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ORIGINAL RESEARCH

Signa Vitae

Predictors of difficult endotracheal intubation in the emergency department: a single-center pilot study

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Abstract

Background: Identifying patients who are at risk of difficult endotracheal intubation is crucial in the emergency department. Therefore, this study evaluated the incidence and predictive factors of difficult tracheal intubation in the emergency department.

Methods: This was a 17-month prospective observational study. A difficult airway was defined as Cormack & Lehane classification grades III and IV at the first attempt of intubation. Patients who visited the emergency department, underwent traditional endotracheal intubation from participating physicians, and provided informed consent by themselves or via their delegates were enrolled in this study. Univariate associations between patient characteristics and difficult endotracheal intubation were identified, and statistically significant factors were included in a multivariate binary logistic regression model. A generalized association plot was used to show the relationships between variables.

Results: A total of 110 patients were enrolled in the study. The incidence of difficult intubation was 35.5% (39/110). In the difficult airway group, significantly higher body mass index (BMI), and incidence of double chin, thick short neck, Mallampati difficulty, small interincisor distance, small thyromental distance, and upper airway obstruction were noted on univariate analysis. A predictive formula for difficult tracheal intubation was successfully established by the combination of four independent predictors: BMI (odds ratio [OR] = 1.270), thyromental distance (OR = 0.614), upper airway obstruction (OR = 4.038), and Mallampati difficulty (OR = 5.163). A cutoff score of four maximized Youden's index, providing sensitivity (79.5%) and specificity (81.7%) (95% CI: 0.794 to 0.938).

Conclusions: We used four predictors of difficult tracheal intubation, namely, BMI, thyromental distance, upper airway obstruction, and Mallampati difficulty, to create a predictive formula. This formula could help emergency physicians to quickly identify and carefully manage patients with difficult endotracheal intubation and consult experts early if necessary.

Keywords

Difficult endotracheal intubation; Body mass index; Thyromental distance; Upper airway obstruction; Mallampati score

1. Introduction

In the emergency department (ED), endotracheal intubation is often abruptly required and unpredictable. Airway assessment is crucial for emergency physicians because identifying patients with difficult airways allows for more careful intubation and early expert consultation. It could decrease intubation attempts and adverse events such as airway trauma, esophageal intubation, aspiration, hypoxemia, hypotension, dysrhythmia, and even cardiac arrest [1].

For this unmet need, researchers have tried to identify predictors of difficult intubation. The Mallampati score (Fig. 1A) is the most commonly used bedside tool for predicting difficult endotracheal intubation. Although it offers easy preoperative performance, it has limited accuracy and only poor to moderate discriminative power when used alone [2]. The LEMON score, another predictor [3], includes "look externally," the 3-3-2 rule, Mallampati score > 3, obstruction, and neck mobility. However, the judgment of "look externally" is too subjective, and the 3-3-2 rule is based on finger widths, which may vary widely among operators. Other predictors include the upper lip bite test, thyromental distance, interincisor gap, sternomental distance [4], thyromental height [5], acromio-axillo-suprasternal notch index [6], and lower jaw protrusion maneu-

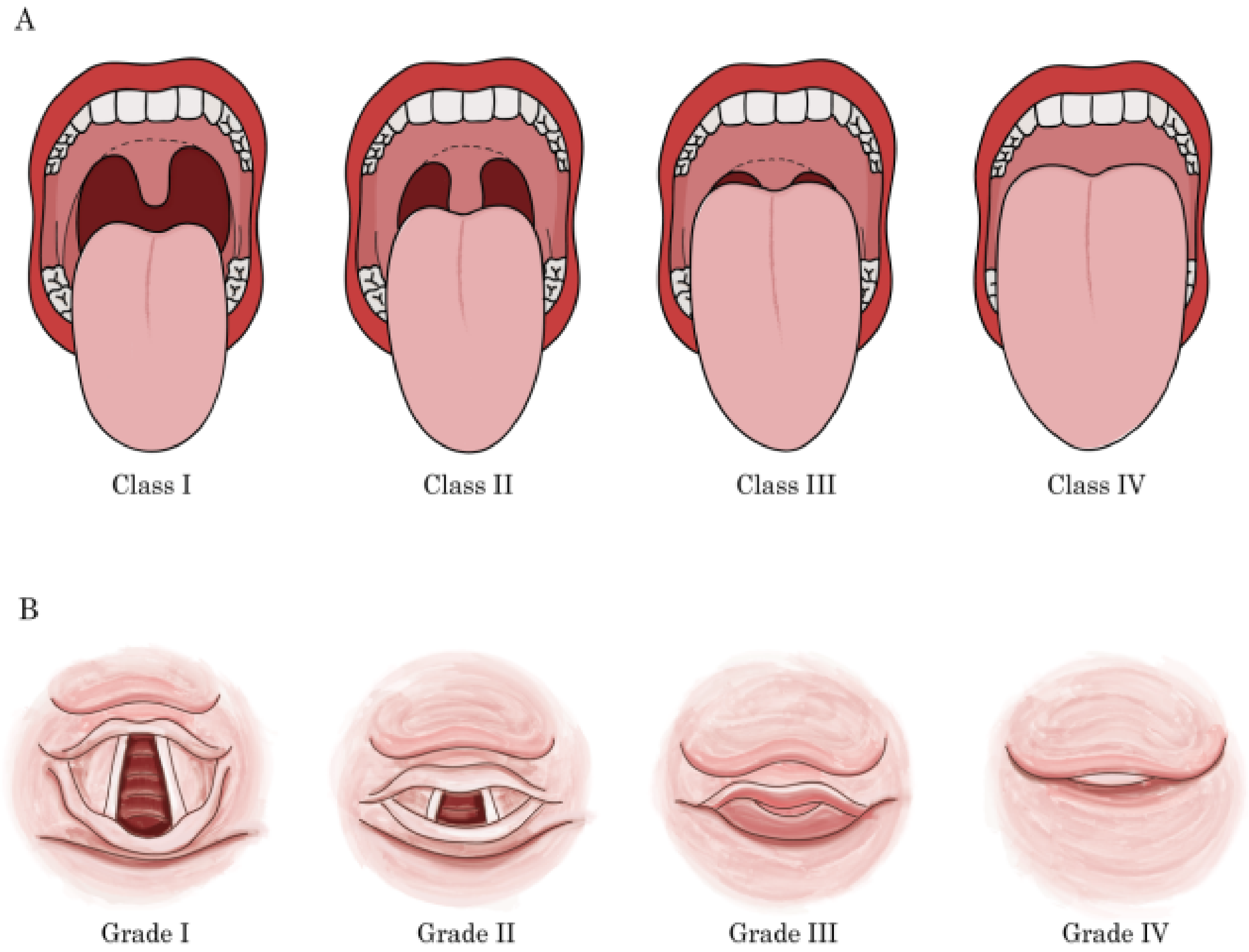

FIGURE 1. (A). The Mallampati score. The Mallampati score is based on the visualization of the pharyngeal structures and is used to predict the degree of difficulty of endotracheal intubation. Class I: visualization of the soft palate, fauces, uvula, and both anterior and posterior pillars. Class II: visualization of the soft palate, fauces, and uvula. Class III: visualization of the soft palate and base of the uvula. Class IV: soft palate not visible. **(B)**. The Cormack & Lehane system classifies laryngeal views obtained by direct laryngoscopy. Grade I: Full view of the glottis. Grade II: Partial view of the glottis. Grade III: Only epiglottis and no glottis visible. Grade IV: Neither glottis nor epiglottis visible.

verability [2]. However, not all of these measurements are generalizable; for example, thyromental height is not a strong predictor of difficult visualization of the larynx in Japanese patients [7]. This issue is important but is rarely studied in Taiwan. Therefore, the current study aimed to evaluate the incidence and predictive value of factors of difficult tracheal intubation in the ED of a medical center in Taiwan.

2. Materials and methods

2.1 Study subjects

This 17-month prospective, observational study was approved by the Institutional Review Board of MacKay Memorial Hospital (11MMHISO64), Taipei, Taiwan, between November 1, 2011, and March 31, 2012. Patients who visited the ED of MacKay Memorial Hospital, a medical center and teaching hospital in north Taiwan, and underwent traditional endotracheal intubation by participating physicians were asked to enroll in this study. Emergency physicians decided to intubate a patient depending on the patient's condition and used drugs such as succinylcholine chloride, midazolam, propofol, etomidate, ketamine, lidocaine, or atropine, as necessary. Participants consented to join this study and signed informed consent by themselves or via their delegates. Exclusion criteria included patient age younger than 20 years, intubation via video laryngoscope, or refusal of consent to join the study.

2.2 Definition and data collection

Patients were categorized into two groups for comparison based on Cormack & Lehane classification of the first endotracheal intubation attempt by direct laryngoscopy. Patients with Cormack & Lehane grades III and IV were defined as

TABLE 1. Comparisons of demographic factors and physical findings between emergency department patients with difficult and non-difficult intubation.

Variable	Difficult (n = 39)	Non-difficult (n = 71)	*P*-value
A. Demographics			
Age (years)	68.74 ± 16.18	69.56 ± 16.69	0.804
Age ≥ 65	27 (69.2%)	46 (64.8%)	0.637
Male	26 (66.7%)	40 (56.3%)	0.290
BMI# (kg/m^2)	25.72 ± 5.19	22.10 ± 3.18	< 0.001***
Difficult mask ventilation	20 (51.3%)	31 (43.7%)	0.549
B. Cause of intubation			
Sepsis	3 (7.7%)	6 (8.5%)	> 0.999
Lung disease†	8 (20.5%)	14 (19.7%)	0.921
Heart disease†	4 (10.3%)	16 (22.5%)	0.11
Renal disease†	2 (5.1%)	0 (0%)	0.124
IHCA†	0 (0%)	2 (2.8%)	0.538
OHCA†	10 (25.6%)	17 (23.9%)	0.843
ICH/CVA†	4 (10.3%)	10 (14.1%)	0.767
Facial trauma	0 (0%)	1 (1.4%)	> 0.999
C. Presentation			
Receding mandible	0 (0%)	2 (2.8%)	0.538
Double chin	11 (28.2%)	4 (5.6%)	0.002*
Snoring	4 (10.3%)	5 (7.0%)	0.718
Lack of teeth	10 (25.6%)	26 (36.6%)	0.240
Sunken cheeks	2 (5.1%)	16 (22.5%)	0.018*
Thick short neck	12 (30.8%)	5 (7.0%)	0.001**
Mallampati difficulty (grade 3/4)	27 (69.2%)	19 (26.8%)	< 0.001***
Poor neck mobility	8 (20.5%)	8 (11.3%)	0.188
D. Anatomical distances (cm)			
Interincisors distance, max	3.09 ± 0.83	3.50 ± 0.82	0.014*
Thyromental distance	6.35 ± 1.13	6.92 ± 1.17	0.014*
Sternomental distance	11.55 ± 2.56	12.34 ± 1.89	0.097
Thyrosternal distance	5.81 ± 2.28	6.20 ± 1.70	0.312
E. Upper airway obstruction			
Upper airway obstruction	26 (66.7%)	24 (33.8%)	0.001**
Sputum impaction	20 (51.3%)	19 (26.8%)	0.01*
Food impaction	3 (7.7%)	3 (4.2%)	0.664
Blood impaction	3 (7.7%)	3 (4.2%)	0.664
F. Intubation-related factors			
Method of intubation			
Rapid sequence or coma	26 (66.7%)	53 (74.6%)	0.373
Sedation without paralysis	13 (33.3%)	18 (25.4%)	0.373
Intubation injury	1 (2.6%)	4 (5.6%)	0.654
Mean number of attempts	2.05 ± 0.68	1.13 ± 0.38	< 0.001***

Data are presented as n (%) or mean ± standard deviation (SD).
 # BMI = body mass index; † lung disease: chronic obstructive pulmonary disease, or pneumonia; heart disease: congestive heart failure, pulmonary edema; renal disease: uremia, pulmonary edema; IHCA = in-hospital cardiac arrest; OHCA = out-of-hospital cardiac arrest; ICH = intracranial hemorrhage; CVA = cerebrovascular accident; Mallampati: difficult = grades 3 and 4, easy = grades 1 and 2.
$*P < 0.05$; $**P < 0.01$; $***P < 0.001$.

having difficult intubation. Patients with Cormack & Lehane classification grade I or II were defined as having non-difficult intubation.

The anatomical distances measured included the interincisor, thyromental, sternomental, and thyrosternal distances. The interincisor distance was defined as the distance between the upper and lower incisors with the mouth opened the widest. The other distances were measured with the neck in full extension (Fig. 2): thyromental distance was measured with a ruler from the prominent point of the mentum to the thyroid notch, thyrosternal distance was measured from the thyroid notch to sternal notch, and the sternomental distance was measured from the mentum to the sternal notch. These three distances formed a triangle. The thyromental and thyrosternal distances together were longer than the sternomental distance, except when the mentum, thyroid notch, and sternal notch were in a straight line.

Before endotracheal intubation, physicians performed foreign body removal or sputum suction to ensure that the airway was well prepared. After this preprocessing, the airway's remaining narrowing was classified as sputum, food, or blood impaction.

Intubation was attempted by chief residents or attending staff, whose extensive experience with emergency intubation could prevent bias related to inexperience. Each participating physician used a specially designed form to check and record the airway situation, including the number of attempts and intubation injuries, and the attending staff made all clinical decisions regarding airway management. A research assistant synthesized and coded the raw data, checked for missing values regularly, and contacted the original physician to clarify or re-measure the missing values.

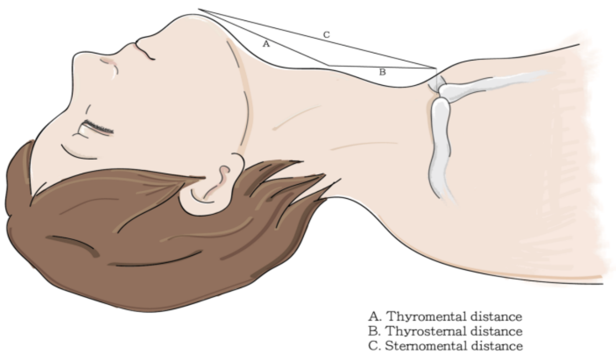

FIGURE 2. Definitions of thyromental, thyrosternal, and sternomental distances. The three anatomical landmarks of airway evaluation include the bony prominent point of the mentum, the thyroid notch, and sternal notch.

2.3 Statistical analysis

On the basis of clinical experience, we estimated that the percentages of difficult and non-difficult Mallampati score (grade 3/4) were 65% and 30%, respectively. To achieve a power greater than 90% with an α value less than 0.05 (two-sided) and an allocation ratio (non-difficult/difficult) of 2, a sample size of 105 was calculted to provide adequate power for the study, using software-G*Power 3.1.

SPSS Statistics 17.0 for Windows (SPSS Inc., Chicago, IL) was used for data management and statistical analysis. Chi-squared tests and Fisher's exact tests were performed for categorical variables, and independent-sample t-tests were used for continuous variables. All individual risk factors found to have statistically significant association with difficult endotracheal intubation in the univariate analysis were included in a multivariate logistic regression model, except for intubation injury and mean number of attempts, because these factors were consequences of intubation, not predictive factors.

On the basis of the logistic regression model results, a predictive formula comprising β coefficients was established. Each β coefficient was multiplied by its independent predictor value, and the results were summed as the final score.

To investigate the relationship between each pair of variables, a correlation matrix with hierarchical dendrogram was performed using RStudio package (RStudio: Integrated Development for R. RStudio, Inc., Boston, MA, USA) and generalized association plots (GAP) [8, 9].

3. Results

A total of 110 adult endotracheal intubation patients were enrolled in this study. The age of the patients ranged from 21 to 96 years and 66% were males. The incidence of difficult endotracheal intubation was 35.5%. Few patients (6.4% (7/110)) were conscious before sedation (Glasgow Coma Scale 15), most presented with confusion (67.3% (74/110)), and 26.3% (29/110) required cardiorespiratory resuscitation.

Table 1 compares demographic factors and physical findings for patients with difficult and non-difficult intubations. The difficult group had higher BMI than the non-difficult group (25.72 $\pm$ 5.19 vs. 22.10 $\pm$ 3.18, $P < 0.001$), but no significant differences in age, sex, and difficult mask ventilation were observed between the two groups. Causes of intubation included sepsis, lung disease, heart disease, renal disease, in-hospital cardiac arrest, out-of-hospital cardiac arrest, intracranial hemorrhage/cerebrovascular accident, and facial trauma. Causes of intubation did not differ significantly between the two groups. Prevalence of double chin (28.2% vs. 5.6%, $P = 0.002$), sunken cheeks (5.1% vs. 22.5%, $P = 0.018$), thick short neck (30.8% vs. 7.0%, $P = 0.001$), and Mallampati difficulty (Class III or IV) (69.2% vs. 26.8%, $P < 0.001$) differed significantly between the two groups. Prevalence of receding mandible, snoring, lack of teeth, and poor neck mobility did not. Among anatomical distances, maximal interincisor distance (3.09 $\pm$ 0.83 vs. 3.50 $\pm$ 0.82, $P = 0.014$) and thyromental distance (6.35 $\pm$ 1.13 vs. 6.92 $\pm$ 1.17, $P = 0.014$) differed significantly between the groups, while sternomental distance and thyrosternal distance did not. The three subitems of upper airway obstruction represented different agents for impaction: sputum, food, and blood. Only overall upper airway obstruction (66.7% vs. 33.8%, $P = 0.001$) and the sputum impaction element (51.3% vs. 26.8%, $P = 0.01$) differed significantly in incidence between the groups. Two methods of intubation were used: rapid sequence or coma and sedation-only without paralysis. Neither method showed significant differences between the groups. Intubation injuries were uncommon, and did not differ statistically in incidence between the groups. Difficult intubations exceeded non-difficult intubations in mean number of attempts (2.05 $\pm$ 0.68 vs. 1.13 $\pm$ 0.38, $P < 0.001$).

Table 2 shows the multivariate ORs for difficult endotracheal intubation. For every one-point increase in BMI, the chance of difficult intubation increased by 27.0% (odds ratio [OR] 1.270, 95% CI, 1.111 to 1.451, $P < 0.001$); for every 1 cm increase in thyromental distance, it decreased by 38.6% (OR 0.614, 95% CI, 0.395 to 0.955, $P = 0.03$). Patients with upper airway obstruction were 4.04 times more likely to have difficult intubation than those without upper airway obstruction (OR 4.038, 95% CI, 1.456 to 11.200, $P = 0.007$). Patients with Mallampati class III or IV were five times more likely to have difficult intubation than those with Mallampati class I or II (OR 5.163, 95% CI, 1.895 to 14.066, $P = 0.001$).

A predictive formula for difficult endotracheal intubation

TABLE 2. Odds ratios of predictors of difficult intubation from multivariable forward conditional logistic regression analysis.

Predictor	Odds ratio	95% Confidence interval	*P*-value	β coefficient
BMI[#] (kg/m^2)	1.270	1.111-1.451	< 0.001	0.239
Thyromental distance (cm)	0.614	0.395-0.955	0.030	-0.488
Upper airway obstruction	4.038	1.456-11.200	0.007	1.396
Mallampati (grade III/IV)	5.163	1.895-14.066	0.001	1.642

 # BMI = body mass index.

was established by combining the β coefficients of four predictors: BMI, thyromental distance, upper airway obstruction, and Mallampati difficulty.

Score for difficult endotracheal intubation

= (BMI * 0.239) + (thyromental distance * -0.488) + (upper airway obstruction * 1.396) + (Mallampati grade 3/4 * 1.642).

Receiver operating characteristic (ROC) curves were drawn to identify the optimal cutoff point (Fig. 3). The area under the ROC curve was 0.866 (95% CI: 0.794 to 0.938, $P < 0.001$), and an integer cutoff score of four showed a sensitivity of 79.5% and specificity of 81.7%, with the highest Youden's index of 61.18% among integer scores (Table 3).

TABLE 3. Integer cut points of receiver operating characteristic (ROC) curve of our predictive formula for difficult endotracheal intubation.

Score	Sensitivity	1-Specificity	Youden's index
1	100.00%	91.55%	8.45%
2	97.44%	66.20%	31.24%
3	92.31%	40.85%	51.46%
4	79.49%	18.31%	61.18%
5	58.97%	7.04%	51.93%
6	17.95%	4.23%	13.72%

Fig. 4 reveals the relationship between each pair of variables based on the Pearson's correlation; both columns and rows represented individual variables and comprised a proximity matrix. Red indicates a positive correlation, and blue a negative one. The darker the color, the higher the Pearson product–moment correlation coefficient. A hierarchical clustering tree was also used to sort the matrix that contained highly related variables, such as thyrosternal distance and sternomental distance, which had a high positive correlation (Pearson coefficient > 0.7). The two distances also had a moderate positive correlation with interincisor distance; however, comparing these three distances with thyromental distance, there was only a Pearson coefficient of 0.2. In the hierarchical clustering tree, sunken cheeks and difficult mask ventilation were proximate, and had a Pearson coefficient of approximately 0.3. The variable of operator identity was located far from not only intubation injury, but also number of attempts, and even difficult intubation in the hierarchical clustering tree. In the matrix, the colors for its relationship to each variable were relatively light.

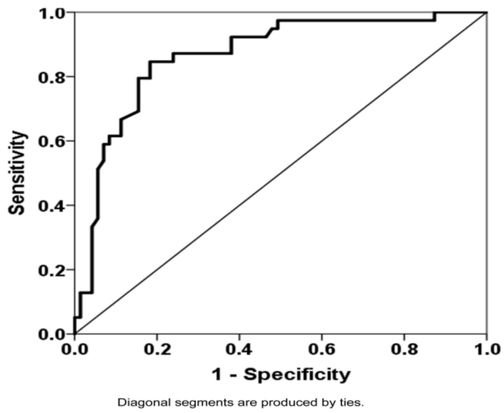

FIGURE 3. Receiver operating characteristic (ROC) curve of our predictive formula for difficult endotracheal intubation. AuROC = 0.866 (95% confidence interval; 0.794, 0.938); Cutoff score = 4; Sensitivity = 79.5%; Specificity = 81.7%.

4. Discussion

The reported incidence of difficult intubation in the ED varies from 2% to 26%, owing to different study definitions and populations [10–12]. The incidence of our study was 35.5%, higher than previous studies, because we defined difficult intubation as Cormack & Lehane classification grade III or IV in the first intubation attempt rather than the final successful attempt [10, 11]. We thought that it should be a fair comparison of different patients, and we supposed participating physicians should be well prepared before the first intubation attempt. Furthermore, the higher incidence of difficult intubation in the first attempt could encourage emergency physicians to pay more attention before airway management so that an unnecessary second or third intubation, as well as complications, can be avoided [13].

Moon *et al.* [14] reported that the elderly are likely to experience difficult endotracheal intubation because neck movement, thyromental distance, and interincisor gap decrease with age, while dentition grade, Mallampati score, and cervical joint rigidity increase with age. We observed no significant difference in the proportion of elderly patients between the difficult and non-difficult intubation groups. We supposed that age was not an independent predictor of difficult intubation, but that anatomical changes due to aging, such as increased Mallampati score [15] and decreased thyromental distance, were independent predictors of difficult intubation [4, 14].

Previously reported multifactor predictive models include

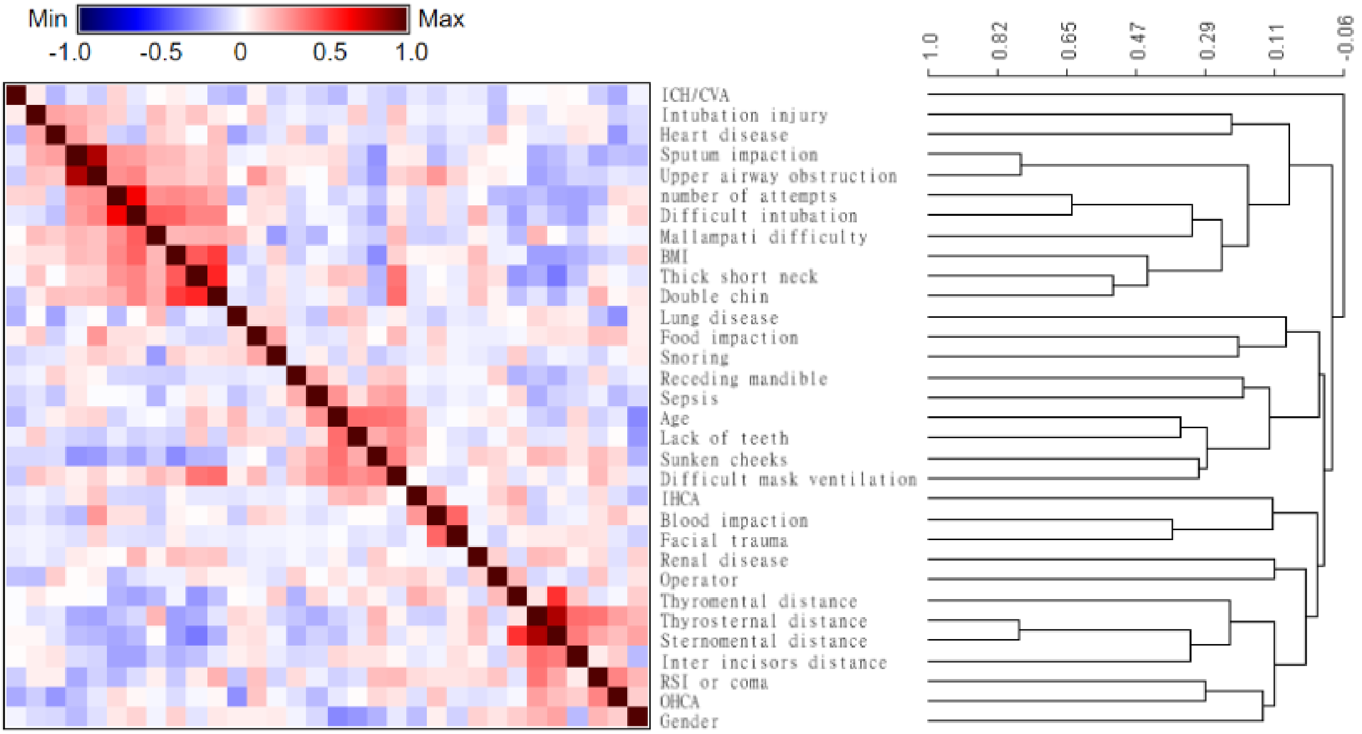

FIGURE 4. Proximity matrix with hierarchical clustering tree between each variable of demographic factors and physical findings. The color in the proximity matrix (or the heatmap) showed that the Pearson's correlation was positive (red) or negative (blue) between each pair of variables, and the hierarchical tree made the related variables became a cluster. A lower hierarchy meant a closer relationship, which could correspond to the correlation coefficient scale on the top of the tree.

Naguib's new model, which is a predictive formula developed using logistic regression with thyromental distance, Mallampati score, interincisor gap, and height [16]. Although the first two factors were also included in our algorithm, interincisor gap was not, despite its significant association with difficult intubation in the univariate analysis. Moreover, our formula used BMI rather than height. Other studies have also reported that difficult intubation is more common among obese patients [17], supporting that BMI may be a more powerful predictor.

In our model, the Mallampati score had the largest OR, identifying it as the most influential factor. Reed *et al.* reported no significant association between Mallampati score and difficult intubation and revised LEMON methods to exclude the Mallampati score. However, they reported that the Mallampati score was not easily available and was obtained in only 57% of patients [11]. In comparison, we assessed the Mallampati scores of all patients successfully, and Reed *et al.*'s negative result may have been a result of too many missing Mallampati scores. We recommend the routine assessment of Mallampati score in all patients regardless of whether treated in the ED or general ward. Given that the Mallampati score had the largest OR value, it could be relied on for the early detection of difficult endotracheal intubation. When these patients require intubation, the necessary time for evaluation may not be sufficient to include all the factors in our model. Preassessment by Mallampati score will allow physicians to be well prepared for this challenge.

Before intubation, all patients of the study were prepared with initial sputum suction and foreign body removal; therefore, upper airway obstruction indicated residual or newly produced issues. As in previous studies, upper airway obstruction was a strong predictor of difficult intubation [3, 18].

GAP analysis identified that thyromental distance is distinct from the other anatomical distances (sternomental, thyrosternal), having a smaller Pearson coefficient with the other distances. Prakash *et al.* [19] did not recommend the sternomental distance as the sole predictor, indicating its weaker predictive role. Unlike thyromental distance, we found that thyrosternal distance was not a good predictor of difficult endotracheal intubation [20]. The moderate correlation of sunken cheeks with difficult mask ventilation can also be shown by GAP analysis, consistent with the result of our previous study, namely, that sunken cheeks were found to independently identify difficult mask ventilation [12]. However, we found that sunken cheeks were associated with non-difficult endotracheal intubation in this study. We suggest that sunken cheeks may imply lower intubation resistance from facial muscles during intubation.

The training level of the operator should also be considered. A similar study excluded cases wherein intubation was performed by low-experience operators, including final-year medical students and first-year internists in general practice [21]. We only included patients who were intubated by chief residents and attending physicians. GAP analysis also demonstrated that identity of the operator has nearly zero correlation with all adverse indexes, such as intubation injury, number of attempts, and even difficult intubation. This indicates that our chief residents and attending physicians have nearly equal levels of skill in endotracheal intubation, supporting that there was less experience-related bias in our study.

There were several limitations. First, the workload of emergency physicians was very heavy so they could only recruit patients when they were not very busy. They also have to consider the situation of the patients and their relatives before obtaining consent after an appropriate explanation. Therefore, we only recruited 110 patients, far fewer than the number of participants in other similar studies [1, 4, 10]. However, the prospective design of the current study meant that we could avoid missing data, unlike in retrospective studies. Second, our formula directly used precise β coefficients, which were not integers because we did not adjust them in order to avoid decreasing sensitivity or specificity. Although this prevents physicians from performing easy calculations, the derived formula can be entered into a simple computer program or application to solve this problem. Third, many of the consents were signed by the patient's delegates after successful intubation. An increasing number of intubation attempts would likely increase the difficulty of enrollment owing to anxiety and irritation. Finally, although this study is a prospective study, it has a relatively small sample size and was conducted in a single medical center in Taiwan. A regional or national study involving multiple medical centers and having a larger sample size should be undertaken to represent the general population.

5. Conclusions

Difficult intubation was associated with increased BMI, low thyromental distance, upper airway obstruction, and Mallampati difficulty (class III or IV). Our predictive formula, based on these variables, could allow careful management and early expert consultation when necessary. Moreover, GAP analysis strengthened the special role of thyromental distance among other anatomical distances and showed the relationships between variables by data visualization.

AUTHOR CONTRIBUTIONS

En-Chih Liao was a major contributor in writing the manuscript. Wen-Han Chang wrote the manuscript and provided his patients. Ching-Hsiang Yu generated the generalized association plot and interpreted all of the Figures and tables. Yat-Pang Chau collected and assembled the data. Fang-Ju Sun analyzed the data via multivariate binary logistic regression model and generated the predictive formula. Wen-Jyun Lai was the contributor of administrative support and also drew the Fig. 1 and Fig. 2. Ding-Kuo Chien was the contributor of conception and design, he also provided his patients to this study. All authors read and approved the final manuscript.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this article.

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