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RESEARCH

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Prediction of difficult mask ventilation in Thai adult patients undergoing elective surgery using ultrasound of distance from skin to hyoid bone, and from skin to thyroid isthmus: a prospective cohort observational study

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Abstract

Background A previous study showed that airway ultrasound, specifically the distance from the skin to the hyoid bone (DSHB), may be correlated with a higher risk of difficult mask ventilation (DMV). However, the study was conducted in Italy and lacks data for the Asian and Thai populations. This study aimed to predict DMV using pre-operative ultrasonography to measure the DSHB and from the skin to the thyroid isthmus (DSTI) in Thai patients undergoing elective surgery under general anesthesia.

Methods In total, 189 patients who underwent general anesthesia during elective surgery were enrolled in this prospective cohort observational study. Pre-operative physical examinations and airway evaluations were performed as usual. Airway ultrasound was performed to measure DSHB and DSTI before the anesthetic procedure. Anesthesiologists and nurse anesthetists performed bag-and-mask ventilation. DMV was assessed and recorded according to Han's mask ventilation classification in which DMV-0 indicates no attempt at mask ventilation; DMV-I indicates successful ventilation by mask; DMV-II indicates ventilation by mask with oral airway/adjuvant ventilation; DMV-III indicates that ventilation required two providers; and DMV-IV indicates the patient's inability to undergo mask ventilation.

Results Thirty (17%) patients were classified as having DMV-0, and DMV-I, II, and III classifications were observed in 126(67%), 18(10%), and 12(6%) patients, respectively. None of the patients were classified as DMV-IV. The DSHB medians were 0.4(0.3–0.6), 0.7(0.5–1), 0.7(0.6–0.8), and 0.6(0.3–0.9) cm in DMV-0, I, II, and III, respectively ($p < 0.001$). The DSTI medians were 0.9(0.8–1.1), 0.8(0.7–1.1), 0.7(0.6–0.9), and 0.8(0.8–1.4) cm for DMV-0, I, II, and III, respectively ($p = 0.041$). Multivariate logistic regression indicated that the following factors were associated with difficult mask ventilation (DMV-III): male sex, modified Mallampati classification III, edentulousness, DSHB, and DSTI, with an area under the curve of 0.89.

Conclusions This study showed that airway ultrasonography to determine DSHB and DSTI during patients' routine physical examinations significantly improved the prediction of DMV. Patients classified as having DMV-III require

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prompt management for airway difficulties. However, the individual factors DSHB and DSTI alone are insufficient to predict DMV.

Trial registration Registration number: TCTR2020093002.

Keywords Airway management, Facemask ventilation, Distance from skin to hyoid bone, Distance from skin to thyroid isthmus, Difficult mask ventilation, Ultrasonography

Background

Bag-and-mask ventilation (BMV) is a fundamental skill in basic airway management that includes airway opening maneuvers and positive-pressure ventilation via a facemask [1]. Effective BMV is an important strategy used to save many patients as part of the cardiopulmonary resuscitation [2] and difficult airway management guidelines [3–5].

Difficult bag-and-mask ventilation (DMV) is reported in 8.9% of patients [6–8]. However, the incidence varies depending on the definition of DMV [9]. Several risk factors for DMV, including age, edentulousness, body mass index, presence of a beard, and history of snoring/obstructive sleep apnea, have been identified in previous studies [6, 7].

Difficult airway management generally includes difficult laryngoscopy, difficult intubation, and sometimes difficult mask ventilation (DMV). Difficult mask ventilation can be predictable or unpredictable and may occur after intubation failure [9]. Management of a difficult airway involves using facemask ventilation, a supraglottic airway, or intubation before the conclusion is reached that the patient cannot be intubated or oxygenated ("Cannot Intubate, Cannot Oxygenate" (CICO) scenario). Tracheostomy or cricothyroidotomy is an invasive procedure used to manage the CICO scenario. Delayed and unresolved airway management can lead to death or brain death [10, 11].

Effective diagnostic tools may predict the possibility of patients experiencing DMV and should be considered as additional pre-operative clinical assessments during routine procedures. Ultrasound provides fast, easy, and accurate details, with diagnostic and therapeutic relevance [12, 13]. Pre-operative ultrasound measurement of the anterior neck soft tissue thickness at different levels, combined with regularly used screening tests, and risk factor assessments for DMV, might enhance our ability to predict difficult DMV.

The previous study showed that airway ultrasound, and specifically the measurement of the distance from the skin to the hyoid bone, was correlated with an increased risk of DMV [17]. However, the study was conducted in Italy and lacks data for the Asian and Thai populations.

The aim of our study was to evaluate pre-operative ultrasound measurements of the distance from the skin to the hyoid bone (DSHB) and the distance from the skin to the thyroid isthmus (DSTI) to predict difficult mask ventilation (DMV) in Thai patients undergoing general anesthesia for elective surgery.

Methods

Study design and setting

This prospective cohort observational study was conducted at Songklanagarind Hospital, Thailand, from June 1/6/2021– 10/3/2023.

Ethical considerations

The study was approved by the Office of the Human Research Ethics Committee, Faculty of Medicine, Prince of Songkla University, Thailand (REC.63–266-8–1). This study was registered with Thai Clinical Trials Registry (TCTR2020093002||http://www.clinicaltrials.in.th/). The date of registration in primary registry was 28/9/2020. The patients provided informed consent to participate in the study. Informed consent was obtained from 189 Thai patients.

Study participants and study criteria

Patients aged $\geq$ 18 years undergoing general anesthesia for elective surgery, were enrolled prospectively. The exclusion criteria were as follows: cancer or trauma to the face, neck, pharynx, or epiglottis; pregnancy; and history of thyroid tracheotomy or surgery.

Outcome: difficult mask ventilation

The outcome of our study was DMV using Han's mask ventilation classification which was DMV III and IV. The DMV grade is classified as follows: DMV-0, ventilation by mask not attempted; DMV-I, ventilation by mask; DMV-II, ventilation by mask with oral airway/adjuvant ventilation, with or without a neuromuscular blocking agent; DMV-III, difficult ventilation (inadequate, unstable, or requiring two providers), with or without a neuromuscular blocking agent; and DMV-IV, unable to undergo mask ventilation, with or without a neuromuscular blocking agent [14, 16].

Data collection

The baseline characteristics and airway assessment, which might be risk factors for DMV, were evaluated. Baseline characteristics were recorded, including age, sex, body mass index (BMI), ASA physical status classification, snoring, and history of OSA requiring CPAP. Airway assessment was conducted based on the modified Mallampati classification, thyromental distance, neck movement, inter-incisor gap, upper lip bite test, and edentulousness.

The variables of interest related to DMV were DSHB and DSTI. Prior to the initiation of this study, airway ultrasounds from 10 patients were verified by Santi Anchalee (SA), Kanatawan Wasoontrarak (KW), and Sumidtra Prathep (SP) to minimize inter-rater variability. In the pre-operative room, with the patient lying supine with the head and neck in the neutral position, ultrasound was performed using a Phillips Lumify portable ultrasound machine (a linear 12 to 14 MHz transducer) (Phillips Healthcare; Amsterdam, Netherlands) to measure anterior neck soft tissue thickness. Following a craniocaudal sagittal scan of the neck with the probe placed on the transverse axis, ultrasound distances were measured as the distance from the skin to the thyroid isthmus (DSTI) and from the skin to the hyoid bone (DSHB) [15] (Fig. 1).

Induction of anesthesia was performed using propofol (2 mg/kg) and fentanyl (1–3 mcg/kg), and bag mask ventilation was conducted using a clear plastic mask. Han's scale was used to evaluate the DMV grade before administration of a neuromuscular blocking agent. The criteria for successful mask ventilation included chest elevation, five consecutive ET-CO_2 readings of > 20 mmHg, maintaining oxygen saturation, ensuring a fresh gas flow rate < 6 LPM, and applying an

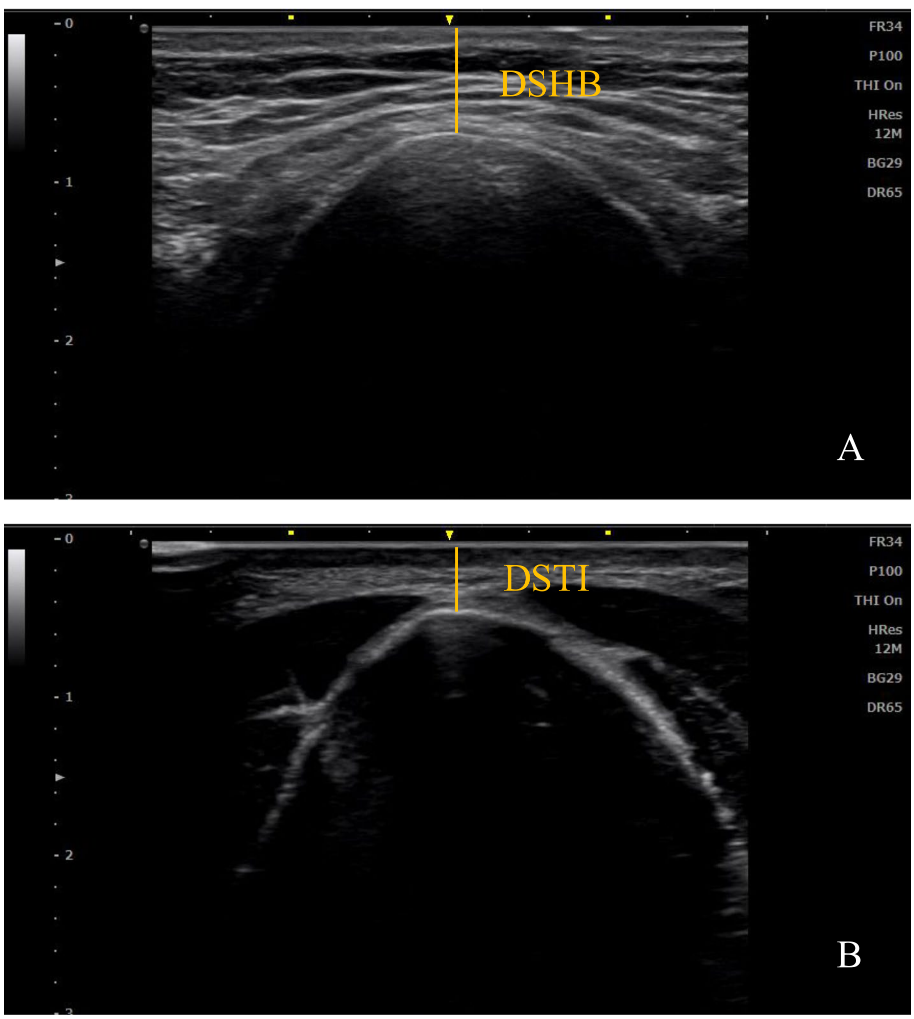

Fig. 1 Ultrasonographic measurement of (**A**) the distance from the skin to the hyoid bone (DSHB) and (**B**) the distance from the skin to the thyroid isthmus (DSTI)

adjustable pressure limiting valve (APL) with a pressure < 20 cmH2O.The principal outcome of this study was to assess whether DSHB and DSTI could predict DMV.

The airway assessors in our study were three individuals who were only able to perform airway assessments on some of the patients undergoing general anesthesia each day (approximately 100 patients per day). This limitation may have introduced selection bias.

Sample size

We hypothesized that DSTI and DSHB could aid in the prediction of the DMV grade. The sample size was 189 patients, calculated using the probability of expected sensitivity and expected specificity with allowable error. Data from a prospective study of 1399 mask ventilation attempts using a DMV grading scale reported an incidence of 8.9% [8]. A dropout rate of 10% was expected.

$$n = \frac{z^2_{1-\frac{\alpha}{2}} p(1-p)}{d^2}$$

$$Z_{1-\frac{\alpha}{2}} = 95\% \text{ confidence level} = 1.959964$$

Sensitivity

Psen = Probability of expected sensitivity = 0.8,
d = Allowable error = 0.20^{22},
nsen = 15.3

Specificity

Pspec = Probability of expected specificity = 0.8,
d = Allowable error = 0.20^{22},
n spec = 15.3

Statistical and data analysis

Based on the principal outcome and assuming a correlation of 0.2, the inclusion of 189 patients was essential to guarantee a power of 80%, with a significance level of 5%. Continuous data were expressed as means (standard deviation (SD)), while categorical data were presented as frequencies (percentages). Continuous variables were analyzed using a t-test or Wilcoxon rank-sum test. Categorical variables were compared using Fisher's exact test. Two or more groups of independent variables and continuous or ordinal dependent variables were analyzed using the Kruskal–Wallis test. Logistic regression analysis was used to identify the parameters associated with DMV. Receiver operating characteristic (ROC) curves were used to verify the factors associated with the sensitivity and specificity of DMV. Data management and analysis were performed using R software, version 4.3.3.

Results

The study was conducted on Thai patients. A total of 189 patients (138 women, 51 men) were eligible for inclusion in this study (Fig. 2). The mean age of the subjects was 52 years old, and the median BMI was 23. The percentage of patients classified as ASA physical status class 3 was 18%. The Modified Mallampati classification III was observed in 15% of patients. The clinical characteristics of the patients are summarized in Table 1.

In this study, 33 (17%) patients presented with DMV-0, 126 (67%) with DMV-I, 18 (10%) with DMV-II, and 12 (6%) with DMV-III. None of the patients had DMV-IV. The DSHB medians were 0.4 (0.3–0.6), 0.7 (0.5–1), 0.7 (0.6–0.8), and 0.6 (0.3–0.9) cm in DMV-0, I, II, and III, respectively ($p < 0.001$). The DSTI medians were 0.9 (0.8–1.1), 0.8 (0.7–1.1), 0.7 (0.6–0.9), and 0.8 (0.8–1.4) cm in DMV-0, I, II, and III respectively ($p = 0.041$). Summary statistics of the ultrasound distance, DSHB, and DSTI for each DMV grade are presented in Table 2.

Univariate logistic regression analysis showed that age (52 (15) vs 63 (15) years ($p = 0.01$)), weight (59 (52–67) vs 68 (60–76) kg ($p = 0.042$)), modified Mallampati classification ($p = 0.002$), and lack of teeth (25 (14%) vs 7 (58%) ($p = 0.001$)) correlated with DMV with statistical significance. Results of the univariate logistic regression analysis are shown in Table 3.

Multivariate logistic regression analysis of factors associated with DMV included male sex, modified Mallampati classification III, edentulousness, DSHB, and DSTI. The multivariate logistic regression data are shown in Table 4.

Scores predicting difficult mask ventilation were calculated as follows: (1.8 × Male) + (-0.6 × Mallampati class II) + (2.1 × Mallampati class III) + (2.2 × lack of teeth) + (-2.4 × DSHB) + (2.8 × DSTI). If the patients were male, the factor was one; for Mallampati class II, the factor was one; for Mallampati class III, the factor was one; for lack of teeth or being edentulous, the factor was one; DSHB was measured in centimeters; and DSTI was measured in centimeters. The cutoff value for the prediction of DMV was 3.6, with a sensitivity of 83%, specificity of 86%, positive predictive value of 0.29, and negative predictive value of 0.99. The receiver operating characteristic (ROC) curve (Fig. 3) shows the probability of DMV, with an area under the curve of 0.89.

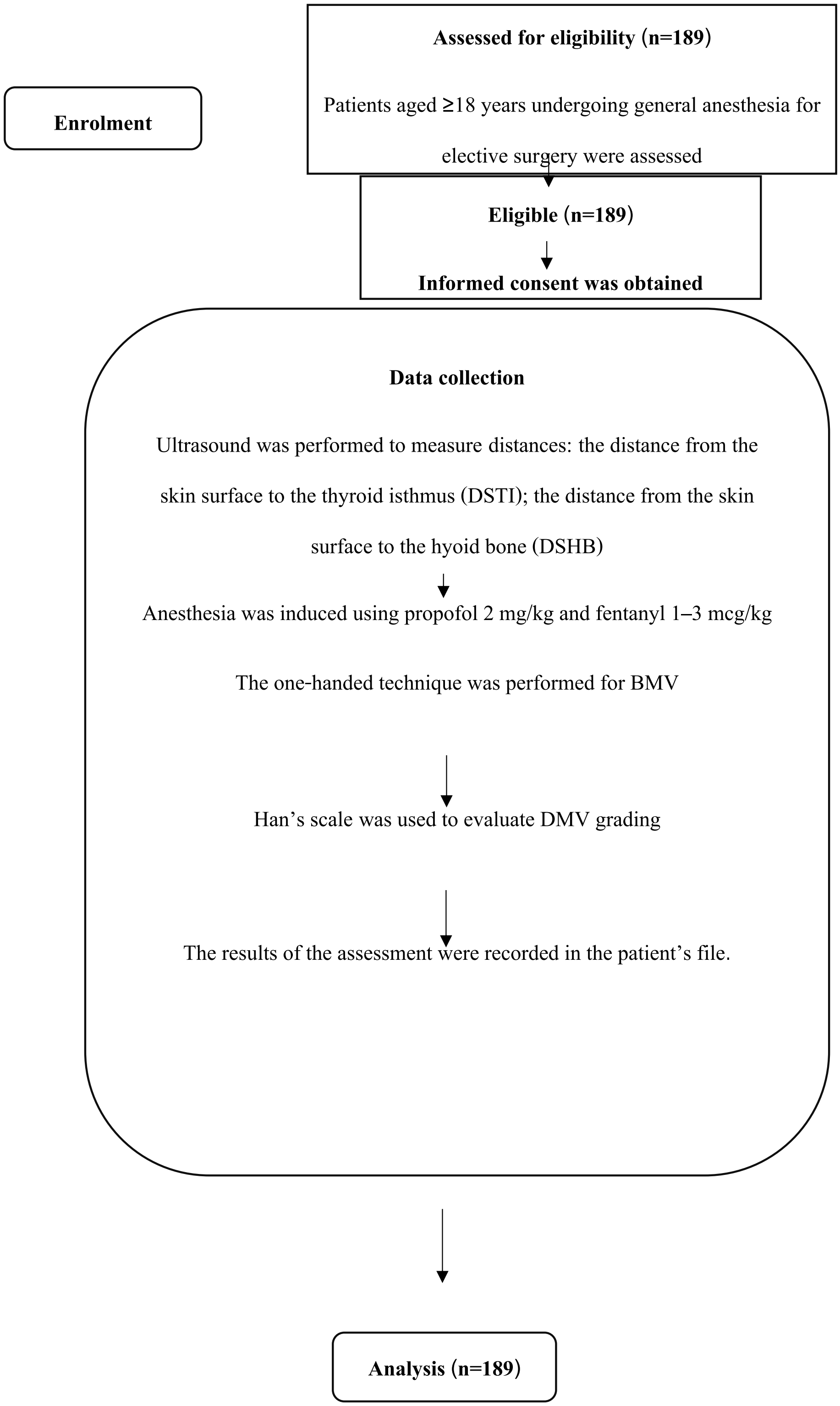

Fig. 2 Flow diagram of the study (BMV: bag-mask ventilation)

Table 1 Patient demographic data and pre-operative variables; data are expressed as number (%), mean (SD), or median (IQR)

Patient Characteristics	
Age	52 (15)
Male	51 (27)
Weight (kg)	59 (52–67)
Height (cm)	159 (155–165)
BMI (kg/m^2)	23 (21–26)
ASA classification	
1	14 (7)
2	142 (75)
3	33 (18)
Modified Mallampati classification	
I	51 (27)
II	109 (58)
III	28 (15)
Flexion range of motion (degree)	45 (45–45)
Extension range of motion (degree)	30 (30–30)
Upper lip bite test (ULBT) Grade	
1	118 (63)
2	55 (29)
3	14 (8)
Snoring	55 (29)
History of OSA requiring CPAP	0(0)
Edentulousness	33 (18)
Thyromental distance (cm)	8 (6–9)
Inter-incisor gap (cm)	4 (4–5)

SD standard deviation, *IQR* interquartile range, *BMI* body mass index, *ASA* American Society of Anesthesiologists, *OSA* obstructive sleep apnea, *CPAP* continuous positive airway pressure

Discussion

In our study, the incidence of DMV was 6.35%, whereas in the previous study, it was 8.9% [8]. This observational study of 189 patients showed an association between ultrasound distance evaluation of the anterior neck soft tissues and DMV. Our statistical results were consistent with previous evidence that the positive relationship between greater DSTI and DSHB thickness and the incidence of DMV was statistically significant [17]. However, the results might not be clinically significant, as there was only a 1 mm difference between each grade of Han's mask ventilation classification. Several risk factors for DMV, including age, edentulousness, body mass index, presence of a beard, and history of snoring/obstructive sleep apnea, have been identified in previous studies [6, 7]. Our univariate logistic regression analysis showed that the factors associated with DMV were age, weight, modified Mallampati classification, and edentulousness. The addition of airway ultrasonography to measure DSHB and DSTI during routine patient physical examinations in conjunction with factors such as edentulousness and modified Mallampati classification III can improve the prediction of DMV, with an area under the curve of 0.89.

The study was conducted in an elective surgery setting, which helped us identify DMV in patients without clinically predictable difficult results. Ultrasound distance measurements were examined independently of difficult airway prediction assessments. Patients with airway abnormalities were excluded because our objective was to provide an additional tool for identifying unexpected DMV. Adhikari et al. reported that DSHB would be the most stable distance [18]. DSHB and the distance from the skin to the epiglottis midpoint (DSEM) were assessed and used to evaluate the prediction of difficult airway management. However, DSEM is highly dependent on the length of the epiglottis. Our study is the first to determine novel ultrasound parameters for improving the sensitivity and specificity of anthropometric parameters for the pre-operative assessment of the upper airway in Thai patients. Although magnetic resonance imaging (MRI), computed tomography (CT), and other imaging procedures can be used to measure neck soft tissue thickness, they are expensive and impractical for use in the operating room. Additionally, radiation is a risk factor for routine workups in patients with normal airways. Ultrasound can be performed at the bedside, is cheap, fast, has no radiation hazard, and is as accurate as MRI [19, 20].

Limitations

This study had some limitations. First, we excluded patients with predicted difficult airway management because the study objective was to explore the use of neck ultrasound in patients with possible DMV that was unpredictable pre-operatively. Second, this study did not use the anthropometric parameters that were presently appraised as a reference. Thus, further studies are required to examine the relationship between

Table 2 Ultrasound distance grading of DMV

	DMV-0 ($n=33$)	DMV-I ($n=126$)	DMV-II ($n=18$)	DMV-III ($n=12$)	p – value
DSHB	0.4 (0.3–0.6)	0.7 (0.5–1)	0.7 (0.6–0.8)	0.6 (0.3–0.9)	< 0.001
DSTI	0.9 (0.8–1.1)	0.8 (0.7–1.1)	0.7 (0.6–0.9)	0.8 (0.8–1.4)	0.041

Numerical data are expressed as median (interquartile range (IQR)) cm. DMV: difficult mask ventilation

DSHB distance from the skin surface to the hyoid bone, *DSTI* distance from the skin surface to the thyroid isthmus

Table 3 Univariate logistic regression analysis of DMV

Factor	DMV-0, I, II (*n* = 174)	DMV-III (*n* = 12)	*p* – value
Age	52 (15)	63 (15)	0.01
Male sex	45 (26)	6 (50)	0.093
Weight (kg)	59 (52–67)	68 (60–76)	0.042
Height (cm)	159 (7)	163 (10)	0.105
BMI (kg/m^2)	23.2 (21.3–25.7)	26.4 (21–29.6)	0.225
ASA classification			0.304
1	14 (8)	0 (0)	
2	131 (75)	8 (67)	
3	29 (17)	4 (33)	
Modified Mallampati classification			0.002
I	48 (28)	3 (25)	
II	105 (60)	3 (25)	
II	21 (12)	6 (50)	
Flexion range of motion (degrees)	45 (45–45)	45 (45–45)	0.594
Extension range of motion (degrees)	30 (30–30)	30 (30–30)	0.635
Upper lip bite test (ULBT) Grade			0.324
1	111 (64)	6 (50)	
2	51 (29)	4 (33)	
3	12 (7)	2 (17)	
Snoring	50 (29)	4 (33.)	0.747
Lack of teeth	25 (14)	7 (58)	0.001
Thyromental distance (cm)	7.5 (6–9)	7.5 (6–8.6)	0.843
Inter-incisor gap (cm)	4 (4–5)	4 (4–4.6)	0.806
DSHB	0.6 (0.4–0.9)	0.6 (0.3–0.9)	0.49
DSTI	0.8 (0.7–1.1)	0.8 (0.8–1.4)	0.259

DMV difficult mask ventilation, *BMI* body mass index, *ASA* American Society of Anesthesiologists, *DSHB* distance from the skin surface to the hyoid bone, *DSTI* distance from the skin surface to the thyroid isthmus

Table 4 Multivariate logistic regression analysis of DMV

Factor	crude OR(95%CI)	adj. OR(95%CI)	P(Wald's test)	P(LR-test)
Male	2.87 (0.88–9.34)	6.2 (1.27–30.22)	0.024	0.019
Modified Mallampati classification: III	4.57 (1.04–20.04)	8.09 (1.22–53.68)	0.03	
Edentulousness	8.34 (2.46–28.36)	8.75 (2.02–37.81)	0.004	0.003
DSHB	0.54 (0.07–4.15)	0.09 (0.01–1.54)	0.098	0.083
DSTI	4.34 (0.82–22.84)	16.4 (1.46–183.87)	0.023	0.012

DMV difficult mask ventilation, *OR* odds ratio, *95%CI* 95% confidence interval, *LR* likelihood ratio, *DSHB* distance from the skin surface to the hyoid bone, *DSTI* distance from the skin surface to the thyroid isthmus

the ultrasound distance and anthropometric parameters. Evaluation of the correlation between DMV and neck circumference would be very interesting [21]. Third, our research was conducted on patients from the Thai population, which is Asian. Therefore, the results might differ from those of other races or global populations. Forth, the airway assessors in our study were three individuals who were only able to perform airway assessments on some of the patients undergoing general anesthesia each day (approximately 100 patients per day). This limitation may have introduced selection bias. Finally, previous studies have shown that rocuronium can improve tidal volume during one-handed mask ventilation [22]. However, in our study, facemask ventilation was assessed before the administration of neuromuscular blockade, which may have contributed

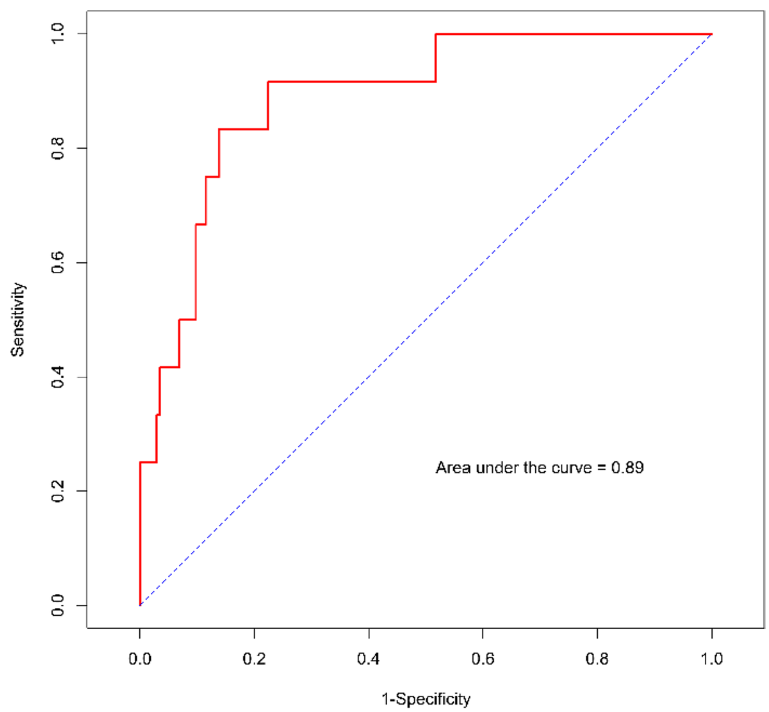

Fig. 3 Receiver operating characteristic (ROC) curve showing the probability of difficult mask ventilation

to the increased difficulty of facemask ventilation. In our institute, cisatracurium is more commonly used than rocuronium, which does not have a specific reversal agent like sugammadex available for rocuronium. Therefore, we decided to assess the difficulty of mask ventilation prior to the administration of neuromuscular blockade. This approach allows us to safely manage airway complications in cases of difficult ventilation and intubation. Consequently, the interpretation and application of our findings should take into account the differences in facemask ventilation before and after neuromuscular blockade.

Conclusions

This prospective observational study showed that the addition of airway ultrasonography to measure DSHB and DSTI during routine patient physical examinations in conjunction with factors such as edentulousness and modified Mallampati classification III can improve the prediction of the degree of DMV. However, DSHB and DSTI alone are insufficient to predict DMV.

Abbreviations

DSHB	The distance from the skin to the hyoid bone
DSTI	The distance from the skin to the thyroid isthmus
BMV	Bag-and-mask ventilation
BMI	Body mass index
DMV	Difficult mask ventilation
CICO	Cannot intubate, cannot oxygenate
SD	Standard deviation
ROC	Receiver operating characteristic
DSEM	Distance from the skin to the epiglottis midpoint
MRI	Magnetic resonance imaging
CT	Computed tomography

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Authors' contributions
S.A. collected the data and wrote the manuscript. K.W. initiated the research, collected the data, and wrote the draft manuscript. P.B. initiated the research and advice. S.C.initiated the research and advice. S.P. initiated the research and wrote the manuscript.

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Data availability
Data is provided within related files.

Declarations

Ethics approval and consent to participate
This study was approved by the Office of the Human Research Ethics Committee, Faculty of Medicine, Prince of Songkla University, Thailand (REC.63–266-8–1). The date of first registration was 28/9/2020. The patients provided informed consent to participate in the study.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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