduled for surgical procedures under general anesthesia with tracheal intubation were assessed for eligibility to be included in the study. Exclusion criteria were known airway malformations, indication for awake intubation, cervical spine pathology

Table 1 Description of the measured anatomic features: Thyromental Distance (TMD), Sternomental Distance (STMD), Ratio of Height to Thyromental Distance (R-H/TMD), Neck Circumference (NC), Ratio of Neck Circumference to Thyromental Distance (R-NC/TMD), Hyomental Distance with head in Neutral Position (HMD-NP) and at maximal Extension (HMD-HE), Ratio of Hyomental Distance at maximal head extension to hyomental distance in the neutral position (R-HMD), Mallampati Class (MLC), Upper Lip Bite Test (ULBT), Mouth Opening (MO) and Head Extension (HE).

Measured anatomic features	Definition/Measurement	Conditions
TMD (cm)	Defined as the straight-line distance (cm) from the lower border of the thyroid notch to the bony point of the mentum	Head extended Closed mouth
STMD (cm)	Defined as the straight-line distance (cm) from the bony point of the mentum to the upper border of the manubrium sterni	Head extended Closed mouth
NC (cm)	Measured at the level of the thyroid cartilage	Head in neutral position
R-H/TMD	Each patient's height (cm) was recorded in order to calculate the R-H/TMD	
R-NC/TMD	Each patient's NC (cm) was recorded in order to calculate the R-NC/TMD	
HMD-NP (cm)	Distance (cm) from the tip of the hyoid bone to the anterior part of the mentum	Head in neutral position Mouth closed Without swallowing
HMD-HE (cm)	Distance (cm) from the tip of the hyoid bone to the anterior part of the mentum	Head maximally extended Without lifting the shoulders
R-HMD	Defined as the ratio of the HMD at extreme head extension to the HMD measured with the head in the neutral position	
MLC	Class 1: soft palate, fauces, entire uvula, anterior and posterior tonsillar pillars visible	Sitting position
	Class 2: soft palate, fauces, uvula visible	Head in neutral position
	Class 3: soft palate and base of uvula visible	Mouth wide open with tongue fully protruding
	Class 4: only hard palate visible.	Without phonation
ULBT	Class 1: lower incisors can bite the upper lip above the vermilion line Class 2: lower incisors can bite the upper lip below the vermilion line Class 3: lower incisors cannot bite the upper lip	
MO (cm)	Measured with the mouth fully open (cm)	
HE (°)	Reference points: angle of the jaw and upper incisor teeth. Measuring side of the goniometer moved parallel to the upper incisors, and maximum extension recorded	Sitting position Head maximally extended

requiring specific manipulation, severe obesity (Body Mass Index, BMI > 35 kg.m^{-2}) and risk of aspiration requiring rapid sequence intubation/application of cricoid pressure (obstetric cases included). A written informed consent was obtained from all participants.

In order to minimize bias, one investigator (C.L.) performed all the anatomic measurements and tests using a measuring tape and a goniometer, and calculated the derived ratios, preoperatively. This investigator was not further involved in the airway management (i.e. laryngoscopy and intubation). The following 12 parameters were assessed: Thyromental Distance (TMD), Sternomental Distance (STMD), Ratio of Height to Thyromental Distance (R-H/TMD), Neck Circumference (NC), Ratio of Neck Circumference to Thyromental Distance (R-NC/TMD), Hyomental Distance with the head in Neutral Position (HMD-NP), Hyomental Distance with the Head at maximal Extension (HMD-HE), Ratio of Hyomental Distance at maximal head extension-to-hyomental distance in the neutral position (R-HMD),[3] Mallampati Class (MLC), Upper Lip Bite Test (ULBT), Mouth Opening (MO) and Head Extension (HE). All parameters are described in Table 1.

In the operating room, standard monitoring was applied to all patients (electrocardiogram, pulse oximeter and non-invasive blood pressure measurement) and a peripheral vein catheter was inserted for administration of drugs and fluids. Anesthesia was induced with propofol 2.5 mg.kg^{-1} and fentanyl 2 μg.kg^{-1}IV. Rocuronium 1 mg.kg^{-1} IV was given to facilitate tracheal intubation (after 90 seconds) with the patient's head in the ''sniffing position''. A senior anesthesiologist, blind to the preoperative measurements, performed a direct laryngoscopy using a Macintosh blade; a nº 3 blade was used for medium sized patients and a nº 4 blade for large sized patients. Sixteen anesthesiologists with a clinical experience of more than 5 years were involved in the airway management of the studied patients. The laryngoscopic view was classified according to the Cormack-Lehane grade from 1 to 4: vocal cords completely visible; arytenoids visible; only epiglottis visible; or only soft palate visible, respectively. Difficult laryngoscopy was defined as a Cormack-Lehane grade 3 or 4 under direct vision, by the use of an appropriate blade size, without application of external maneuvers.

The sensitivity, specificity, positive and negative predictive values for difficult laryngoscopy were assessed for all studied variables. Receiver Operating Characteristic (ROC) curves were used to identify the optimal cut-off point of each variable and the Area Under Curve (AUC) was calculated to assess its prognostic accuracy. Multivariate analysis with logistic regression, including TMD, STMD, R-H/TMD, NC, R-NC/TMD, HMD-NP, HMD-HE, R-HMD, MLC, ULBT, MO and HE, was used to create a model predicting difficult laryngoscopy. Variables that do not require the patient's cooperation to be measured (TMD, STMD, R-H/TMD, NC, R-NC/TMD, HMD-NP, HMD-HE and R-HMD) were included in another multivariate analysis for the development of a second risk prediction model.

The primary end-point of the study was the predictive value of the multivariate model. Secondary end-points were the accuracy of each single test in the whole sample and differences between the genders, regarding the optimal cut-off points and the diagnostic value of the studied tests when using gender-specific cut-off points.

The sample size of the study was based on the reported incidence of difficult laryngoscopy in 50,760 patients without airway malformations 5.8% (4.7%−7.5%)[2] and in a representative sample (387 patients) of the Greek population (12.6%).[4] A sample size of at least 640 patients would be necessary, as estimated for a 99% Confidence Interval (CI) by the use of the Epi Info statistical package (version 7.2.2.6). We decided to increase it by about 2-fold in order to maintain its power to detect the agreement between the Cormack-Lehane grade and the predictors. The statistical analysis was performed using SPSS Software (version 22) and Med Calc (version 11.6). Variables were tested for normality of distribution with Kolmogorov-Smirnov test. Mann-Whitney test was used for the comparisons of Cormack-Lehane grade, TMD, STMD, R-H/TMD, NC, R-NC/TMD, HMD-NP, HMD-HE, R-HMD, MLC, ULBT, MO and HE between men and women. ROC analysis was used to assess the optimal cut-off values of predictors and AUC with 95% CI. Sensitivity, specificity, positive and negative predictive values were calculated in order to test the predictive power of each variable. The incidence of Cormack-Lehane grade $\geq$ 3 among the 16 anesthesiologists who performed the laryngoscopies was compared using the X^2 test. The level of statistical significance for the comparisons was set at 0.05 ($p < 0.05$). Results are presented as mean±SD, 95% CI or as n (%). Logistic regression analysis was used to produce the multivariate models. The Hosmer-Lemeshow test was used to assess goodness of fit of the risk prediction models ($p > 0.05$).

Results

Data from 1134 patients were analyzed. Demographic characteristics and Cormack-Lehane grades are shown in Table 2. There was no change of the laryngoscopic blade size in any patient. The incidence of difficult laryngoscopy (Cormack-Lehane grade 3 or 4) was 10.5%, without statistically significant difference among the involved anesthesiologists (X^2 = 6.884, p = 0.142). In 1091 patients (96.2%), tracheal intubation was achieved at first attempt and in 34 patients (3%) at second attempt, after the application of external pressure/maneuvers, the use of a gum elastic bougie and/or an endotracheal tube of smaller size. In nine cases (0.8%) intubation was achieved at third attempt, either by another anesthesiologist or with the use of extra equipment or other special devices (i.e. intubating laryngeal mask).

Table 2 Demographic data and the Cormack-Lehane grade of the laryngoscopic view in the studied sample. Values are expressed as mean ± SD or as n (%).

Patients' characteristics	Values
Men	560 (49.4%)
Women	574 (50.4%)
Age (years)	49.4 ± 18.4
Weight (kg)	75.8 ± 14.2
Height (cm)	169.4 ± 9
Body Mass Index (BMI, kg. m^{-2})	26.4 ± 4
Cormack-Lehane grade 1	849 (74.9%)
Cormack-Lehane grade 2	166 (14.6%)
Cormack-Lehane grade 3	86 (7.6%)
Cormack-Lehane grade 4	33 (2.9%)

Logistic regression analysis was performed using a forward LR method, which incorporated all the studied variables. A model including 5 variables, namely MLC, ULBT, HE, HMD-HE and R-NC/TMD, exhibited high prognostic value; $x^2(5) = 109.12$, $p < 0.001$). The Hosmer−Lemeshow test indicated a good model fit (p = 0.85, $p > 0.05$). The ROC curve of the risk model − describing its screening characteristics − found the AUC to be 0.86 (95% CI 0.83−0.88, $p < 0.001$), showing that the model had a statistically significant diagnostic accuracy. The sensitivity, specificity, positive and negative predictive values of the logistic regression model were 82.3% (95% CI 70.5%−90.8%), 74.8% (95% CI 71.3%−78.1%), 26.6% (95% CI 23.3−30.2%) and 97.4% (95% CI 95.7%−98.5%), respectively (Fig. 1).

A second multivariate analysis was performed using a forward LR method that included variables that do not require the patient's cooperation for their measurement: TMD, STMD, R-H/TMD, NC, R-NC/TMD, HMD-HE, HMD-NP, R-HMD. A model incorporating two of the above variables, namely R-NC/TMD and HMD-HE, exhibited good prognostic value, $x^2(2) = 63.5$, $p < 0.001$. The Hosmer-Lemeshow test indicated a good logistic regression model fit (p = 0.68 > 0.05). The AUC of this model was found to be 0.77 (95% CI 0.74−0.8, $p < 0.001$). The sensitivity, specificity, positive and negative predictive values of the model were 75.2% (95% CI 71.8%−78.4%), 70.8% (95% CI 58.2%−81.4%), 22.2% (95% CI 16.3%−29.5%) and 96.2% (95% CI 95.4%−96.9%), respectively (Fig. 2).

The statistical characteristics of the proposed two multivariate models with the variables selected to be included or not in the final equation − on the basis of their statistical significance − are presented in the Tables 3 and 4.

Table 3 Multivariate model characteristics with 5 variables.

Variables included in the equation due to statistical significance					
	B	S.E.	Odds Ratio	95% C.I.	*p*-value
MLC	0.56	0.14	1.75	1.32-2.32	< 0.001
ULBT	0.8	0.21	2.22	1.48-3.34	< 0.001
R-NC/TMD	0.7	0.22	2	1.31-3.1	0.01
HE	-0.06	0.02	0.94	0.9-0.98	0.002
HMD-HE	-0.6	0.16	0.55	0.4-0.75	< 0.001
Constant	-2.45	1.8	0.09		0.17
$x^2(5) = 109.12$, $p < 0.001$					
AUC					
Area	0.86				
95% CI	0.82–0.9				
p-value	< 0.001				
Variables not included in the equation due to lack of statistical significance					
	Score			*p*-value	
MO	3.43			0.06	
TMD	1.15			0.28	
STMD	0.002			0.96	
R-H/TMD	0.3			0.58	
NC	1.25			0.26	
HMD-NP	0.72			0.4	
R-HMD	0.4			0.84	

Table 4 Multivariate model characteristics with 2 variables that don't require patient's cooperation for measurement.

Variables included in the equation due to statistical significance					
	B	S.E.	Odds Ratio	95% C.I.	*p*-value
R-NC/TMD	0.81	0.19	2.25	1.56-3.25	< 0.001
HMD-HE	-0.7	0.15	0.5	0.37-0.67	< 0.001
Constant	-2.37	1.37	0.09		0.08
x^2 $(2) = 63.5$, $p < 0.001$					
AUC					
Area	0.77				
95% CI	0.74-0.8				
p-value	< 0.001				
Variables not included in the equation due to lack of statistical significance					
	Score			*p*- value	
TMD	2.69			0.1	
STMD	1.56			0.21	
R-H/TMD	0.05			0.82	
NC	3.08			0.08	
HMD-NP	0.87			0.35	
R-HMD	0.08			0.78	

TMD, Thyromental Distance; STMD, Sternomental Distance; R-H/TMD, Ratio of Height to Thyromental Distance; NC, Neck Circumference; R-NC/TMD, Ratio of Neck Circumference to Thyromental Distance; HMD-HE, Hyomental Distance with Head at maximal Extension; HMD-NP Hyomental Distance with head in Neutral Position; R-HMD, Ratio of Hyomental Distance at maximal head extension to hyomental distance in the neutral position; MO, Mouth Opening; HE, Head Extension.

The optimal cut-off points, sensitivity, specificity, positive and negative predictive values, and AUC for each test are presented in Table 5. The HE had the highest sensitivity, although NC, HMD-NP, HMD- HE and R-HMD exhibited high sensitivity, too (> 70%).

The mean values of all measured variables, except for HE ($p = 0.93$), differed significantly between genders ($p < 0.05$) and their optimal cut-off values were also gender dependent, as shown in Table 5.

Discussion

Large scale studies, prospective or retrospective, investigating the accuracy of bed-side tests and multivariate risk

Table 5 Cut-off points and measures of diagnostic accuracy of the studied predictive tests in the whole sample and each gender.

Predictive test	Cut-off value	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	AUC mean (95% CI)	p
TMD (cm)	≤ 7.5	38.7	85	23.2	92.2	0.64 (0.61–0.687)	< 0.001
TMD male	≤ 8	45.7	83.6	24	92.9		
TMD female	< 7	48.9	86.86	30.4	93.6		
STMD (cm)	≤ 17	68.9	54.7	15.1	93.7	0.67 (0.64–0.7)	< 0.001
STMD male	≤ 18.5	81.43	48.98	15.8	95.7		
STMD female	≤ 15	48.98	80.19	22.5	93.1		
R-H/TMD	> 21.25	47.1	81.6	23.1	92.9	0.66 (0.63–0.69)	< 0.001
R-H/TMD male	> 21.25	38.57	85.71	24.1	92.2		
R-H/TMD female	> 21.6	55.1	81.9	26.3	94		
NC (cm)	> 38	70.6	49.6	14.1	93.5	0.61 (0.59–0.64)	< 0.001
NC male	> 40.5	72.86	39.59	12.4	92.6		
NC female	> 38.5	44.9	82.67	23.3	92.7		
R-NC/TMD	> 4.94	52.9	78.7	22.6	93.4	0.69 (0.66–0.72)	< 0.001
R-NC/TMD male	> 4.94	51.43	75.7	19.5	92.9		
R-NC/TMD female	> 4.81	61.2	78.29	24.9	94.5		
HMD-HE (cm)	≤ 5.5	73.8	60.3	17.9	95.2	0.71 (0.68–0.74)	< 0.001
HMD-HE male	≤ 5.5	66.67	67.8	19.5	94.5		
HMD-HE female	≤ 5	84.62	58.56	19.3	97		
HMD-NP (cm)	≤ 4.5	73.8	58	17.1	95	0.7 (0.66–0.73)	< 0.001
HMD-NP male	≤ 4.5	64.1	64.7	17.6	93.9		
HMD-NP female	≤ 4	84.6	57.46	18.9	97		
R-HMD	> 1.2	73.8	54	15.9	94.6	0.66 (0.63–0.7)	< 0.001
R-HMD male	> 1.2	64.1	59.4	15.6	93.4		
R-HMD female	> 1.22	88.46	53.87	18.4	97.5		
MO (cm)	≤ 3.8	53.4	74.7	19.9	93.2	0.69 (0.66–0.72)	< 0.001
MO male	≤ 4.4	77.1	52	15.9	95.1		
MO female	≤ 3.7	51	78.1	21.5	93.1		
HE (°)[a]	≤ 35	78.5	60.4	18.9	96	0.72 (0.69–0.75)	< 0.001

TMD, Thyromental Distance; STMD, Sternomental Distance; R-H/TMD, Ratio of Height to Thyromental Distance; NC, Neck Circumference; R-NC/TMD, Ratio of Neck Circumference to Thyromental Distance; HMD-HE, Hyomental Distance with Head at maximal Extension; HMD-NP, Hyomental Distance with head in Neutral Position; R-HMD, Ratio of Hyomental Distance at maximal head extension to hyomental distance in the neutral position; MO, Mouth Opening; HE, Head Extension; PPV, Positive Predictive Value; NPV, Negative Predictive Value; AUC, Area Under Curve indicating the diagnostic accuracy of each test.

Statistical significance was set at $p < 0.05$.

[a] The cut-off point for HE was same for males and females.

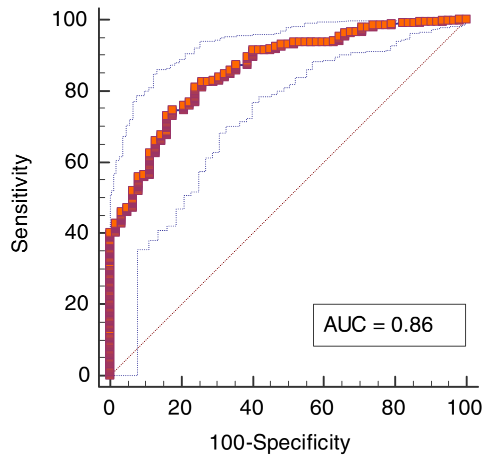

Fig. 1 Receiver Operating Characteristic (ROC) curve of the predictive model including 5 variables: Mallampati Class (MLC), Upper Lip Bite Test (ULBT), Head Extension (HE), Hyomental Distance with Head at maximal Extension (HMD-HE), Ratio of Neck Circumference to Thyromental Distance (R-NC/TMD).

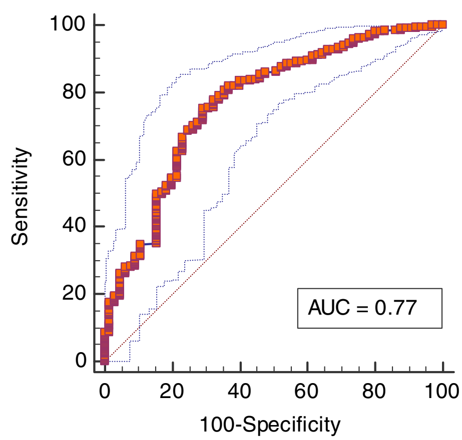

Fig. 2 Receiver Operating Characteristic (ROC) curve of the predictive model including 2 variables that do not require patient's cooperation for measurement: Ratio of Neck Circumference to Thyromental Distance (R-NC/TMD) and Hyomental Distance with Head at maximal Extension (HMD-HE).

models of difficult laryngoscopy are lacking.[5,6] The present study was prospective observational, included more than 1100 patients, evaluated 12 predictive tests and proposed two multivariate predictive models that could be used in cooperative and uncooperative patients.

Compared to previous research, we found a relatively high incidence of difficult laryngoscopy (10.5%);[2] possible explanations include the assessment of laryngoscopic view without external pressure or helpful maneuvers, and also the specific morphological features of the studied sample. However, similarly high prevalence (> 10%) has also been reported by other investigators.[4,7–9]

The primary end point of our study was the creation of an optimal predictive model. A model incorporating MLC, ULBT, HE, HMD-HE, R-NC/TMD exhibited a satisfyingly high predictive accuracy, significantly improved compared to the single predictive tests and other models that included fewer or other variables. The AUC (0.86), sensitivity, specificity and negative predictive value of this five-variable model demonstrated a high enough accuracy to make it a reliable tool for the prediction of difficult laryngoscopy.

Unfortunately, our results cannot be directly compared to the findings of other similar studies due to differences in the methodology, the definitions of difficult laryngoscopy/intubation, the assessed variables/risk indexes, and the racial characteristics of the studied population.[5–11] A study from Nigeria assessed five predictors in 380 West African patients. The authors found that the best combination for this race was MLC, TMD, MO, with sensitivity, specificity and positive predictive value of 84.6%, 94.6% and 35.5% respectively, but they did not report any results about AUC.[10] Another similar study from Indonesia included 277 Malay patients; the authors assessed three tests (MLC, TMD, R-HMD) and their combination. The 3 variable model exhibited good accuracy (AUC = 0.83), with sensitivity, specificity and negative predictive value of 60.7%, 88.8% and 69.9%, respectively.[11]

In the present study, we also assessed and analyzed eight variables that can be measured without the patient's cooperation; a model incorporating two of these variables, namely R-NC/TMD and HMD-HE, showed good prognostic accuracy (AUC = 0.77). We consider that it could be used in patients with physical or mental impairment, unable to perform other common tests such as MLC and ULBT. In a previous study including 341 Caucasians, four specific anatomic features of the neck that can be measured with minimal patient cooperation, namely TMD, STMD, R-H/TMD and NC, were studied.[4] The authors incorporated all four of them in a risk model, but it only achieved a moderate to fair predictive accuracy (AUC = 0.68).

The optimal cut-off points of TMD, R-H/TMD, NC, R-NC/TMD, HMD-HE, HMD-NP, R-HMD and MO in our sample were similar to those reported in previous studies,[4,12–19] while the cut-off point of STMD was higher compared to other studies.[20] Such measurements may differ among populations with dissimilar physical characteristics.[5] Additionally, different ways of measuring and scoring the head and neck extension may affect the results and make direct comparisons between studies difficult.[17] In our study we used the method described by Turkan et al.,[16] and the values and cut-off points for HE were in accordance with this study.

Similarly to previous research, we found different cut-off points in men and women.[21] However, the gender-specific cut-off points did not affect significantly the predictive accuracy of the tests, except for STMD, which became more accurate in men, and for HMD-HE, HMD-NP and R-HMD, that were more accurate in women.

In agreement with other studies we found that all tests are poor single predictors of difficult laryngoscopy, and thus, not reliable if used alone.[4,13,15,17–19]

Ideally, a predictive test should be both highly sensitive and specific, in order to identify almost all difficult laryngoscopies with the least false positive predictions. False negative predictions can lead to unanticipated difficult airway, inadequately prepared anesthesiologist and unfavorable sequelae for the patient. On the other hand, false positive predictions can cause unnecessary preparation and inconvenience, but no harm to the patient. Thus, the most critical problem in clinical practice is associated with false negative predictions, which are incorporated in the calculation formula of sensitivity and negative predictive value. Among the studied predictors, HE showed the best combination of high sensitivity and high negative predictive value, and thus, it was the most accurate single predictor. However, it requires the use of a goniometer, as well as patient's cooperation. The HMD-NP, HMD- HE and R-HMD were also highly ranked compared to the rest of the tests. While in other studies the R-H/TMD and NC were found to be accurate single predictors,[9,13,14] that was not the case in our sample.

All tests had a low positive predictive value, in accordance with previous findings.[4,10] As Yentis mentions in his editorial,[22] positive predictive value will always be low when the outcome of interest (in our case, difficult laryngoscopy) is not common.

A possible limitation of our study is that laryngoscopy was performed by different anesthesiologists; in order to eliminate bias we added the criterion of a more than 5 year clinical experience. Moreover, we performed a statistical analysis which showed that the incidence of difficult laryngoscopies did not differ among them. Another limitation, which cannot be avoided in this type of studies, is that our results are mostly affected by morphological characteristics and possibly do not apply to different racial groups. Therefore, our findings should be regarded carefully and extrapolated with caution to other populations.

Summary

A model including five variables (MLC, ULBT, HE, HMD-HE and R-NC/TMD) showed satisfyingly high accuracy in predicting difficult laryngoscopy. Another model including two variables (R-NC/TMD and HMD-HE) exhibited good prognostic performance and may be more practical in patients unable to cooperate. Among the studied tests, the HE was the most accurate single predictor of difficult laryngoscopy. Gender-specific cut-off points should be used for STMD, as they improved the prognostic accuracy in men and for the HMD-HE, HMD-NP and R-HMD, as they improved the prognostic accuracy in women.

Glossary

Thyromental Distance (TMD), Sternomental Distance (STMD), Ratio of Height to Thyromental Distance (RSternomental Distance (STMD), Ratio of Height to Thyromental Distance (R-H/TMD), Neck Circumference (NC), Ratio of Neck Circumference to Thyromental Distance (R-NC/TMD), Hyomental Distance with head in Neutral Position (HMD-NP) and at maximal Extension (HMD-HE), Ratio of Hyomental Distance at maximal head extension to hyomental distance in the neutral position (R-HMD), Mallampati Class (MLC), Upper Lip Bite Test (ULBT), Mouth Opening (MO), Head Extension (HE), Area Under Curve (AUC), Confidence Interval (CI).

Conflicts of interest

The authors declare no conflicts of interest.

Acknowledgments

The authors thank Mr Theodoros Sfakianakis, MSc for helping in the statistical analysis of data.

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