ORIGINAL ARTICLE

# Morphometric and ultrasonographic determinants of difficult laryngoscopy in obese patients: A prospective observational study

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## Abstract

**Background:** Obese people have a higher risk of difficult laryngoscopy due to their thick neck, large tongue, and redundant pharyngeal soft tissue. However, there is still no established predictive factor for difficult laryngoscopy in obese population.

**Methods:** We conducted a prospective assessor-blind observational study to enroll adult patients with a body mass index of 30 $kg\cdot m^{-2}$ or higher undergoing laparoscopic sleeve gastrectomy at a medical center between May 2020 and August 2021. Conventional morphometric characteristics along with ultrasonographic airway parameters were evaluated before surgery. The primary outcome was difficult laryngoscopy, defined as a Cormack and Lehane's grade III or IV during direct laryngoscopy. Logistic regression analyses were performed to evaluate the association between included factors and difficult laryngoscopy. Discrimination performance of predictive factors was assessed using area under the receiver operating characteristic curve (AUC).

**Results:** A total of 80 patients were evaluated, and 17 (21.3%) developed an event of difficult laryngoscopy. Univariate analyses identified five factors associated with difficult laryngoscopy, including age, sex, hypertension, neck circumference, and cross-sectional area of tongue base. After adjusting for these variables, neck circumference was the only independent influential factor, adjusted odds ratio: 1.227 (95% confidence interval, 1.009–1.491). Based on Youden's index, the optimal cutoff of neck circumference was 49.1 cm with AUC: 0.739 (sensitivity: 0.588, specificity: 0.889; absolute risk difference: 0.477, and number needed to treat: 3).

**Conclusion:** Greater neck circumference was an independent risk factor for difficult laryngoscopy in obese patients. This finding provides a way of reducing unanticipated difficult airway in this high-risk population.

**Keywords:** Difficult airway; Difficult intubation; Neck circumference; Obstructive sleep apnea; Tongue base

## 1. INTRODUCTION

Obesity is a major epidemic of the twenty-first century.[1] The global prevalence of overweight and obese individuals has doubled since 1980, and almost a third of the population worldwide is now classified as being overweight or obese.[1] Obesity increases the risk of various types of diseases, including cardiovascular and metabolic disorders, liver and gallbladder diseases, gastroenterological cancers, and osteoarthritis.[2,3] Accordingly, the number of obese patients requiring surgical procedures and anesthesia care is expected to continue growing.

Obese people represent an evident challenge in anesthesia due to their higher risk of difficult airway compared with the nonobese population.[4,5] Obese patients also have a higher risk of difficult laryngoscopy due to their short, thick neck, large tongue, and significant redundant pharyngeal soft tissue, which impedes visualization of the glottis during a laryngoscopy.[5] A previous study has shown that the risk of difficult tracheal intubation in obese patients is three times higher than for nonobese patients.[5] However, there is still no established predictor for difficult airway in obese patients. Some studies have reported that body mass index (BMI) and oropharyngeal Mallampati score serve as predictors for difficult laryngoscopy.[6–8] However, other studies refuted these correlations.[9–12] Some previous studies have demonstrated that neck circumference and an abundance of pretracheal soft tissue, measured ultrasonically, may predict difficult laryngoscopy.[8,11,13,14] By contrast, other studies showed no association between neck circumference, anterior neck soft tissue depth, and difficult laryngoscopy.[15,16] The results of previous studies were mixed and inconclusive due to the inconsistent and incomprehensive evaluations of airway characteristics

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which are potentially related to difficult laryngoscopy.[6–16] In addition, the predictive role of ultrasonographic airway measures for difficult laryngoscopy has been rarely explored in obese populations.[13,15]

We conducted a prospective observational study to explore potential risk factors for difficult laryngoscopy in obese patients undergoing bariatric surgery. In this study, ultrasound, an accessible imaging modality for anesthesiologists, was used to evaluate the tongue size and pretracheal soft tissue of obese patients. This study aimed to discover influential factors and to determine the prognostic ability of these factors for difficult laryngoscopy in obese patients.

## 2. METHODS

### 2.1. Clinical setting and patient selection criteria

This study was reviewed and approved by the Institutional Review Board of Taipei Medical University in Taiwan (approval no. TMU-JIRB-N202002076), and registered in the international directory, www.clinicaltrials.gov (identifier: NCT04395248). Informed verbal and written consent were obtained from all participants before their inclusion within the study. All methods within this study were performed in accordance with the Helsinki Declaration and relevant regulations.

We prospectively enrolled patients undergoing laparoscopic sleeve gastrectomy at a medical center between May 2020 and August 2021. The inclusion criteria were, age 20–65 years and BMI ≥30 kg·m$^{-2}$. Exclusion criteria were, known difficult airway, a history of head and neck surgery or radiation therapy, cervical spine injury or implants, severe cardiovascular disease (e.g., coronary arterial disease and aortic dissection), peripheral capillary oxygen saturation <90% in room air, pregnancy, and patient refusal (Fig. 1).

### 2.2. Preoperative physical examination

Before surgery, all enrolled patients were examined for the classic morphometric factors associated with a difficult airway, as

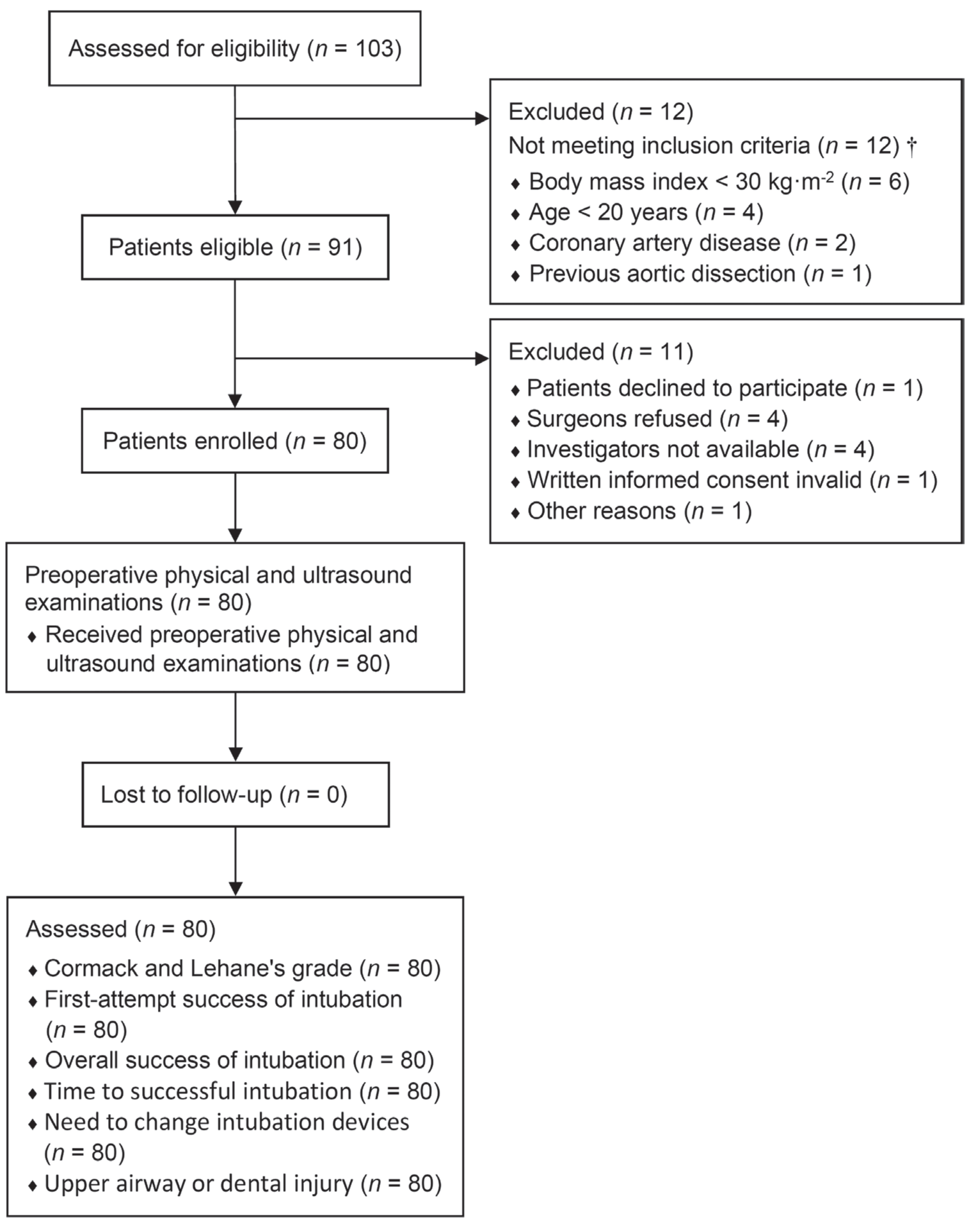


**Fig. 1** Study flow diagram. † Not mutually exclusive since patients could have more than one exclusion criterion.

described in the lean population, including interincisor distance (<3 cm or not),[17] mentohyoid distance (<4 cm or not),[17] thyromental distance (<6.5 cm or not),[5] neck movement (<80 degrees or not),[18] and modified Mallampati score.[19] In addition, neck circumference was measured at the thyroid cartilage.[8,11,14] An upper lip bite test and a mandibular prognathism test were also conducted for each participant.[20,21]

### 2.3. Ultrasound evaluation for upper airway

Ultrasound was used to assess the upper airway of all enrolled patients before surgery, including pretracheal soft tissue depth[13] and tongue size.[22] Regarding pretracheal soft tissue, the distance from the skin to the anterior aspect of the trachea was measured in the central axis of the neck at three levels: vocal cords, thyroid isthmus, and suprasternal notch.[13] In addition, a previous study has shown that the increased tongue volume and deposition of fat at the tongue base in obese people were highly associated with obstructive sleep apnea.[23] To quantify the size of the tongue base using ultrasound, the patient was placed in a seated position, and a convex transducer (GE C1-5-RS, GE Healthcare, Chicago, IL, USA) at frequencies 1.5 to 5.0 MHz on a portable ultrasound device (LOGIQ, GE Healthcare, Chicago, IL, USA) was introduced to the skin of the neck in the submental region coronally, immediately cephalad to the body of the hyoid bone, and then in the area between the hyoid bone and the symphysis of the mandible. To obtain a standardized scanning level of the tongue base, the mucosal covering of the tongue was employed as the anterior border and the geniohyoid muscle as the posterior border, as internal landmarks. In addition, color flow Doppler was used to localize the lingual arteries on both sides of the lower lateral borders of the tongue base, where they entered the tongue base inferiorly[22] (Fig. 2). The ultrasound transducer was then placed in the sagittal plane to visualize the mid-tongue. The patients were instructed to avoid tongue movements, swallowing, or talking. The maximal width and height of the tongue base and the maximal height of the mid-tongue were measured. The cross-sectional area (CSA) of the tongue base was calculated using the following formula: $CSA = \text{tongue base width} \times \text{tongue base height} \times \pi \times 0.25$. All ultrasonographic measurements were performed twice to calculate the average value. The physical and ultrasonographic examinations were conducted by an independent attending anesthesiologist (Y.-H.T.).

### 2.4. Determination of difficult laryngoscopy

Upon arrival at the operating room, patients were initially placed in a ramped position and then moved into a reverse Trendelenburg position to achieve a 30-degree incline of the thorax before preoxygenation. After preoxygenation with 100% oxygen for 5 min, general anesthesia was induced with propofol 1.5–2.0 mg·kg$^{-1}$ ideal body weight, fentanyl 2–3 μg·kg$^{-1}$ total body weight, and rocuronium 0.8–1.0 mg·kg$^{-1}$ ideal body weight. After the abolition of the eyelash reflex, rocuronium 0.8–1.0 mg·kg$^{-1}$ ideal body weight was infused and immediately followed by a flush of 20 mL normal saline to hasten neuromuscular blockade.[24,25] At 1 minute after rocuronium infusion, direct laryngoscopy intubation was performed. The laryngoscopy intubation was performed using a size–3 or –4 Macintosh blade (Rüsch Inc., Duluth, GA, USA) and a 7.5 or 8.0 mm styleted

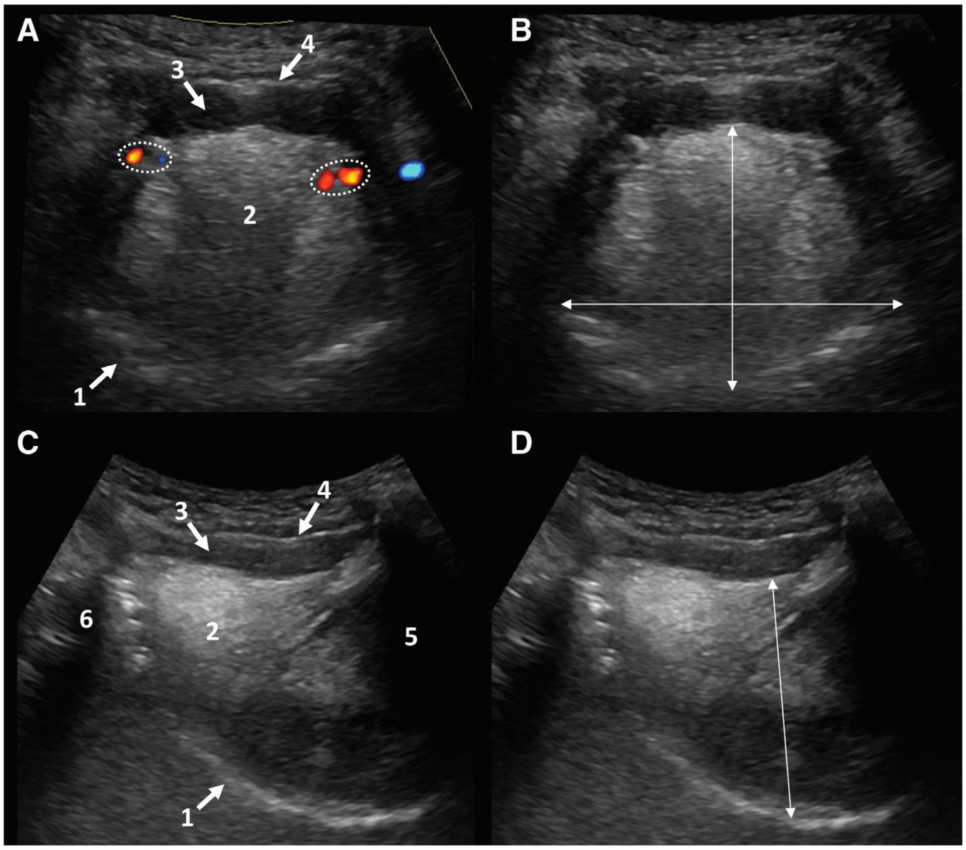


**Fig. 2** Ultrasonographic measurement of tongue base and mid-tongue width and height. A, Lingual arteries were seen with color flow Doppler (dotted ellipses) on both sides of lower lateral borders of tongue base, where they entered tongue base inferiorly. Also seen were (1) mucosal covering of tongue, (2) genioglossus muscle, (3) geniohyoid muscle, and (4) mylohyoid muscle. B, Maximal width and height of tongue base. C, (1) Mucosal covering of tongue, (2) genioglossus muscle, (3) geniohyoid muscle, (4) mylohyoid muscle, and acoustic shadows reflecting (5) body of mandible, and (6) hyoid bone. D, Maximal height of mid-tongue.

endotracheal tube (Unomedical, ConvaTec Inc., Deeside, Wales, UK). An attending anesthesiologist (Y.-M.W. or S.-Y.H.) performed and described the laryngoscopy intubation, while two senior nurse anesthetists were the assistants. All were blinded to the preoperative physical and ultrasound assessments.

The primary outcome was difficult laryngoscopy. The laryngoscopy view was graded according to the Cormack and Lehane classifications with external laryngeal pressure applied.[26] Laryngoscopy views graded as III or IV were defined as difficult. The correct placement of the endotracheal tube was confirmed by end-tidal capnography. To further examine the parameters of difficult laryngoscopy, we also evaluated first-attempt success, overall success of intubation, time to successful intubation, need to change intubation devices, upper airway injury (bleeding, abrasion, or laceration), and dental injury (bleeding, trauma, or fracture). In addition, difficult tracheal intubation was assessed using the Intubation Difficulty Scale with seven parameters, and was defined as a summed score ≥5, as rated by the intubator and assistants.[27]

### 2.5. Statistical analysis

In a post hoc power calculation, the 17 patients with a neck circumference ≥49.1 cm had a 0.588 incidence rate of difficult laryngoscopy, while the 63 patients with a neck circumference <49.1 cm had a 0.111 incidence rate of difficult laryngoscopy in this cohort, which yields a statistical power of 0.98 to detect the event of difficult laryngoscopy, accepting a type I error of 5%.[28] The Shapiro–Wilk test and the Kolmogorov–Smirnov test were used to examine the normality of the included variables. Normally distributed variables were presented as the mean ± standard deviation. Non-normally distributed data were expressed as the median with an interquartile range, minimum and maximum. The distributions of baseline patient characteristics and outcome variables were compared between patients with and without difficult laryngoscopy using chi-square tests or Fisher's exact test for categorical variables and either *t*-tests or Wilcoxon rank-sum tests for continuous variables, as appropriate. Univariate logistic regression analyses were performed to evaluate the association between the included factors and difficult laryngoscopy. Significant factors from the univariate analyses were incorporated into the multivariable logistic regression model to determine the independent factors for difficult laryngoscopy. The diagnostic utility of predictive factors was estimated using area under the receiver operating characteristic curve (AUC). The optimal cutoff value for continuous variables was determined using the joint maximum sensitivity and specificity of the receiver operating characteristic curves (Youden's index) associated with difficult laryngoscopy.[29] As a sensitivity analysis, patients with a BMI <35 kg·m$^{-2}$ were excluded to examine the independent factor and its diagnostic utility for difficult laryngoscopy. A two-sided significance level of $p < 0.05$ was used to define a statistically significant difference. All statistical analyses were conducted using Statistics Analysis System (SAS), version 9.4 (SAS Institute Inc., Cary, NC, USA).

## 3. RESULTS

### 3.1. Baseline patient characteristics

A total of 80 patients were evaluated. Among them, 17 (21.3%) developed an event of difficult laryngoscopy. Patients with difficult laryngoscopy were more likely to be older and male and to have a history of hypertension (Table 1). Among the enrolled patients, 4 (5%) were rated as having a difficult tracheal intubation.

**Table 1**

**Baseline patient and clinical characteristics**

| | Difficult laryngoscopy *n* = 17 | | No difficult laryngoscopy *n* = 63 | | *p* |
|---|---|---|---|---|---|
| Age, year | 41.6 | 8.9 | 35.3 | 8.8 | 0.0104 |
| Sex, male | 12 | 70.6 | 26 | 41.3 | 0.0317 |
| Body mass index, linear, kg·m$^{-2}$ | 40.9 | 37.8–42.5 (31.9–47.4) | 40.1 | 35.0–45.5 (30.9–59.2) | 0.9765 |
| Body mass index, binary, kg·m$^{-2}$ | | | | | 0.8751 |
| <40 | 8 | 47.1 | 31 | 49.2 | |
| ≥40 | 9 | 52.9 | 32 | 50.8 | |
| Waist circumference, cm | 126.7 | 11.3 | 124.9 | 15.0 | 0.6454 |
| ASA physical status | | | | | 0.8751 |
| II | 8 | 47.1 | 31 | 49.2 | |
| III | 9 | 52.9 | 32 | 50.8 | |
| Current cigarette smoking | 9 | 52.9 | 25 | 39.7 | 0.3264 |
| Current alcohol drinking | 4 | 23.5 | 10 | 15.9 | 0.4817 |
| Coexisting disease | | | | | |
| Hypertension | 12 | 70.6 | 15 | 23.8 | 0.0003 |
| Diabetes mellitus | 5 | 29.4 | 9 | 14.3 | 0.1620 |
| Chronic kidney disease | 1 | 5.9 | 1 | 1.6 | 0.3820 |
| Fatty liver | 16 | 94.1 | 48 | 76.2 | 0.1704 |
| Obstructive sleep apnea | 10 | 58.8 | 22 | 34.9 | 0.0742 |
| Preoperative blood test | | | | | |
| Hemoglobin, g·dL-1 | 14.7 | 13.5–15.5 (11.6–16.2) | 14.3 | 13.8–15.5 (8.7–17.8) | 0.7551 |
| Creatinine, mg·dL-1 | 0.78 | 0.72–0.99 (0.54–1.25) | 0.73 | 0.60–0.83 (0.40–1.51) | 0.0766 |
| eGFR, mL·min·1.73 m$^{-2}$ | 93.7 | 90.9–119.5 (68.3–153.9) | 116.9 | 94.2–128.1 (53.9–189.9) | 0.1384 |
| Urea nitrogen, mg·dL-1 | 12 | 9–14 (7–18) | 11 | 10–13 (5–26) | 0.6960 |
| Sodium, mmol·L$^{-1}$ | 140 | 138–142 (130–145) | 138 | 137–139 (134–143) | 0.0504 |
| Potassium, mmol·L$^{-1}$ | 4.0 | 3.6–4.1 (3.3–4.4) | 3.9 | 3.7–4.1 (3.3–4.4) | 0.7224 |
| Alanine aminotransferase, U·L$^{-1}$ | 40 | 26–57 (21—159) | 31 | 23–39 (12–242) | 0.2895 |
| Aspartate aminotransferase, U·L$^{-1}$ | 35 | 23–46 (18–142) | 35 | 22–47 (12–305) | 0.7596 |
| $SpO_2$ in room air, % | 97 | 96–97 (93–98) | 97 | 96–98 (94–100) | 0.3083 |

Values are mean ± standard deviation, counts (percent), or median (interquartile range; minimum and maximum).

ASA = American Society of Anesthesiologists; eGFR = estimated glomerular filtration rate; $SpO_2$ = peripheral capillary oxygen saturation.

### 3.2. Parameters of laryngoscopy and tracheal intubation

Among the 17 patients with difficult laryngoscopy, three were rated as a Cormack-Lehane grade IV. First-attempt success rates for intubation were 88.2% and 100.0% for those with and without difficult laryngoscopy, respectively ($p$ = 0.0430) (Table 2). In all patients, the trachea was intubated successfully by direct laryngoscopy. Patients with difficult laryngoscopy had a higher risk of upper airway injury (3, 17.7%) compared with those without difficulty (1, 1.6%), $p$ = 0.0286. There was no difference in time to successful intubation, need to change intubation devices, or dental injury between the two groups.

### 3.3. Physical and ultrasound characteristics associated with difficult laryngoscopy

Patients with difficult laryngoscopy had a greater neck circumference (median 49.5 cm, IQR, 43.2–51.5 cm) compared with those without difficulty (median 43.0, IQR, 41.0–46.0 cm); the mean difference was 4.6 cm [95% confidence interval (CI), 2.2–7.1]. In addition, the CSA of the tongue base was larger in those with difficult laryngoscopy (mean 17.4 ± 5.7 cm$^2$) compared to their counterparts (14.6 ± 3.5 cm$^2$), mean difference 2.9 cm$^2$ (95% CI, 0.7–5.1) (Table 3). Based on Youden's index, the optimal cutoff neck circumference value was 49.1 cm with a 0.588 sensitivity and a 0.889 specificity. The absolute risk difference of neck circumference <49.1≥ cm was 0.477 (95% CI, 0.231–0.724) with a number needed to treat of 3. In the same way, the cutoff of the tongue base CSA was determined to be 16.4 cm$^2$ with a sensitivity of 0.647 and a specificity of 0.698. The absolute risk difference of tongue base CSA and <16.4≥ cm$^2$ was 0.346 (95% CI, 0.092–0.599) with a number needed to treat of 3. Table 4 shows the factors significantly associated with difficult laryngoscopy in the univariate analyses, including age, sex, hypertension, neck circumference, and CSA of the tongue base. After adjusting for these variables, neck circumference was the only independent predictive factor for difficult laryngoscopy, with an adjusted odds ratio of 1.227 (95% CI, 1.009–1.491). Supplementary Table S1 http://links.lww.com/JCMA/A145 shows the results of the univariate and multivariable analyses among patients with a BMI ≥35 kg·m$^{-2}$.

**Table 2**

**Parameters of laryngoscopy and tracheal intubation**

| | Difficult laryngoscopy $n$ = 17 | | No difficult laryngoscopy $n$ = 63 | | $p$ |
|---|---|---|---|---|---|
| Cormack and Lehane's classification | | | | | <0.0001 |
| I | 0 | 0 | 37 | 58.7 | |
| II | 0 | 0 | 26 | 41.3 | |
| III | 14 | 82.4 | 0 | 0 | |
| IV | 3 | 17.7 | 0 | 0 | |
| First-attempt success of intubation | 15 | 88.2 | 63 | 100.0 | 0.0430 |
| Overall success of intubation | 17 | 100.0 | 63 | 100.0 | NA |
| Time to successful intubation, s | 26 | 18–40 (13–130) | 23 | 18–29 (11–61) | 0.1229 |
| Need to change intubation devices | 0 | 0 | 0 | 0 | NA |
| Upper airway injury | 3 | 17.7 | 1 | 1.6 | 0.0286 |
| Dental injury | 0 | 0 | 0 | 0 | NA |

Values are counts (percent) or median (interquartile range; minimum and maximum).

### 3.4. Diagnostic utility for difficult laryngoscopy

The AUC of neck circumference ≥49.1 cm and the CSA of tongue base ≥16.4 cm$^2$ for difficult laryngoscopy were 0.739 (95% CI, 0.612–0.865) and 0.673 (0.543–0.803), respectively. A combination of both factors offered better predictive performance than either alone with an AUC of 0.801 (0.674–0.928). In subgroup analyses, the predictive performance of neck circumference and CSA of the tongue base was better in patients with a BMI ≥40 kg·m$^{-2}$ (Table 5). Supplementary Table S2 http://links.lww.com/JCMA/A145 shows the diagnostic utility of neck circumference and CSA of the tongue base as dichotomous variables among patients with a BMI ≥35 kg·m$^{-2}$.

## 4. DISCUSSION

The results of this prospective observational study demonstrated that neck circumference was an independent predictive factor for difficult laryngoscopy in obese patients. None of the classic risk factors for difficult intubation described in the lean population, such as modified Mallampati score, were satisfactory in obese patients. Using the method of ultrasonography, we also discovered that CSA of the tongue base was potentially associated with difficult laryngoscopy, although this association disappeared after controlling for covariates. The predictive ability of neck circumference and tongue base size was better in patients who were morbidly obese. Considering the higher risk of difficult tracheal intubation and peri-intubation rapid desaturation in obese patients, our results provide a way of reducing unanticipated difficult airway and preventing hypoxemia during tracheal intubation in this high-risk population.

Although obese patients have a higher risk of difficult laryngoscopy, there is still no definite predictor in the current literature due to conflicting results in previous studies.[6–16] Differences in the measurements and definitions of difficult airway and the evaluated airway characteristics are potentially responsible for the discrepancies in previous findings. We found that greater neck circumference was linked to difficult laryngoscopy, in line with some previous studies[8,11,14] but not the study by Magalhaes *et al.*[16] This might be explained by the significantly lower BMI and neck circumference in the study by Magalhaes *et al.* compared with those of our study and others.[8,11,14,16] Moreover, our results suggested that neither BMI nor modified Mallampati score were correlated with difficult laryngoscopy, contrasting with some previous studies[6–8] but agreeing with others.[9–12] Eiamcharoenwit *et al.* reported that neck circumference and modified Mallampati score show limited predictive performance for difficult intubation among obese parturients.[30] In our study, the optimal cutoff value for neck circumference was 49.1 cm and yielded an AUC of 0.739, with a risk difference of 0.477, which was higher than those in the previous study.[30] This might be due to the smaller average neck circumference of the study by Eiamcharoenwit *et al.* in comparison with our study.[30]

Interestingly, our study found that CSA of the tongue base may be used as a potential predictor for difficult laryngoscopy in obese patients. Previous studies have shown that tongue base size is associated with the diagnosis of obstructive sleep apnea and its severity.[22,23] Of note, obstructive sleep apnea has been reported to be associated with difficult intubation in obese and nonobese patients.[16,31,32] Our subgroup analysis showed that the predictive performance of tongue base CSA was better in those with obstructive sleep apnea compared with others, which is compatible with previous studies.[16,22,23,31,32] Our results suggested that the increased volume and fat deposition at the tongue base might impede visualization of the glottis and tracheal intubation.

**Table 3**

**Preoperative physical and ultrasound findings**

| | Difficult laryngoscopy $n = 17$ | | No difficult laryngoscopy $n = 63$ | | P |
|---|---|---|---|---|---|
| Physical findings | | | | | |
| Interincisor distance <3 cm | 0 | 0 | 1 | 1.6 | >0.9999 |
| Any loose teeth | 1 | 5.9 | 3 | 4.8 | >0.9999 |
| Mentohyoid distance <4 cm | 0 | 0 | 2 | 3.2 | >0.9999 |
| Thyromental distance <6.5 cm | 0 | 0 | 0 | 0 | NA |
| Neck movement < 80 degrees | 4 | 23.5 | 7 | 11.1 | 0.2341 |
| Neck circumference, cm | 49.5 | 43.2–51.5 (38.5–59.5) | 43.0 | 41.0–46.0 (34.5–56.0) | 0.0020 |
| Modified Mallampati score | | | | | 0.2921 |
| Class I or II | 10 | 58.8 | 28 | 44.4 | |
| Class III or IV | 7 | 41.2 | 35 | 55.6 | |
| Upper lip bite test | | | | | 0.2341 |
| Class I | 10 | 58.8 | 47 | 74.6 | |
| Class II or III | 7 | 41.2 | 16 | 25.4 | |
| Mandibular prognathism test | | | | | 0.5157 |
| Class A | 12 | 70.6 | 50 | 79.4 | |
| Class B or C | 5 | 29.4 | 13 | 20.6 | |
| Ultrasound findings | | | | | |
| Height of tongue base, mm | 45.2 | 40.6–47.8 (27.9–64.0) | 40.7 | 37.1–46.0 (29.7–52.3) | 0.0560 |
| Width of tongue base, mm | 47.8 | 41.6–53.6 (31.9–62.6) | 46.3 | 40.7–48.6 (26.7–58.5) | 0.0996 |
| CSA of tongue base, cm$^2$ | 17.4 | 5.7 | 14.6 | 3.5 | 0.0118 |
| Maximal height of mid-tongue, mm | 49.7 | 6.5 | 47.7 | 6.4 | 0.2561 |
| Pretracheal soft tissue depth, mm | | | | | |
| Level of vocal cords | 7.7 | 6.5–9.2 (3.8–11.4) | 7.7 | 5.9–10.0 (3.8–18.6) | 0.9812 |
| Level of thyroid isthmus | 9.2 | 7.2–10.6 (6.0–21.8) | 9.1 | 6.5–11.8 (3.8–21.0) | 0.5025 |
| Level of suprasternal notch | 13.4 | 12.2–14.9 (9.0–26.4) | 15.3 | 12.2–18.0 (8.8–34.9) | 0.1123 |
| Average depth | 9.3 | 9.0–11.3 (7.3–18.2) | 10.6 | 8.8–12.8 (6.3–22.2) | 0.5604 |

Values are mean ± standard deviation, counts (percent), or median (interquartile range; minimum and maximum).
CSA = cross-sectional area.

The overall incidence of difficult intubation was 5% in our study, which is similar to the 3–4% reported by three previous studies[12,14,30] but considerably lower than the 13% reported by Riad *et al.*[8] This difference might be a result of the higher proportion of morbidly obese patients (i.e., BMI ≥40 kg·m$^{-2}$) in the study by Riad *et al.*[8] although some studies have refuted the association between BMI and difficult tracheal intubation among obese patients.[9–12]

There were some limitations to our study. First, our patient sample was relatively small and might be underpowered for some statistics. Second, some ultrasonographic parameters were not examined, such as skin to epiglottis and skin to hyoid distances.[33] Third, our results may not be applicable to non-Asian populations due to the ethnic differences in morphometric and airway characteristics.[34] Fourth, although the risk of difficult laryngoscopy, defined as a Cormack and Lehane's grade III or IV, was as high as 21.3% in this study, all patients were intubated successfully by direct laryngoscopy. The predictive role of neck circumference for difficult tracheal intubation remains undetermined if video laryngoscopy serves as a standard technique to establish an airway for obese patients.[35] Last, the study cohort included patients with a BMI between 30 and 35 kg·m$^{-2}$, who might not have indications for laparoscopic sleeve gastrectomy.[36]

**Table 4**

**Univariate and multivariable logistic regression analyses for difficult laryngoscopy**

| | Univariate | | Multivariable | |
|---|---|---|---|---|
| | Crude OR (95% CI) | p | Adjusted OR (95% CI)[a] | p |
| Age, year | 1.079 (1.014–1.149) | 0.0167 | 1.054 (0.972–1.143) | 0.2056 |
| Sex, male vs. female | 3.415 (1.073–10.868) | 0.0376 | 0.689 (0.099–4.789) | 0.7064 |
| Hypertension | 7.678 (2.328 –25.328) | 0.0008 | 3.264 (0.760–14.021) | 0.1116 |
| Neck circumference, cm | 1.223 (1.080–1.384) | 0.0015 | 1.227 (1.009–1.491) | 0.0399 |
| CSA of tongue base, cm$^2$ | 1.002 (1.000–1.003) | 0.0205 | 1.001 (0.999–1.003) | 0.2576 |

CI = confidence interval; CSA = cross-sectional area; OR = odds ratio.
[a]Adjusted for age (linear), sex, hypertension, neck circumference (linear), and CSA of tongue base (linear).

In conclusion, our study found that greater neck circumference was independently associated with difficult laryngoscopy in obese patients. Using ultrasound quantification of the tongue base size, this study also showed that CSA of the tongue base may serve as an index to identify high-risk patients before tracheal intubation, although this result needs further validation using datasets from patients with different characteristics (e.g., a greater BMI or an unparalyzed state). Our findings provide a way of decreasing unanticipated difficult airway in obese populations. The high risk of desaturation during tracheal intubation warrants more studies to discover novel predictors for difficult intubation in obese patients.

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**Table 5**

**Diagnostic utility of neck circumference and tongue base cross-sectional area for predicting difficult laryngoscopy**

| | Neck circumference ≥49.1 cm | | CSA of tongue base ≥16.4 cm² | | Both factors | |
|---|---|---|---|---|---|---|
| | AUC (95% CI) | *p* | AUC (95% CI) | *p* | AUC(95% CI) | *P* |
| All | 0.739 (0.612–0.865) | 0.0002 | 0.673 (0.543–0.803) | 0.0094 | 0.801 (0.674–0.928) | <0.0001 |
| Body mass index ≥40 kg·m⁻² | 0.780 (0.618–0.941) | 0.0007 | 0.701 (0.534–0.869) | 0.0184 | 0.868 (0.752–0.984) | <.0001 |
| Body mass index <40 kg·m⁻² | 0.688 (0.508–0.867) | 0.0404 | 0.637 (0.437–0.837) | 0.1785 | 0.742 (0.531–0.953) | 0.0249 |
| Obstructive sleep apnea | 0.686 (0.503–0.870) | 0.0464 | 0.668 (0.487–0.850) | 0.0696 | 0.771 (0.593–948) | 0.0029 |
| No obstructive sleep apnea | 0.761 (0.561–0.962) | 0.0107 | 0.652 (0.442–0.861) | 0.1563 | 0.781 (0.557–1.000) | 0.0141 |

AUC = area under receiver operating characteristic curve; CI = confidence interval; CSA = cross-sectional area.

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