

Advances in Ultrasound Measurement of Upper Airway Parameters to Predict Difficult Airways in Patients with OSAS

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Abstract

Obstructive sleep apnea syndrome (OSAS) is a common disease characterized by repeated upper airway collapse during sleep. Obstruction, collapse, and stenosis are due to abnormalities of the upper airway anatomy is an important factor in the pathogenesis of OSAS, and the characteristics of a narrowed or obstructed upper airway anatomy increase the difficulty of tracheal intubation, and the risk of a difficult airway at the time of anaesthesia induction is significantly higher. Traditional bedside predictors of difficult laryngoscopy include the modified mallampati test (MMT), thyromental distance (TMD), mouth opening (MO), neck mobility, and upper and lower lip occlusion test. It has been pointed out that traditional assessment methods are based on observation and measurement of the patient's body surface, which are incomplete and inadequate, and that traditional assessment methods require the patient to be awake and to cooperate with the physician to complete the assessment. Therefore, there is an urgent need for more reliable, objective, and non-invasive preoperative assessment methods. Ultrasound has the advantages of real-time observation of the upper respiratory tract, easy operation, low cost, and no exposure to ionizing radiation. In recent years, it has gradually been applied to preoperative airway assessment, and ultrasound is used to measure the internal structure of the patient's airway and related organ tissues. The measured parameters include the thickness of the anterior neck soft tissue at the levels of the epiglottis, hyoid bone, vocal cords, thyrohyoid membrane, and thyroid isthmus plane, as well as the volume of the tongue, the thickness of the tongue, and the hyoid bone distance ratio, etc. Recent research efforts have focused on determining validated critical values for these ultrasound parameters and developing standardized scanning protocols. Additionally, combining multiple ultrasound parameters or integrating them with traditional predictive indicators has shown enhanced predictive performance.

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Keywords

Obstructive Sleep Apnea Syndrome, Difficult Airway, Difficult Laryngoscopy, Ultrasound

1. Introduction

In 2022, the American Society of Anesthesiologists (ASA) updated the concept of a difficult airway to refer to anticipated or unanticipated difficulties or failures in airway management encountered by physicians trained in clinical anaesthesia, including, but not limited to, one or more of the following: mask ventilation, laryngoscopy, ventilation using a supraglottic airway, tracheal intubation, extubation, or invasive airway [1]. Unlike the old guidelines, the new ones not only stress the difficulty of mask ventilation and intubation, but also particularly emphasize the difficulty or failure of one or more of laryngoscopy, supraglottic airway ventilation, extubation, or establishment of invasive airway [2]. Difficult laryngoscopy refers to the inability to see any part of the glottis after multiple attempts at laryngoscopy. The incidence of difficult airways in clinical settings varies depending on the definition, ranging from 0.5% to 10% [3] [4]. The incidence of difficulty in exposing the glottis with a laryngoscope is 1.5% to 13.0%, and the incidence of difficulty in tracheal intubation is 1.9% to 10% [5] [6].

Analysis by the American Society of Anaesthesiologists has shown patient mortality rates as high as 73% in medical malpractice claims related to difficult airway events [7]. Patients with high-risk factors for difficult airway, if not identified preoperatively, may in a few cases experience the double dilemma of neither intubation nor ventilation after induction of anaesthesia, which may lead to hypoxic asphyxia and even irreversible brain damage. Encountering an unanticipated difficult airway is very likely to increase the patient's tissue damage and even lead to a series of consequences such as tracheotomy, which prolongs the patient's hospital stay, increases perioperative-related complications, and is inconsistent with the concepts of Minimally Invasive Surgery (MIS) and Enhanced Recovery After Surgery (ERAS) in recent years. Therefore, predetermination and appropriate management of the difficult airway play an important role in preventing anaesthesia-related mortality and complications. This article summarises the research progress in ultrasound measurement of upper airway parameters for prediction of difficult airways, and provides a reference for the value of ultrasound in predicting difficult airways for clinical applications.

2. The Relationship between OSAS and Difficult Airway

Obstructive sleep apnea syndrome (OSAS) is a sleep disorder of breathing in which repeated complete and/or incomplete obstruction of the upper airway during sleep causes apnea and/or hypoventilation, and is mainly characterised by intermittent nocturnal hypoxaemia, hypercapnia, and disturbances in sleep archi-

ture. Many studies have shown that patients with OSAS are at increased risk of perioperative complications, including hypoxaemia, pneumonia, difficult intubation, pulmonary embolism, cardiac arrhythmias, and unanticipated transfers to the ICU. Obstruction, collapse, and stenosis due to abnormalities of the upper airway anatomy are important factors in the pathogenesis of OSAS, and the characteristics of a narrowed or obstructed upper airway anatomy increase the difficulty of tracheal intubation, and the risk of a difficult airway at the time of anaesthesia induction is significantly higher. The risk of a difficult airway during induction of anaesthesia is significantly higher. Recent studies have reported 176 million OSAS patients in China in the age group of 30 - 69 years [8], and the total prevalence of OSAS in adults in China is 3.93%, with males being 2.62 times more likely than females [9], and most OSAS patients are not clinically diagnosed because of the specificity of the diagnosis and treatment of this disease, and the low level of awareness of this disease among the public and health professionals. Such patients are at higher risk of perioperative-related complications when undergoing surgical procedures.

The results of study [10] showed that patients with obstructive sleep apnoea hypoventilation syndrome were 8 times more likely to have a difficult airway than the general population due to their short neck, obesity, and airway obstruction planes mainly located in the oropharynx. The difficulty of perioperative anaesthesia management of patients with OSAS lies in the management of the airway, and the difficult airway is the main cause of perioperative mishaps. Unanticipated difficult airway is a serious challenge for anaesthesiologists in airway management. The death of OSAS patients due to difficult airway has been reported both at home and abroad [11]. The Guidelines for the Management of Difficult Airways developed by the Anesthesiology Branch of the Chinese Medical Association [12] state that more than 90% of patients with difficult airways can be detected through preoperative assessment, so it is important to accurately assess whether OSAS patients have a combined difficult airway and its severity during the perioperative period, and to formulate appropriate anesthesia protocols and airway management strategies. This can reduce the incidence of serious anaesthetic complications due to difficult airway, and thus significantly improve perioperative patient safety.

3. Limitations of Traditional Clinical Methods for Predicting a Difficult Airway

A simple physical examination during the preoperative visit and a history of previous difficult airway intubation for surgical anaesthesia were the clinical judgmental information we relied on. Traditional bedside predictors of difficult laryngoscopy (DL) include the modified mallampati test (MMT), thyromental distance (TMD), mouth opening (MO), neck mobility, and the upper and lower lip occlusion test. It has been pointed out that traditional assessment methods are based on observation and measurement of the patient's body surface, which are incom-

plete and inadequate [13], and that traditional assessment methods require the patient to be awake and cooperative with the physician to complete the assessment. However, trauma patients admitted in an emergency often have a coma and traumatic brain injury and are unable to cooperate with a physician to complete an airway assessment. Roth *et al.* [14] showed that the proportions of different indicators missed in DL to measure individual body surface anatomical structures: the MMT amounted to 47%, the TMD to 63%, and the MO to 78%. The MMT reflects the tongue volume to a certain degree, but its limited predictive ability [15] and the requirement for patients to perform compulsory actions reduce its application value in predicting difficult airways, especially in unconscious patients [16]. This shows that some traditional methods alone are not sufficient to help anaesthetists accurately predict the probability of a difficult airway.

4. Imaging Applications for Predicting Difficult Airways

Several studies have shown [17] [18] that the likelihood of a difficult airway can be predicted by measuring the size and relative positional relationships of various bony structures in the head and neck on X-ray images; Ji *et al.* [19] reported that CT has comparable sensitivity to X-ray in predicting intubation difficulties and that its measurement indicators have the same predictive ability. Similarly, MRI has been used in recent years in the search for predictors of difficult airways due to its outstanding visualisation of soft tissues [20]. However, CT, X-rays, and MRI all share common problems: they require large equipment, cannot provide real-time dynamic monitoring at the bedside, are costly, and the radiation hazards of the rays are common characteristics that determine their limitations in predicting difficult airways.

Ultrasound is also an objective measurement method compared to the above imaging methods, and its ability to measure the internal structure of the patient's airway and its associated organs and tissues through ultrasound can effectively avoid the influence of subjective factors on the assessment results. Ultrasound has similar diagnostic value to CT and X-ray and is far superior to MMT in predicting difficult airways, with the advantages of real-time observation of the upper airway, easy operation, low cost, and no need to withstand ionising radiation. Ultrasound is considered a useful tool for assessing the anatomy of the upper airway and calculating the distance between anatomical structures [21] [22]. In recent years, with the development of technology, visualisation devices such as ultrasound are gradually being used for preoperative airway assessment, which has been supported in the anaesthesia [23]-[25] and emergency medicine [26] [27] literature.

5. Research Progress on Ultrasound Measurement of Airway Structural Indicators

5.1 Anterior Neck Soft Tissue Thickness

Anterior cervical soft tissue thickness is measured in the epiglottis plane (distance from skin to epiglottis, DSE), hyoid bone plane (distance from skin to hyoid bone,

DSH), vocal cords plane (distance from skin to vocal cords, DSV), thyrohyoid membrane plane (distance from skin to thyrohyoid membrane), thyroid isthmus plane (distance from skin to thyroid isthmus, DST), and suprasternal notch plane (distance from skin to suprasternal notch).

Sriniva-sarangan *et al.* [28] showed that increased anterior neck soft tissue thickness was highly correlated with DL and derived their cut-off value of increased anterior cervical soft tissue thickness at the level of the epiglottis for predicting DL to be 1.83 cm. Pinto *et al.* [29] investigated the accuracy of ultrasound lateral scanning to measure the distance from the skin to the epiglottis in predicting difficult airways. Huang Meifang [30] and other scholars believe that, compared with traditional airway assessments and other ultrasound indicators, DSE has a better predictive ability in predicting DL. When the distance from the epiglottis to the skin is greater than 2.10 cm, patients are prone to difficulties in laryngoscopy exposure. In Alejandro [31]'s study, the thickness of DSE at the epiglottic level was greater in patients with DL. DSE and DSE-DSG (distance from skin to glottis) had the highest diagnostic accuracy for DL. $DSE \geq 3$ cm could predict DL. $DSE-DSG \geq 1.9$ cm can predict DL. Multivariate analysis confirmed that the combination of DSE and DSE-DSG with classic tests (MMT, TMD, and upper and lower lip occlusion test) could improve the preoperative detection of DL.

Ezri *et al.* [32] used ultrasound to measure the soft tissue thickness in the anterior neck region of patients and showed that the anterior neck soft tissue thickness in the plane of the vocal plane and the suprasternal notch was a good predictor of DL in morbidly obese patients. Adhikari *et al.* [33] demonstrated that patients with DL had thicker soft tissue thickness in the plane of the hyoid bone and in the plane of the thyrohyoid membrane. In the study of Adhikari *et al.* [33], a critical value of 2.8 cm was obtained for the plane of the thyrohyoid membrane. Chen JM [34] showed that ultrasound-measured thicknesses of the thyrohyoid membrane plane, the anterior neck tissue thickness in the plane of the vocal cords, and the difference between the two could be used to predict difficult laryngoscopic exposures, with the values of 2.19 cm, 1.05 cm, and 1.19 cm, respectively. When performing tracheal intubation in clinical practice, there may be situations where the epiglottis is too long and covers the glottis, making it difficult to expose with the direct laryngoscope. Therefore, the experiment set the difference between the thyrohyoid membrane plane and the vocal cord plane, and this value can be anatomically considered to be related to the length of the epiglottis.

5.2. Tongue Volume, Tongue Longitudinal Cross-Sectional Area, and Tongue Thickness

The tongue body is located above the hyoid bone. In the sleep state, airway muscle tension decreases, and gravity and other effects cause relaxation and backward displacement of the tongue body, which often occurs in obstructive sleep apnoea syndrome and is a common cause of difficult airway [35]. The results of the study

[36] showed that the longitudinal tongue cross-sectional area was positively correlated with DL, while an increased longitudinal tongue cross-sectional area was a risk factor for DL, indicating that ultrasound indicators are more useful for the prediction of a difficult airway in patients with OSAS than conventional measurements and subjective measurements such as the upper and lower lip occlusion test and MMT.

Ohri *et al.* [37] compared the effects of three different tongue volume calculation methods on predicting the difficulty of laryngoscopy exposure. The three calculation methods are: 1) the product of the median sagittal tongue cross-sectional area and the cross-sectional tongue width; 2) the product of the coronal tongue cross-sectional area and the cross-sectional tongue length; 3) the product of the tongue length, tongue width, and tongue height. The conclusion was that all three calculation methods were equally effective in predicting DL.

Zheng Zhenwei *et al.* [38] showed that ultrasound-measured tongue longitudinal cross-sectional area was a good predictor of a difficult airway and found that a tongue longitudinal cross-sectional area of greater than 18.7 cm² with a tongue volume of greater than 82.1 cm³ was of good value in the prediction of DL. Tongue thickness refers to the maximum vertical distance from the skin under the chin to the dorsal surface of the tongue [39]. Yao *et al.* [40] analyzed 2254 patients and found that a tongue thickness greater than 6.1 cm was an independent predictor of difficult tracheal intubation, and a tongue thickness/TMD ratio of greater than 0.87 was also an important predictor of difficult tracheal intubation.

5.3. The Hyoid

The hyoid distance ratio is measured using the distance between the head in the neutral and extended positions, and its ability to differentiate the ease of intubation in patients. In both obese and morbidly obese patients, those with a hyoid distance ratio of >1.1 were easy to intubate, while those with a ratio of <1.1 were difficult to intubate [41]. Lin *et al.* [42] suggested that DL may occur in patients with a mandible-hyoid bone-glottis angle of <125.5° or the glottis-superior edge of the thyroid cartilage distance (DGTC) >1.22 cm. The research conducted by Chen Xu *et al.* [43] indicates that ultrasonic measurement of the distance between the hyoid bone and the epiglottis can effectively predict DL. The ultrasonic measurement of the distance between the hyoid bone and the epiglottis for predicting DL is more efficient than conventional airway assessment methods. When the measurement value is ≤1.4 cm [43], it suggests that it may be difficult to expose the laryngoscope.

5.4. The Genioglossus

The origin and insertion points of the genioglossus muscle are the mental spine of the mandible and the hyoid bone, respectively, and its length can indirectly reflect the length of the mandible. Liu Chunhong *et al.* [44] demonstrated that a shortened genioglossus muscle length has good predictive efficacy for the diagnosis of obstruc-

tive sleep apnea-hypopnea syndrome in DL, with a cut-off value of 4.09 cm.

6. Model for Predicting Difficult Airways

6.1. Rating Prediction Model

The scoring prediction model for difficult airways is a comprehensive scoring model that integrates multiple single-factor indicators with high predictive power. Currently, those with relatively good predictive performance and wide application include the LEMON scoring method, the MACOCHA scoring method, the SARI scoring method, the Wilson scoring method, and the Arne scoring method, etc.

6.2. The Model of Ultrasound-Predicted Difficult Airway

In Rishabh Agarwal's research [45], the accuracy of DSH was superior to the other three ultrasound parameters included in the study (tongue thickness, visibility of the hyoid bone, and the distance from the skin to the thyrohyoid membrane). By combining the four ultrasound parameters into different prediction models, "Model 1" (the four ultrasound parameters) had the highest AUC (0.992). "Models 2 and 4" were the next best (AUC 0.981), while "Model 3" had the lowest AUC (0.975). Considering the inclusion of three parameters in a single submandibular window, with no need for intraoral probe placement, and with an acceptable AUC, "Model 2" (DSH, tongue thickness, and distance from the skin to the thyrohyoid membrane) seems to be a viable option. In the study by Ni [46], there were statistically significant differences in the patient's gender, MMT, DSE, the distance between the thyroid cartilage and epiglottis (DTE), and DST indicators. After the DSH was evaluated in combination with gender, BMI, and MMT, the sensitivity and specificity were 90.9% and 90.4%, respectively, and the AUC value reached 0.9328, forming a more optimal prediction model.

In domestic and international studies on ultrasound for predicting difficult airways, due to differences in ethnicity, the lack of standardized scanning protocols, and variations in ultrasound equipment, even for the same predictive indicators, there are different cutoff values for the predictions. Currently, most studies focus on the general population and obese individuals, while there are relatively few studies on special populations. The existing prediction indicators are applicable to the OSAS population, and in the future, further research can be conducted on OSAS patients to obtain more suitable prediction cutoff values and prediction models for OSAS patients.

7. Outlook

Ultrasound, as an indispensable "visual stethoscope" for anesthesiologists, enjoys advantages such as bedside use, real-time operation, no radiation, non-invasive nature, ease of operation, low cost, etc., and is widely used in clinical practice. Especially for patients who are unconscious and unable to cooperate, ultrasound has more advantages. The imaging quality and measurement accuracy of ultrasound are affected by the skills of the operator and the measurement environment.

Therefore, the expanded application of ultrasound in the field of airway management cannot be separated from the improvement of the operator's skills and the continuous progress in the imaging display of ultrasound equipment. To overcome this weakness, it is necessary to develop and standardize educational programs [47]. In recent years, the field of artificial intelligence has also begun to be applied in the field of airway management. Artificial intelligence improves the accuracy and efficiency of ultrasound in identifying anatomical structures and promotes the expanded application of ultrasound in airway management. In the future, with the standardization of education [47], the upgrade of ultrasound equipment, and the general improvement of ultrasound technology, ultrasound will be the best means for evaluating the constantly changing airways of patients.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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