A predictive formula for difficult endotracheal intubation in the emergency department

En-Chih Liao
Mackay Medical College
Wen-Han Chang
Mackay Memorial Hospital
Ching-Hsiang Yu
Mackay Medical College
Cheng-Ying Shen
Mackay Medical College
Fang-Ju Sun
Mackay Memorial Hospital
Wen-Jyun Lai
Mackay Memorial Hospital
Ding-Kuo Chien (mmhter2017@gmail.com)
Mackay Memorial Hospital

Original research

Keywords: difficult endotracheal intubation, body mass index, thyromental distance, upper airway obstruction, Mallampati score, emergency department

Posted Date: August 4th, 2020

DOI: https://doi.org/10.21203/rs.3.rs-49018/v1

Abstract

Background

Current predictors for evaluating difficult endotracheal intubation had poor accessibility or sensitivity at the emergency department, so we evaluated the incidence and predictive factors, then built an easy-to-use predictive formula.

Methods

This was a 17-month prospective observational study. For the 110 patients, difficult airway was defined as Cormack & Lehane classification grade III and IV at first attempt of intubation. The univariate associations between patient characteristics and difficult endotracheal intubation were then analyzed, and the significantly associated factors were included in a multivariate binary logistic regression model then a predictive formula was generated. Generalized association plot (GAP) was used to show the relationship between each variable.

Results

The incidence of difficult intubation in our study was 35.5%. In the difficult airway group, significantly higher rates ($p < 0.05$) of high body mass index (BMI); double chin; thick, short neck; Mallampati difficulty; smaller inter-incisors distance; smaller thyromental distance; and upper airway obstruction were noted. Finally, a predictive formula for difficult intubation was successfully established by the combination of four 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 cut-off score of 4 provided the best sensitivity (79.5%) and specificity (81.7%)(95% CI: 0.794 to 0.938).

Conclusions

Our predictive formula could be used by emergency physicians to quickly identify and carefully manage patients with potentially difficult intubation. Early expert consultation could be sought when necessary.

Background

Airway assessment is important for emergency physicians because identifying patients with difficult airways allows for more careful intubation and early expert consultation; decreased 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 the predictors of difficult intubation. Because of the urgency in the emergency department (ED), the predictive method should be as simple as possible. The Mallampati score (Fig. 2A) is the most commonly used bedside tool for predicting difficult endotracheal intubation. While it offers easy preoperative performance, it has limited accuracy and only poor to moderate discriminative power when used alone (2). LEMON score is another predictor, which includes look externally, the 3-3-2 rule, Mallampati score more than 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 vary among operators.

To address the limitations of the Mallampati and LEMON score, researchers have proposed the use of the upper lip bite test, thyromental distance, inter-incisor gap, sternomental distance (3), thyromental height (4), acromio-axillo-suprasternal notch index (5), and lower jaw protrusion maneuverability (2). However, not all of these measurements are universal; for example, thyromental height is not a strong predictor of difficult visualization of the larynx in Japanese patients (6). Other researchers have proposed combinations of these measures for precise prediction. Srivilaithona et al. showed that the weighted combination of five independent predictors (male sex, large tongue, limited mouth opening, poor neck mobility, and obstructed airway) helped to discriminate difficult intubation patients (7); however, the use of so many predictors is not suitable for ED. In this study, we evaluated the incidence and predictive factors of difficult intubation and developed an easy-to-use predictive formula for emergency physicians.

Materials And Methods

Study subjects

This 17-month (2011/11/1-2013/3/31) prospective observational study was approved by the Institutional Review Board of MacKay Memorial Hospital (11MMHISO64). In this duration, patients who visited the emergency department of MacKay Memorial Hospital (a medical center and teaching hospital in north Taiwan) and underwent traditional endotracheal intubation (procedure code: 40078) by participant physicians were asked for enrollment to this study. These participants consented to join this study and wrote informed consent by themselves or were volunteered by their delegates. The exclusion criterions included patient age under 20 years old, intubated by non-participant physicians, intubation via video-laryngoscope, or refused to join the study by themselves or delegates. Comatose patients were included if their delegate agreed after routine intubation.

Definition and data collection

First intubation attempt that could be classified as Cormack & Lehane classification grade III or IV were termed difficult (Fig. 2B), and Cormack & Lehane classification grade I or II were termed non-difficult. These scores were assigned during the first view by direct laryngoscopy. Patients were categorized into two groups for comparison and evaluation.

The anatomical distances measured included the inter-incisor, thyromental, sternomental, and thyrosternal distances (Fig. 3). The inter-incisor distance was defined as the distance between the upper and lower incisors, with the patient's mouth most widely opened. The other distances were measured with the patient's neck in full extension. As shown in Fig. 3, thyromental distance was measured from the bony, prominent point of the mentum to the thyroid notch with the patient's mouth closed; 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. Rulers were provided to all participant physicians for easy access.

When the patient's mouth was open, the physicians performed initial foreign body removal or sputum suction so that the airway was well-prepared. After this preprocessing, the remaining narrowing of the airway was classified as sputum, food, or blood impaction.

Generally, the initial intubation was attempted by the chief residents or attending staffs, whose extensive experience with emergency intubation could prevent bias due to inexperience, and all of them are emergency medicine specialists. Each chief resident or staff member used a specially designed form to check and record the patient's airway condition, including number of attempts, and the attending staff made all clinical decisions regarding airway management. A research assistant synthesized and code the raw data, also checked for missing values regularly, and contacted the original intubating physician for clarification or re-measurement of the missing values, finally, the data would be sent to the statistics center of our hospital. The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Statistical analysis

SPSS Statistics for Windows, version 17.0 (SPSS Inc., Chicago, IL) was used for data management and statistical analysis. Categorical variables were described using frequency distributions and reported as n (%), while continuous variables were reported as mean ± standard deviation.

Univariate analysis was used to evaluate the association between patient characteristics and difficult endotracheal intubation. Categorical variables were assessed by Pearson's chi-squared or Fisher's exact tests, while continuous variables were assessed by Student's *t* tests. Statistical significance was set at an alpha level of 0.05. Odds ratios (ORs) and 95% confidence intervals (CIs) of individual patient characteristics were also computed to assess the potential risk factors for difficult endotracheal intubation.

All individual risk factors significantly associated with difficult endotracheal intubation in the univariate analysis were included in a multivariate binary logistic regression model to reduce the type I error, except for intubation injury and the mean number of attempts, because these factors were consequences of successful intubation; thus, they could not serve as predictive factors.

Based on the results of the logistic regression model, a predictive formula comprising the β coefficient of no more than 4 independent predictors due to one-in-ten rule was established. To calculate predictive score, 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 variables, a correlation matrix with hierarchical dendrogram was performed with RStudio package (RStudio: Integrated Development for R. RStudio, Inc., Boston, MA.) and generalized association plots (GAP)(39, 40).

Results

In this 17-month duration, up to 1960 patients were intubated in emergency department of MacKay Memorial Hospital, but 316 patients were intubated by non-participant physicians, 21 patients were less than 20-year-old, and 1513 patients were not consentable, so finally 110 adult endotracheal intubation patients (66 men and 44 women) met our criteria and were enrolled in this study, and there were no missing data from them (Fig. 1). Their ages ranged from 21 to 96 years. The incidence of difficult endotracheal intubation was 35.5%. The difficult airway group had higher BMI than the non-difficult airway group, but no significant differences in age, sex, and difficult mask ventilation were observed between two groups (Table 1A).

The causes of intubation (Table 1B) included sepsis, lung disease, heart disease, renal disease, in-hospital cardiac arrest, out-of-hospital cardiac arrest, neurological problems such as intracranial hemorrhage/cerebrovascular accident, and facial trauma (in one case); however, causes of intubation did not differ significantly between two groups (Table 1B).

The presentations of intubated patients are shown in Table 1C. The prevalence of double chin; sunken cheeks; thick, short neck; and Mallampati difficulty (grade 3 or 4) differed significantly between the two groups. However, the prevalence of receding mandible, snoring, lack of teeth, and poor neck mobility did not.

Table 1D shows the four anatomical distances in the head and neck. Two of the variables, maximal inter-incisor distance and thyromental distance, differed significantly between the groups ($p = 0.014$). However, the other two variables, sternomental distance and thyrosternal distance, had no significant difference between the groups which means the two distances were almost equal between two groups.

Upper airway obstruction is shown in Table 1E. The three subitems of upper airway obstruction represented different agents for impaction: sputum, food, and blood. Only upper airway obstruction and sputum impaction differed significantly.

Table 1F shows the methods of intubation, related injuries, and the mean number of attempts. Before anesthesia induction, 6.4% (7/110) of patients were fully conscious (Glasgow Coma Scale 15), half (55/110) were confused, and 26.3% (29/110) required cardiorespiratory resuscitation. Because not all our patients were comatose, two methods of intubation were used: rapid sequence or coma and sedation-only without paralysis. Neither of the two methods showed significant differences. Intubation injury and the mean number of attempts were also important factors, but only the mean number of attempts differed significantly.

Table 2 shows the multivariate ORs of difficult endotracheal intubation. For every one-point increase in BMI, the chance of difficult intubation increased by 27.0% (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 with non-upper airway obstruction (OR 4.038, 95% CI, 1.456 to 11.200, $p = 0.007$). Patients with Mallampati grades of 3 or 4 were 5.16 times more likely to have difficult intubation than those with Mallampati grades of 1 or 2 (OR 5.163, 95% CI, 1.895 to 14.066, $p = 0.001$).

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 [52.56–84.92]	69.56 [52.87–86.25]	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 [20.53–30.91]	22.10 [18.92–25.28]	< 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

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 = grade 3 and 4, easy = grade 1 and 2

*p < 0.05; **p < 0.01; ***p < 0.001

Variable	Difficult (n = 39)	Non-difficult (n = 71)	p-value
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)			
Inter-incisors distance, max	3.09 [2.26–3.92]	3.50 [2.68–4.32]	0.014*
Thyromental distance	6.35 [5.22–7.48]	6.92 [5.75–8.09]	0.014*
Sternomental distance	11.55 [8.99–14.11]	12.34 [10.45 ± 14.23]	0.097
Thyrosternal distance	5.81 [3.53–8.09]	6.20 [4.50–7.90]	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 [1.37–2.73]	1.13 [0.75–1.51]	< 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 = grade 3 and 4, easy = grade 1 and 2

*p < 0.05; **p < 0.01; ***p < 0.001

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	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 3/4)	5.163	1.895–14.066	0.001	1.642
# BMI = body mass index				

Finally, we established a predictive formula of difficult endotracheal intubation by the combination of the β coefficients of four predictors: BMI, thyromental distance, upper airway obstruction, and Mallampati difficulty (grade 3 or 4).

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 cut-off point (Fig. 4). The area under the ROC curve was 0.866 (95% CI: 0.794 to 0.938, $p < 0.001$), and an integer cut-off score of 4 showed a sensitivity of 79.5% and specificity of 81.7%, demonstrating perfect classification with the highest Youden's index of 61.18% (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%

Figure 5 revealed the relationship between each variable based on Pearson's correlation, both columns and rows represented individual variables, and comprised a proximity matrix. Red indicated positive correlation and blue indicated negative one. The darker the color, the higher the Pearson product-moment correlation coefficient. Hierarchical clustering tree was also used to sort the matrix that put the variables which were highly related together, such as thyrosternal distance and sternomental distance, which had a high positive correlation with more than 0.7 of Pearson coefficient, and the two distances also had a moderate positive correlation with inter-incisor distance, however, compared the three distances with thyromental distance, there was only 0.2 of Pearson coefficient. In the hierarchical clustering tree, age and lack of teeth, also sunken cheeks and difficult mask ventilation were proximate, and both the two pairs of variables had approximately 0.3 of Pearson coefficient. The variable of operator was far to not only intubation injury, but also number of attempts, and even difficult intubation in the hierarchical clustering tree, and in the matrix, the colors for its relationship to each variable were almost light.

Discussion

Anatomical changes such as dental loss, head and neck joint changes (8–11) affect airway management, including intubation and ventilation (12). A prospective study reported that head and neck movement, thyromental distance, and inter-incisor gap decreased with age; however, the dentition grade, Mallampati score, and cervical joint rigidity increased. Therefore, the authors concluded that middle-aged or elderly adults had a higher risk of difficult endotracheal intubation (13). However, we observed no significant difference in the proportion of elderly patients between the difficult and non-difficult intubation groups. This difference may be because our age cutoff was 65 years, while Rose and Cohen showed that patients in the 40–59-year age range were at risk for difficult endotracheal intubation (8); we defined this middle-aged group as "non-elderly," which may have masked the effect of aging on difficult intubation.

We recorded the indications for intubation because they may have been key factors; for example, head and neck trauma may decrease neck mobility and even affect the measurement of thyromental, thyrosternal, and sternomental distances. Endotracheal intubation is often considered a contraindication in cases with maxillofacial trauma as maxillomandibular fixation may be disturbed (14). Therefore, it was recommended that intubation of the laryngeal mask airway be included in the algorithm for these patients (15). However, our study included only one patient with facial trauma, which limited our evaluation. No other indications for intubation, including lung, heart, and renal disease, differed significantly between two groups. Therefore, the cause of intubation may not be a major factor related to difficult intubation.

The lack of significant differences in some presentation variables may have been due to trouble in measurement or definition such as lack of teeth and poor neck mobility. Varying presentations were possible for the "lack of teeth"; "lack" could range from one to all. If all the teeth are lost, it will be difficult for upper and lower gums to come into contact, limiting temporomandibular joint movement (16). The location of tooth loss also requires clarification. Evidence has revealed that the loss of posterior teeth results in over-closure of the oral cavity (17) while the loss of anterior teeth may allow easy access to the airway and prevent intubation-related teeth loss (18, 19). Regarding poor neck mobility, despite Brit Long's report of the positive likelihood ratio of impaired neck mobility for predicting difficult endotracheal intubation (20), and in Wilson's difficult endotracheal intubation predictive model, head and neck movement was divided into three levels to calculate the risk (21). Nevertheless, measurement is difficult in humpbacked patients because their kyphotic deformities are related to spinal osteoporosis and degeneration of intervertebral discs (17); as the neck of patients cannot fully extend, clearly discriminating neck and back stiffness from non-precise measurement is difficult, as shown by our raw data.

Intubation injuries included mechanical damage to the patients' teeth and/or airways, hematoma formation, and even aspiration of gastric contents (29–31). The most common cause of postintubation injuries was overfilled cuffs (31). A systematic review reported a high prevalence of intubation-related laryngeal injury (83%) (32). However, in our study, the rates were 2.6% and 5.6% in the difficult and non-difficult endotracheal intubation groups, respectively; both were significantly lower than previously reported, which may be due to the high consensus among the participant physicians in the present study. Thus, they were likely more careful and attentive when evaluating and intubating these patients.

The four key predictive factors in our formula were reasonable; the combination of Mallampati classification and thyromental distance is preferable for airway assessment because of its better specificity and positive predictive value over either alone (33). However, this combination had low sensitivity, indicating the need for additional predictive factors; thus, the results of our study may be a possible solution to this obstacle.

The previously reported multi-factor predictive models included Naguib's new model, a predictive formula developed using logistic regression that includes thyromental distance, Mallampati score, inter-incisor gap, and height (34). While the first two factors were also included in our algorithm, inter-incisor 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 (35), indicating that BMI is a more powerful predictor.

In our formula, Mallampati score had the largest coefficient, making it the most important factor. A previous study reported no significant association between an increased Mallampati score and difficult intubation; thus, their revised LEMON methods excluded the weight of Mallampati score (36). However, they also reported that the Mallampati score was not easily available and was obtained in only 57% of patients. In comparison, we assessed all patients successfully; thus, their negative result may have been a result of too many missing Mallampati scores.

Based on our findings, we recommend the routine assessment of Mallampati score in all patients regardless of whether the patient has been admitted to the ED or general ward. Because the Mallampati score had the largest β coefficient value, it can allow early detection of those with a high risk of difficult endotracheal intubation; when these patients require intubation, the necessary time for evaluation may not be enough, so pre-assessment will allow physicians to be well-prepared for this challenge.

In our study, all patients were pre-treated with initial sputum suction and foreign body removal; therefore, recorded upper airway obstruction indicated at least middling to severe obstruction due to residual or newly produced issues. As a component of the modified LEMON criteria, the sensitivity and negative predictive value of upper airway obstruction are well-validated (37). Our results showed that none of the upper airway obstruction subclasses were significant. Previous studies did not evaluate upper airways obstruction subclasses separately or only reported the percentages of each kind of impaction overall (38). To our knowledge, our study is the first to show that individual evaluation of each kind of impaction may show non-significant results, but grouping all impaction types into a single variable can reveal significant differences.

Sternomental and thyrosternal distances did not differ significantly in our study. GAP analysis implied that although sternomental, thyrosternal, and thyromental were anatomical distances, but thyromental distance had its distinctness due to the smaller Pearson coefficient to all the other distances. Ramadhani reported sternomental distance as an indicator of head and neck mobility in 1996 (22). One study reported a significant difference in this anatomical distance between the single and multiple-attempt laryngoscopy groups (23). However, our study did not compare single and multiple attempts, and several factors, such as the difficulty in evaluating neck mobility, may affect the results. Another study also did not recommend sternomental distance as the sole predictor (24), indicating its weaker predicting role. In contrast, the non-significant difference in thyrosternal distance was consistent with the findings of previous studies. Unlike thyromental distance, thyrosternal distance was not a good bedside parameter for predicting difficult endotracheal intubation (25–28).

In previous studies, it has been proven that the number of remained dentate decreased when people become older and older, and the elderly also had higher proportion of becoming completely edentulous (41, 42), our GAP analysis also found the same trend, the variables of age and lack of teeth were moderately correlated. Besides, the moderately correlation of sunken cheeks and difficult mask ventilation can also be shown by GAP analysis, which matches the result of previous studies, sunken cheeks was found to independently identify difficult mask ventilation (43, 44), so by the above two associations, this visualization tool is reasonable and reliable. However, we found sunken cheeks was a predictor of non-difficult endotracheal intubation in this study, it may imply less intubation resistant from facial muscle.

The training level of operator should be considered, so similar study excluded the case which is intubated by low experience operators, including last year of medical student and first-year internist in general practice (45). Therefore, we only included the patients who were intubated by chief residents and attending physicians, and the GAP analysis also demonstrated that the variable of operator has almost zero correlation to all of the adverse index such as intubation injury, number of attempts, and even difficult intubation, implied that our chief residents and attending physicians have almost equal level of the skill of endotracheal intubation, so there was less experience related bias in our study.

Our study had some limitations. First, our formula directly used the β coefficient and the four coefficients were not integers because we did not adjust them to avoid decreasing the sensitivity or specificity. While this prevents easy calculation by physicians, the derived formula can be entered into a computer as a simple program or application to solve this problem. Second, because our emergency physicians had heavy work, they could only enroll patients when they were relatively unbusy, therefore, we included only 110 patients, which was far fewer than the numbers included in other similar studies, however, as approximately 1000 patients are intubated in the emergency department of MacKay Memorial Hospital each year, our study of 110 patients could be considered a sampling survey, and we also plan to enroll a new group of patients to validate our derived formula. Furthermore, the prospective design meant that we could avoid missing data, unlike in retrospective studies. Third, most of the agreements were signed by the patient's delegates after successful intubation; an increasing number of intubation attempts would likely increase the difficulty of enrollment due to patient family anxiety and irritation. However, the participant physicians participating in this study may be more careful and have highly consensus about intubation; therefore, the incidence of difficult intubation may not have been underestimated.

Conclusions

In this study, difficult intubation was associated with increased BMI, lesser thyromental distance, upper airway obstruction, and Mallampati difficulty (grade 3 or 4), our predictive formula which based the above variables allowed careful management and early expert consultation when necessary. Moreover, GAP analysis strengthened the special role of thyromental distance among other anatomical distances, and also shown the interactive relationship between each variables by data visualization.

Abbreviations

ED
Endotracheal intubation
GAP
Generalized association plot
BMI
Body mass index
OR
Odds ratio
IHCA
In-hospital cardiac arrest
OHCA
Out-of-hospital cardiac arrest
ICH

Intracranial hemorrhage

CVA

cerebrovascular accident

Declarations

Competing interests

The authors declare that they have no competing interests.

Funding

We appreciate the grant supporting by the grant (1081B30, MMH-MM-10915) from Mackay Medical College, New Taipei City, Taiwan.

Availability of data and materials

The datasets are available from the corresponding author on reasonable request.

Authors' 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. Cheng-Ying Shen 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 Figure 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.

Ethics approval and consent to participate

This study was approved by the Institutional Review Board of MacKay Memorial Hospital (11MMHIS064) Oct 29, 2011.

All participants signed informed consent by themselves or were volunteered by their delegates.

Consent for publication

All participants provided their consent by themselves or their delegates.

Acknowledgements

We thank the staff of the emergency department of MacKay Memorial Hospital for treating critical patients. We also thank the participating physicians for collecting the essential data during their busy and stressful situation to help complete this challenging study.

References

1. Hasegawa K, Shigemitsu K, Hagiwara Y, et al. Association between repeated intubation attempts and adverse events in emergency departments: an analysis of a multicenter prospective observational study. Ann Emerg Med. 2012;60(6):749–54.e742.
2. Khaled ER, Adnan AM, Mohammad H, et al. Prediction of difficult intubation depending on two different Methods of airway assessment: a prospective study. Middle East J Anaesthesiol. 2018;25(2):181–7.
3. Vannucci A, Cavallone LF. Bedside predictors of difficult intubation: a systematic review. Minerva Anestesiol. 2016;82(1):69–83.
4. Etezadi F, Ahangari A, Shokri H, et al. Thyromental height: a new clinical test for prediction of difficult laryngoscopy. Anesth Analg. 2013;117(6):1347–51.
5. Hungund S, Ashwini HR, Deshpande N, et al. Comparison between acromioaxillo-suprasternal notch index and thyromental distance in predicting difficult visualization of larynx in Indian population. International Journal of Scientific Research. 2019;8(2):51–3.
6. Yabuki S, Iwaoka S, Murakami M, et al. Reliability of the thyromental height test for prediction of difficult visualisation of the larynx: A prospective external validation. Indian J Anaesth. 2019;63(4):270–6.
7. Srivilaithon W, Muengtaweepongsa S, Sittichanbuncha Y, et al. Predicting Difficult Intubation in Emergency Department by Intubation Assessment Score. J Clin Med Res. 2018;10(3):247–53.
8. Rose DK, Cohen MM. The airway: problems and predictions in 18,500 patients. Can J Anaesth. 1994;41(5 Pt 1):372–83.
9. Karkouti K, Rose DK, Wigglesworth D, et al. Predicting difficult intubation: a multivariable analysis. Can J Anaesth. 2000;47(8):730–9.
10. Koh LK, Kong CE, Ip-Yam PC. The modified Cormack-Lehane score for the grading of direct laryngoscopy: evaluation in the Asian population. Anaesth Intensive Care. 2002;30(1):48–51.
11. Ezri T, Warters RD, Szmuk P, et al. The incidence of class "zero" airway and the impact of Mallampati score, age, sex, and body mass index on prediction of laryngoscopy grade. Anesth Analg. 2001;93(4):1073–5.
12. Johnson KN, Botros DB, Groban L, et al. Anatomic and physiopathologic changes affecting the airway of the elderly patient: implications for geriatric-focused airway management. Clin Interv Aging. 2015;10:1925–34.
13. Moon HY, Baek CW, Kim JS, et al. The causes of difficult tracheal intubation and preoperative assessments in different age groups. Korean J Anesthesiol. 2013;64(4):308–14.
14. Mohan R, Iyer R, Thaller S. Airway management in patients with facial trauma. J Craniofac Surg. 2009;20(1):21–3.
15. Tentillier E, Heydenreich C, Cros AM, et al. Use of the intubating laryngeal mask airway in emergency pre-hospital difficult intubation. Resuscitation. 2008;77(1):30–4.

16. Whittaker DK, Davies G, Brown M. Tooth loss, attrition and temporomandibular joint changes in a Romano-British population. J Oral Rehabil. 1985;12(5):407–19.
17. Lee S-Y, Shih S-C, Leu Y-S, et al. Implications of Age-Related Changes in Anatomy for Geriatric-Focused Difficult Airways. International Journal of Gerontology. 2017;11(3):130–3.
18. Lockhart PB, Feldbau EV, Gabel RA, et al. Dental complications during and after tracheal intubation. J Am Dent Assoc. 1986;112(4):480–3.
19. Sowmya B, Raghavendra P. Management of dental trauma to a developing permanent tooth during endotracheal intubation. J Anaesthesiol Clin Pharmacol. 2011;27(2):266–8.
20. Long B, Koyfman A, Gottlieb M. Factors Predicting Difficult Endotracheal Intubation. Acad Emerg Med. 2019;26(11):1294–6.
21. Wilson ME, Spiegelhalter D, Robertson JA, et al. Predicting difficult intubation. Br J Anaesth. 1988;61(2):211–6.
22. Al Ramadhani S, Mohamed LA, Rocke DA, et al. Sternomental distance as the sole predictor of difficult laryngoscopy in obstetric anaesthesia. Br J Anaesth. 1996;77(3):312–6.
23. Elumalai G. Common Nasal Anomalies and Its Implications on Intubation in Head and Neck Surgeries. Journal of Surgery. 2016;4:81–4.
24. Prakash S, Mullick P, Bhandari S, et al. Sternomental distance and sternomental displacement as predictors of difficult laryngoscopy and intubation in adult patients. Saudi J Anaesth. 2017;11(3):273–8.
25. Merah NA, Wong DT, Ffoulkes-Crabbe DJ, et al. Modified Mallampati test, thyromental distance and inter-incisor gap are the best predictors of difficult laryngoscopy in West Africans. Can J Anaesth. 2005;52(3):291–6.
26. Wong SH, Hung CT. Prevalence and prediction of difficult intubation in Chinese women. Anaesth Intensive Care. 1999;27(1):49–52.
27. Yildiz TS, Korkmaz F, Solak M, et al. Prediction of difficult tracheal intubation in Turkish patients: a multi-center methodological study. Eur J Anaesthesiol. 2007;24(12):1034–40.
28. Khan ZH, Maleki A, Makarem J, et al. A comparison of the upper lip bite test with hyomental/thyrosternal distances and mandible length in predicting difficulty in intubation: A prospective study. Indian J Anaesth. 2011;55(1):43–6.
29. Nolan JD. Prehospital and resuscitative airway care: should the gold standard be reassessed? Curr Opin Crit Care. 2001;7(6):413–21.
30. Murphy MF, Walls RM. The Difficult and Failed Airway. In: *In*: Manual of Emergency Airway Management. Philadelphia: Lippincott Williams and Wilkins; 2000. pp. 31–9.
31. Cierniak M, Timler D, Sobczak R, et al. Analysis of the incidence of postintubation injuries in patients intubated in the prehospital or early hospital conditions of the hospital emergency department and the intensive care unit. Ther Clin Risk Manag. 2015;11:1489–96.

32. Brodsky MB, Levy MJ, Jedlanek E, et al. Laryngeal Injury and Upper Airway Symptoms After Oral Endotracheal Intubation With Mechanical Ventilation During Critical Care: A Systematic Review. Crit Care Med. 2018;46(12):2010–7.
33. Mallhi AI, Abbas N, Naqvi SM, N, et al. A comparison of Mallampati classification, thyromental distance and a combination of both to predict difficult intubation. Anaesthesia Pain Intensive Care. 2018;22(4):468–73.
34. Naguib M, Ensor JE, O'Sullivan C. Predictive Performance of Three Multivariate Difficult Tracheal Intubation Models: A Double-Blind, Case-Control Study. Anesth Analg. 2006;103(6):1581.
35. Juvin P, Lavaut E, Dupont H, et al. Difficult tracheal intubation is more common in obese than in lean patients. Anesth Analg. 2003;97(2):595–600.
36. Reed MJ, Dunn MJ, McKeown DW. Can an airway assessment score predict difficulty at intubation in the emergency department? Emerg Med J. 2005;22(2):99–102.
37. Hagiwara Y, Watase H, Okamoto H, et al. Prospective validation of the modified LEMON criteria to predict difficult intubation in the ED. Am J Emerg Med. 2015;33(10):1492–6.
38. Sakles JC, Corn GJ, Hollinger P, et al. The Impact of a Soiled Airway on Intubation Success in the Emergency Department When Using the GlideScope or the Direct Laryngoscope. Acad Emerg Med. 2017;24(5):628–36.
39. Wu HM, Tien YJ, Chen CH. GAP: A graphical environment for matrix visualization and cluster analysis. Comput Stat Data Anal. 2010;54(3):767–78.
40. Chen CH. Generalized association plots: Information visualization via iteratively generated correlation matrices. *Statistica Sinica* 2002;7–29.
41. Bælum V, Luan WM, Chen X, Fejerskov O. Predictors of tooth loss over 10 years in adult and elderly Chinese. Commun Dent Oral Epidemiol. 1997;25(3):204–10.
42. Yamamoto K, Suzuki A, Toyama Y, Sasakawa T, Kunisawa T, Takahata O, Iwasaki H. The Pentax-AWS is particularly suitable for facilitating intubation in edentulous geriatric patients. Journal of anesthesia. 2009;23(3):471–1.
43. Sreekantha DK, Saldanha RS, Krishnappa JG, Mehandale SG, Glen RRC, Prajna MK. Predicting difficulties in Mask Ventilation using Machine Learning techniques. *In* 2019 *IEEE International Conference on Distributed Computing, VLSI, Electrical Circuits and Robotics (DISCOVER)* (pp. 1–6). IEEE.
44. Lee SY, Chien DK, Huang MY, Huang CH, Shih SC, Wu KM, Ku HC, Chang WH. Patient-specific Factors Associated with Difficult Mask Ventilation in the Emergency Department. International Journal of Gerontology. 2017;11(4):263–6.
45. Srivilaithon W, Muengtaweepongsa S, Sittichanbuncha Y, Patumanond J. Predicting difficult intubation in emergency department by intubation assessment score. Journal of Clinical Medicine Research. 2018;10(3):247.

Figures

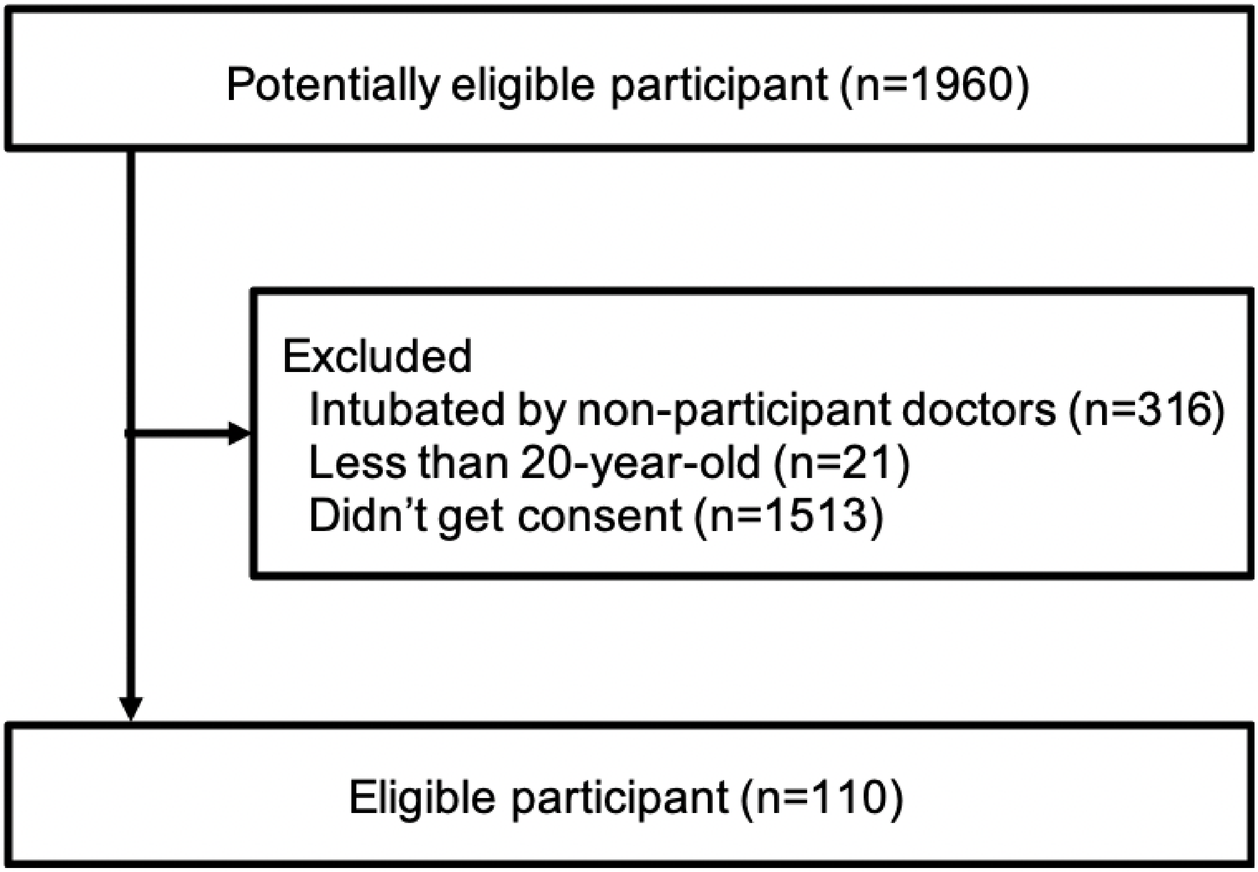

Figure 1

The study flow diagram. In this duration, we had 1960 endotracheal intubated patients who were potentially eligible study subjects, but after excluded the patients who were intubated by non-participant physicians, underage patients, and non-consentable ones, finally, 110 patients were included for further analysis.

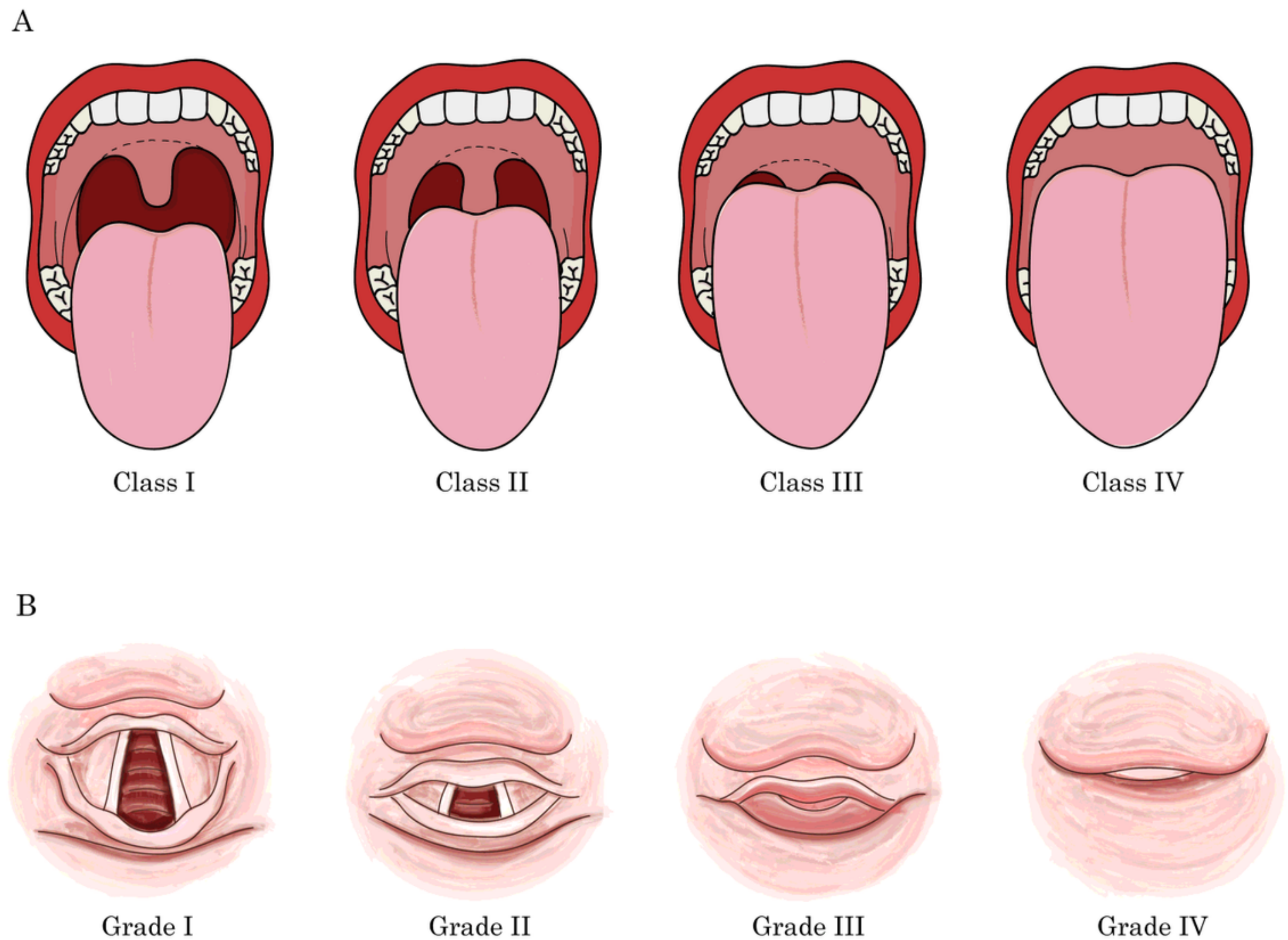

Figure 2

(A). The Mallampati score or classification is a grading system based on the visualization of the pharyngeal structures during laryngoscopy that is used to predict the degree of difficulty of endotracheal intubation. The score comprises four categories. 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 into four grades based on the visible structures. 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.

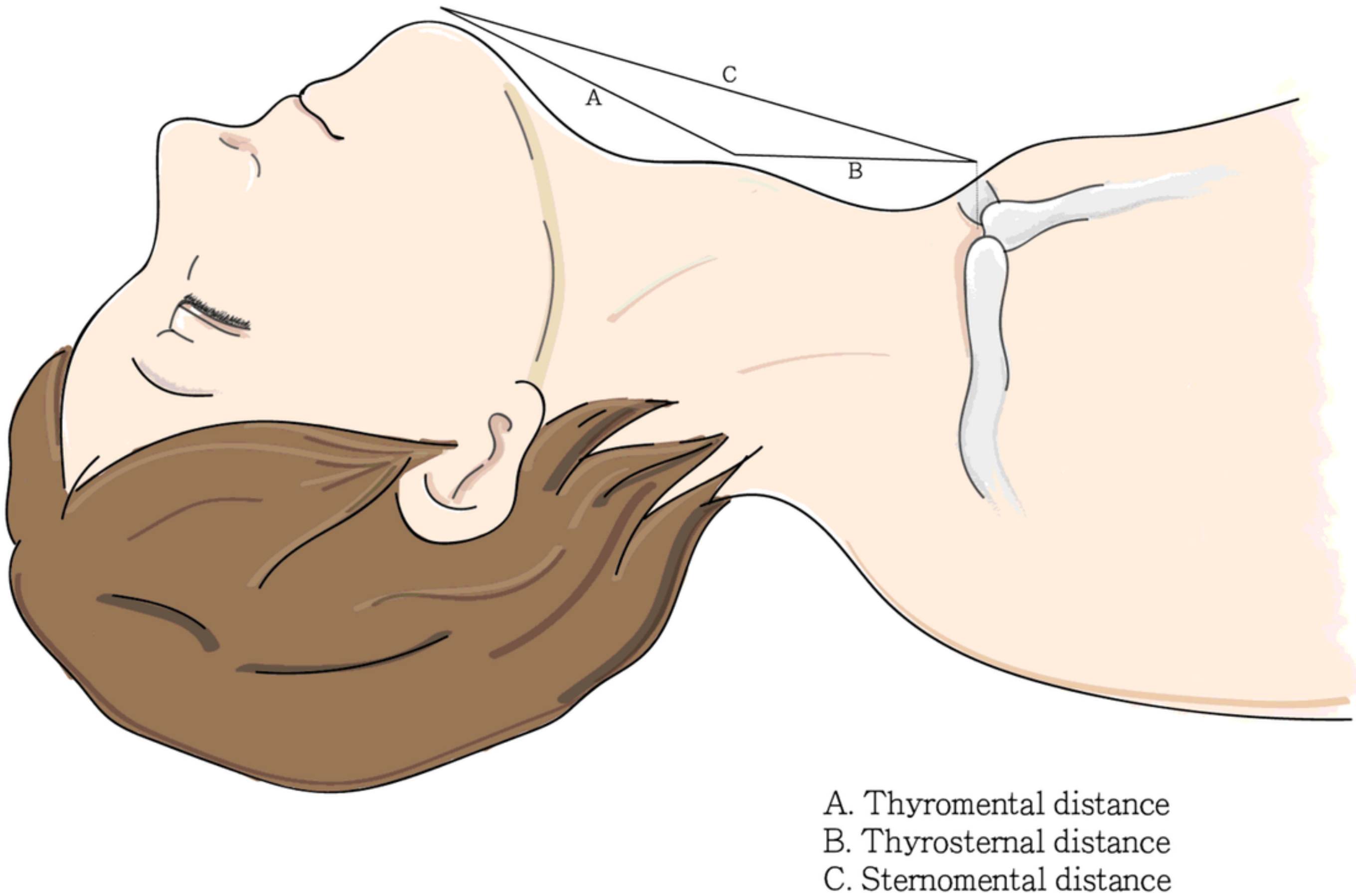

Figure 3

Definitions of thyromental, thyrosternal, and sternomental distances. The three anatomical landmarks of airway evaluation include the bony prominent point of the mentum and the thyroid notch and sternal notch. The combination of two of these three landmarks allows measurement of the three distances (A, B, C), which form a triangle. In most patients, A plus B is larger than C, but some patients' neck could be extended so that C is equal to A plus B.

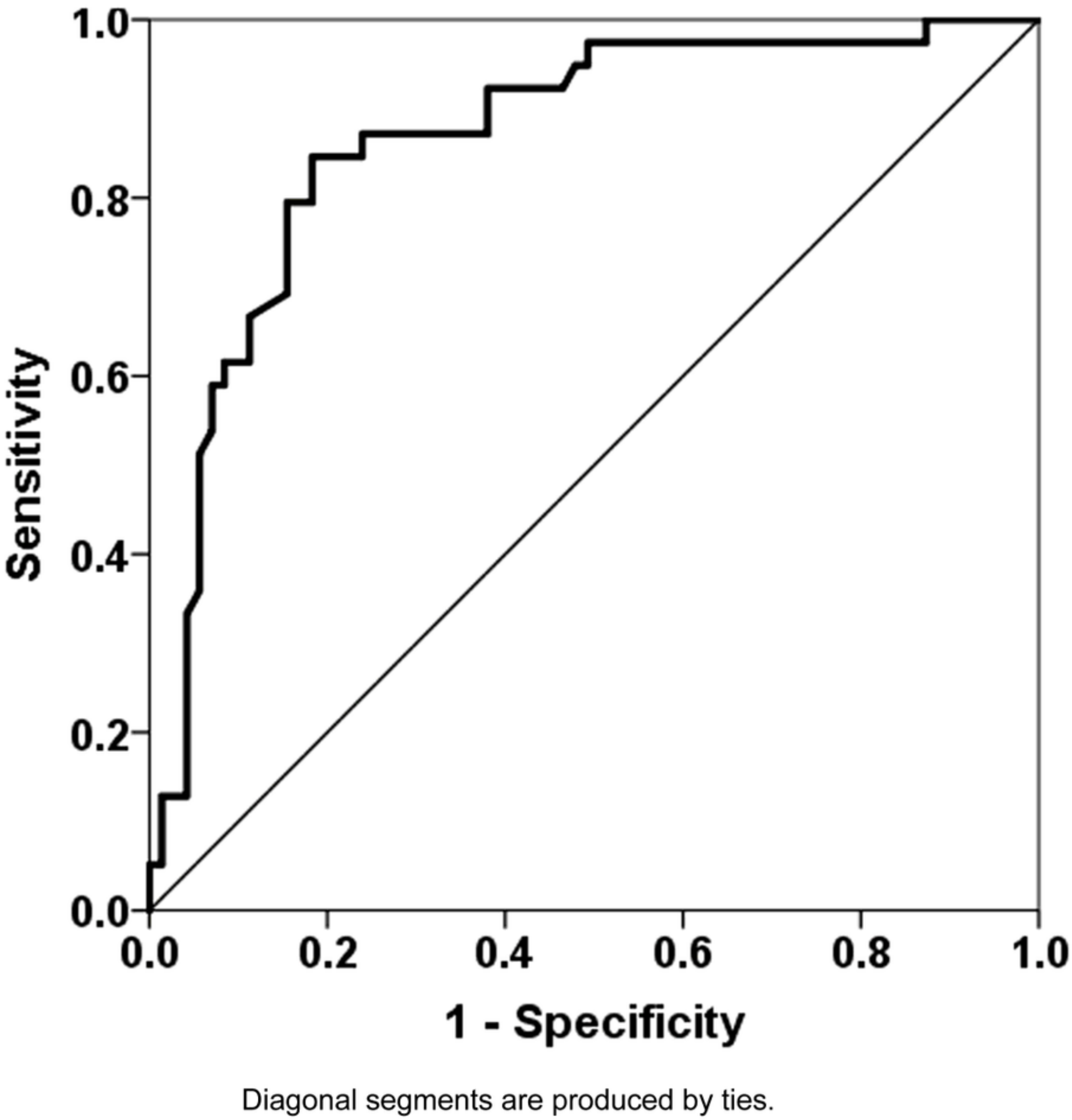

Figure 4

Receiver operating characteristic (ROC) curve of our predictive formula for difficult endotracheal intubation. ROC curves depicting the relationship between the sensitivity and specificity of our model for predicting difficult endotracheal intubation. The area under the ROC (AuROC) shows the discriminating power. AuROC=0.866 (95% confidence interval; 0.794, 0.938); Cut-off score = 4; Sensitivity=79.5%; Specificity=81.7%.

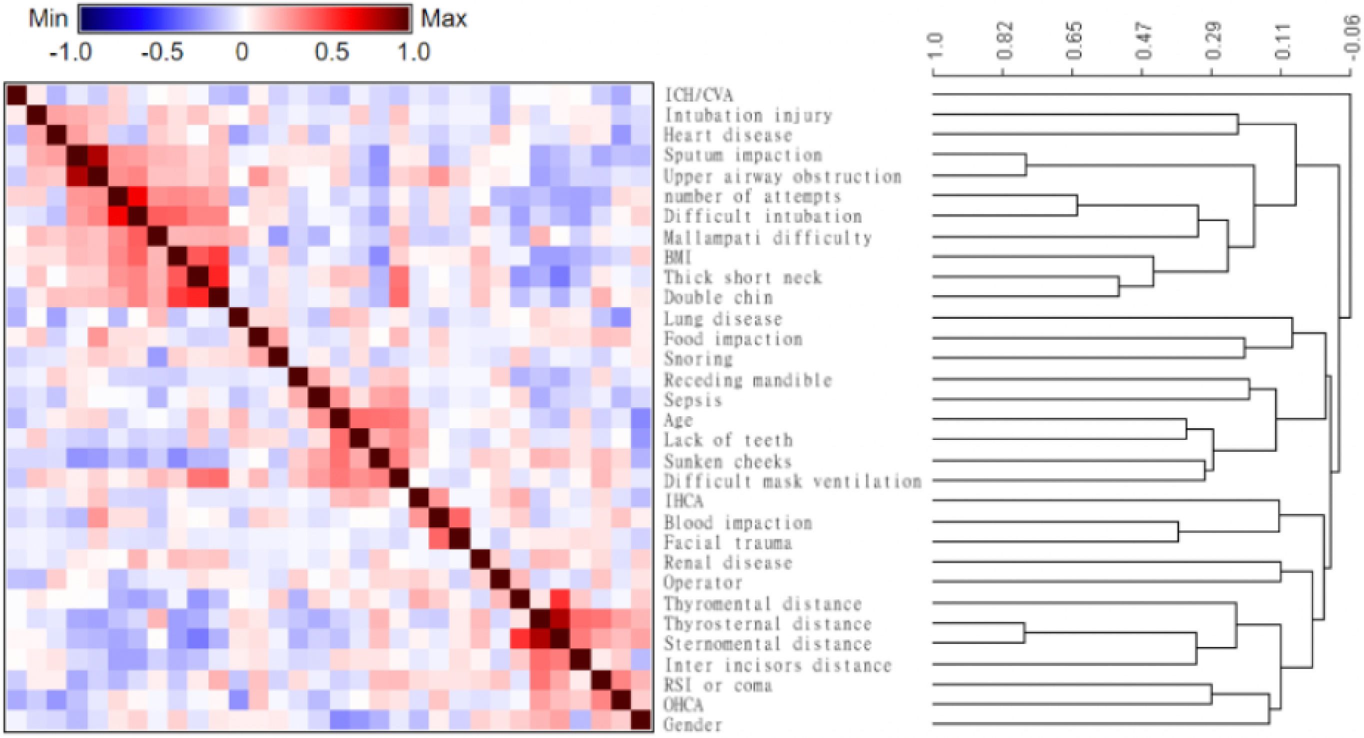

Figure 5

Proximity matrix with hierarchical clustering tree between each variable of demographic factors and physical findings. The color in 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, the lower hierarchy meant the closer relationship, which could correspond to the correlation coefficient scale on the top of the tree.