HSR (LONDON),
HOUGHTON STREET REVIEW JOURNAL
ISSN: 2058-5519|Impact factor-15.9
http://houghtonstreetreview.com/index.php/hsr

INDIVIDUAL ANATOMICAL CHARACTERISTICS OF THE UPPER AIRWAY AND THEIR SIGNIFICANCE IN PREDICTING DIFFICULT ENDOTRACHEAL INTUBATION

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doi:https://doi.org/10.5281/zenodo.24495665

ABSTRACT Background. Difficult endotracheal intubation is a clinically important airway event associated with hypoxemia, airway trauma, aspiration, and perioperative morbidity. Individual anatomical characteristics of the face, oral cavity, mandible, pharynx, larynx, and cervical spine influence the alignment and visualization of the glottis, but no single bedside test reliably predicts all forms of airway difficulty.

Objective. To review the anatomical features of the upper airway that are relevant to difficult endotracheal intubation and assess the role of conventional bedside examination and airway ultrasonography in preoperative prediction.

Materials and methods. A narrative review was conducted using international practice guidelines, consensus recommendations, systematic reviews, meta-analyses, and foundational studies on airway anatomy and difficult intubation. Evidence was synthesized by anatomical region and by assessment method. No original patient data or new clinical measurements were collected.

Results. Relevant anatomical predictors include restricted mouth opening, limited mandibular protrusion, a large tongue relative to oral cavity size, reduced mandibular space, limited atlanto-occipital and cervical extension, increased neck circumference, prominent incisors, and altered upper airway anatomy due to obesity, tumors, trauma, surgery, or radiation. Mallampati classification, thyromental distance, inter-incisor distance, upper lip bite test, and neck mobility are useful components of a composite assessment, but their predictive performance is limited when used individually. Ultrasound measures such as skin-to-epiglottis distance, anterior neck soft-tissue thickness, hyomental distance and its ratio, and tongue dimensions may add anatomical information; protocols and thresholds remain heterogeneous.

Conclusion. Prediction of difficult intubation should be based on a structured, multivariable assessment that integrates patient history, external anatomical examination, airway measurements, and selective imaging. Ultrasound is a promising adjunct, not a replacement for clinical assessment or a prepared airway strategy.

Keywords: upper airway; airway anatomy; difficult intubation; endotracheal intubation; Mallampati classification; thyromental distance; airway ultrasound; laryngoscopy.

INTRODUCTION

Endotracheal intubation is a fundamental procedure in general anesthesia, emergency medicine, and critical care. It provides a secure airway for ventilation and protection against aspiration in selected patients. Despite advances in videolaryngoscopy, supraglottic airway devices, flexible endoscopy, and airway ultrasound, unanticipated difficulty can still occur. Difficult intubation may lead to repeated

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ISSN: 2058-5519|Impact factor-15.9
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airway attempts, oxygen desaturation, airway injury, aspiration, and, in severe cases, cannot-intubate/cannot-oxygenate (CICO) events [1–3].

The upper airway is a complex anatomical pathway extending from the external nose and oral cavity through the pharynx and larynx to the trachea. Successful direct laryngoscopy depends on adequate mouth opening, displacement of the tongue and soft tissues, suitable mandibular space, and sufficient head and neck mobility to obtain a view of the glottic inlet. Individual variation in these structures changes the geometry of the airway and the relationship between the oral, pharyngeal, and laryngeal axes [4,5].

Traditional preoperative assessment uses history, inspection, and bedside measurements such as the Mallampati score, thyromental distance, inter-incisor distance, sternomental distance, neck movement, and upper lip bite test. These tests are practical but imperfect. Systematic reviews have demonstrated that single bedside tests have limited sensitivity and should not be used as definitive exclusion tests for difficult laryngoscopy [6,7].

The 2022 American Society of Anesthesiologists (ASA) Practice Guidelines recommend evaluating multiple demographic and clinical characteristics, reviewing relevant records and patient history, and conducting a focused physical examination of facial features and anatomical landmarks. Airway ultrasound and other advanced assessments may be considered when they can clarify the nature of anticipated difficulty [1].

The present review focuses on the anatomical basis of difficult endotracheal intubation and the role of conventional and ultrasound-based assessment in identifying patients who may require an alternative airway strategy.

OBJECTIVE

To describe individual anatomical characteristics of the upper airway associated with difficult endotracheal intubation and evaluate the clinical value and limitations of bedside anatomical tests and point-of-care ultrasound in preoperative airway assessment.

MATERIALS AND METHODS

Study design. This article is a narrative literature review structured according to the major sections of the IMRAD format. It is not an original clinical cohort study and contains no newly collected patient-level data.

Sources and search approach. The review was based on international airway-management guidelines, consensus recommendations, systematic reviews, meta-analyses, and foundational studies addressing upper airway anatomy, bedside prediction of difficult laryngoscopy, and ultrasound assessment. Priority was given to the ASA 2022 Practice Guidelines, Difficult Airway Society (DAS) recommendations, Canadian Airway Focus Group consensus, and peer-reviewed evidence syntheses on clinical and ultrasound predictors [1–3,6–10].

The evidence was organized into four domains: (1) anatomical structures that influence laryngoscopy and tube passage; (2) conventional bedside predictors; (3) ultrasound-derived anatomical measurements; and (4) clinical integration and airway planning. Findings were summarized descriptively. Because the included studies used different definitions of difficult laryngoscopy, difficult intubation, and difficult mask ventilation, no pooled estimate was recalculated.

Limitations. This narrative review may be affected by selection bias and does not provide a registered systematic search or formal risk-of-bias assessment. Ultrasound thresholds and scanning

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protocols vary between studies, and prediction performance may differ by population, operator experience, device, and outcome definition.

RESULTS

1. Anatomical basis of upper airway patency and laryngoscopic exposure

The oral cavity is bounded anteriorly by the lips and teeth, superiorly by the hard and soft palate, laterally by the cheeks, and inferiorly by the floor of the mouth and tongue. The tongue is a major soft-tissue structure relevant to laryngoscopy. A large tongue relative to the available oral cavity can make displacement difficult and may obscure the posterior oropharynx. Limited mandibular dimensions or reduced ability to protrude the mandible further restrict the space available for tongue displacement [4,5].

The pharynx is a collapsible muscular tube divided into nasopharynx, oropharynx, and laryngopharynx. Its caliber is influenced by the mandible, tongue base, soft palate, pharyngeal muscles, and surrounding soft tissues. Obesity and obstructive sleep apnea may be associated with increased soft-tissue volume and altered upper airway collapsibility. These conditions may complicate both mask ventilation and laryngoscopy, although the degree of difficulty cannot be inferred from body mass index alone [1,3].

The larynx is supported by a cartilaginous framework that includes the thyroid, cricoid, and arytenoid cartilages. The epiglottis forms an important landmark during laryngoscopy. Anterior displacement of the larynx, restricted neck extension, or an unfavorable relationship between the oral and laryngeal axes may impair glottic visualization. Cervical spine disease, trauma, previous surgery, radiation fibrosis, and congenital craniofacial differences can alter these relationships [4,5].

The hyoid bone is a key anatomical landmark connecting the tongue and floor-of-mouth musculature with the laryngeal complex. The distance between the hyoid and skin, the distance from skin to epiglottis, and the hyomental distance may provide indirect information about anterior neck soft-tissue thickness and mandibular space. These measures have been explored as ultrasound predictors of difficult laryngoscopy [8–11].

2. Individual anatomical characteristics associated with difficult intubation

Mouth opening and inter-incisor distance. Reduced mouth opening limits insertion and manipulation of the laryngoscope blade and may prevent adequate visualization of the glottis. Causes include temporomandibular joint disease, trauma, fibrosis after radiotherapy, infection, and congenital restriction. Inter-incisor distance is commonly measured with the mouth maximally open; the interpretation should account for dentition, pain, and patient cooperation.

Mandibular size and protrusion. A short or receding mandible can reduce the submandibular space available for displacement of the tongue. The ability to bring the lower incisors in front of the upper incisors (upper lip bite test) is a functional assessment of mandibular protrusion. Limited protrusion may indicate reduced mandibular mobility or unfavorable craniofacial geometry.

Tongue size and oral cavity relationship. Relative macroglossia, a crowded oropharynx, and a high Mallampati class may indicate limited space for laryngoscope insertion and tongue displacement. The Mallampati classification is based on the visibility of oropharyngeal structures with the patient sitting, mouth open, and tongue protruded without phonation. It is influenced by patient effort, posture, and examiner technique and should be combined with other findings [6,12].

Thyromental and hyomental distances. Thyromental distance approximates the space between the mentum and thyroid cartilage when the neck is extended. A short distance may reflect a small

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ISSN: 2058-5519|Impact factor-15.9
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mandibular space or anterior laryngeal position. Hyomental distance and its ratio between neutral and extended positions have also been studied as indicators of submandibular space and mobility. Thresholds vary across studies and should not be treated as universal cutoffs.

Neck circumference and soft-tissue distribution. Increased neck circumference may reflect greater anterior and lateral soft-tissue volume, which can complicate mask ventilation and laryngoscopy. The effect is influenced by the distribution of adipose tissue, neck mobility, and other anatomical features. Neck circumference is therefore a risk marker rather than a standalone diagnostic test.

Cervical spine and atlanto-occipital mobility. Adequate extension helps align the oral and pharyngeal axes during direct laryngoscopy. Restricted extension due to ankylosing spondylitis, rheumatoid arthritis, cervical fusion, trauma, or degenerative disease may impair glottic exposure and may require modified positioning or an alternative technique.

Dentition and facial anatomy. Prominent upper incisors, fragile or loose teeth, limited mouth opening, facial asymmetry, micrognathia, retrognathia, and previous maxillofacial surgery can influence laryngoscope insertion and blade manipulation. Scarring, tumors, edema, infection, and radiation changes may distort the airway and require more advanced evaluation.

Anatomical feature	Potential effect on intubation	Common assessment
Restricted mouth opening	Limits blade insertion and manipulation	Inter-incisor distance; TMJ examination
Large tongue / crowded oropharynx	Reduces space for tongue displacement and glottic view	Modified Mallampati; oral examination; ultrasound tongue measures
Micrognathia / retrognathia	Reduces submandibular space; may displace larynx anteriorly	Facial profile; mandibular protrusion; thyromental distance
Short thyromental / hyomental distance	May indicate limited mandibular space or anterior laryngeal position	Tape measure; ultrasound where appropriate
Limited neck extension	Restricts positioning and axis alignment	Cervical range-of-motion examination
Large neck circumference / anterior soft tissue	May complicate mask ventilation and glottic exposure	Neck circumference; airway ultrasound
Prominent or fragile incisors	May impede blade passage and increase dental injury risk	Oral and dental examination
Tumor, trauma, surgery, radiation or edema	Distorts normal landmarks and may narrow the airway	History, examination, imaging, bedside endoscopy as indicated

3. Conventional bedside assessment tools

Modified Mallampati classification. Mallampati classes III and IV are associated with a greater likelihood of difficult laryngoscopy in some populations. However, the test alone has limited sensitivity and is affected by posture, phonation, patient cooperation, and examiner variability. It is best used as one component of a broader assessment [6,12].

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ISSN: 2058-5519|Impact factor-15.9
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Thyromental distance. A reduced thyromental distance may suggest limited mandibular space and a more anterior laryngeal position. The measurement depends on neck extension and the exact anatomical landmarks used. Differences in thresholds across studies reduce its value as a universal binary predictor.

Upper lip bite test. This test evaluates mandibular protrusion and the relationship between the lower incisors and upper lip. It is simple and functional, but may be unreliable in patients with missing teeth, restricted jaw movement, facial pain, or poor cooperation.

Inter-incisor distance and neck mobility. These tests directly assess mechanical constraints to laryngoscope insertion and positioning. They should be documented separately because a patient may have normal oropharyngeal visibility but restricted mouth opening or neck extension.

Composite scores. Risk indices combine several findings, including Mallampati class, thyromental distance, mouth opening, neck movement, body habitus, and previous airway history. Composite assessment may improve risk stratification compared with a single test, but score performance depends on the population in which it was developed and validated [7,13].

Assessment method	What it evaluates	Important limitation
Modified Mallampati	Oropharyngeal visibility and relative tongue/oral cavity space	Variable sensitivity; depends on posture and cooperation
Thyromental distance	Mandibular space and relative laryngeal position	Measurement and threshold variability
Upper lip bite test	Mandibular protrusion and jaw mobility	Affected by dentition and TMJ function
Inter-incisor distance	Mouth opening	Does not assess all causes of difficult laryngoscopy
Neck range of motion	Cervical extension and positioning capacity	May not reflect internal airway anatomy
Neck circumference	External soft-tissue distribution	Not specific; obesity alone does not define difficulty
Previous difficult airway history	Prior observed performance and anatomical context	Records may be incomplete; airway may change over time

4. Ultrasound assessment of upper airway anatomy

Point-of-care ultrasound can provide non-invasive, bedside information about airway structures that are not directly visible during external inspection. A linear transducer is commonly used for superficial structures, while a lower-frequency transducer may be required for deeper anatomy. Ultrasound can assess tongue thickness or volume, hyomental distance, skin-to-hyoid distance, skin-to-epiglottis distance, anterior neck soft-tissue thickness, and the position of the cricothyroid membrane [8–11].

Skin-to-epiglottis distance. This measurement estimates the thickness of anterior neck soft tissue overlying the epiglottis. Increased distance has been associated with difficult laryngoscopy or intubation in several studies, although the optimal measurement level and cutoff differ between protocols.

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ISSN: 2058-5519|Impact factor-15.9
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Hyomental distance and hyomental distance ratio. The distance from the hyoid bone to the mentum can be measured in neutral and extended positions. The ratio between these measurements may reflect the ability of the submandibular space to expand with extension. Systematic reviews have reported associations with difficult laryngoscopy, but have emphasized heterogeneity and the need for standardized methods [9,10].

Tongue thickness and volume. Ultrasound can estimate tongue dimensions and may help identify relative macroglossia or increased soft-tissue bulk. The relationship between tongue size and difficult laryngoscopy is influenced by oral cavity dimensions, mandibular anatomy, and patient positioning.

Evidence synthesis. A 2022 systematic review and meta-analysis included 33 studies evaluating 27 ultrasound indices. Anterior tissue thickness had pooled sensitivity of 76%, specificity of 77%, and AUROC of 0.83; anatomical position indices had sensitivity of 74%, specificity of 86%, and AUROC of 0.87. The included ultrasound protocols were heterogeneous, and the authors suggested combining ultrasound with clinical assessment rather than relying on a single measurement [8]. A further systematic review published in 2025 included 60 studies and 10,580 patients, reporting promising performance for selected skin-to-vocal-cord, skin-to-epiglottis, and skin-to-hyoid measurements, while calling for more standardized combined assessment [11].

Ultrasound should be regarded as an adjunct. It does not directly reproduce the dynamic conditions of laryngoscopy, and its performance depends on equipment, operator training, patient habitus, probe position, and measurement definitions. It should not delay airway management in an emergency.

5. Clinical integration and prediction strategy

A structured airway assessment begins with the patient's history, including previous difficult intubation or mask ventilation, obstructive sleep apnea, snoring, head and neck surgery, radiotherapy, trauma, infection, tumor, and relevant cervical spine disease. Prior anesthesia records may be particularly valuable because they document the technique used, laryngoscopic view, number of attempts, and rescue devices [1,2].

The physical examination should then assess facial profile, mouth opening, mandibular protrusion, dentition, Mallampati class, thyromental distance, neck circumference, and cervical mobility. Multiple findings should be interpreted together. If significant distortion, a mass, restricted movement, or uncertainty remains, additional evaluation such as flexible endoscopy or imaging may be indicated.

The assessment must distinguish difficult laryngoscopy from difficult tracheal tube passage, difficult mask ventilation, difficult supraglottic airway placement, and difficulty with emergency front-of-neck access. These are related but distinct clinical problems. A patient may have a good laryngoscopic view but difficult tube passage, or easy intubation but difficult mask ventilation.

The 2022 ASA guideline recommends considering awake airway management when difficult ventilation is anticipated, aspiration risk is increased, the patient may not tolerate a brief apneic period, or emergency invasive airway access is expected to be difficult. The decision should be based on the whole clinical situation, operator expertise, available equipment, and a clear backup plan [1,14].

6. Safety implications and limitations of prediction

No preoperative test can guarantee that intubation will be easy or difficult. A normal Mallampati score does not exclude difficulty, and an abnormal score does not mean intubation will necessarily fail. The predictive value of a test depends on the prevalence of difficult airway in the assessed population and the test's sensitivity and specificity. False reassurance may be dangerous when a single normal result is used to dismiss other concerning features.

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ISSN: 2058-5519|Impact factor-15.9
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A safe plan includes appropriate positioning, preoxygenation, equipment checks, assignment of roles, availability of videolaryngoscopy and supraglottic devices, and a predefined escalation strategy. The DAS guideline emphasizes limiting repeated attempts, maintaining oxygenation, communicating failure clearly, and progressing through a structured airway algorithm [2].

Anatomical prediction is also limited by dynamic and physiological factors. Airway edema, bleeding, secretions, reduced muscle tone after induction, pregnancy-related changes, acute trauma, and rapidly evolving pathology may alter airway conditions. The preoperative examination should therefore be updated when the clinical state changes.

DISCUSSION

The reviewed literature supports a central anatomical principle: difficult endotracheal intubation is often the result of an unfavorable relationship between the oral cavity, tongue, mandible, pharynx, larynx, and cervical spine rather than a single isolated measurement. A large tongue within a small oral cavity, restricted mandibular protrusion, short mandibular space, limited mouth opening, and reduced cervical extension can combine to impair laryngoscopic exposure.

Conventional bedside tests remain important because they are rapid, inexpensive, and widely available. Their limitation is not that they lack anatomical meaning, but that each test captures only one part of a complex three-dimensional and dynamic airway. The systematic review by Shiga et al. and subsequent evidence assessments have shown that individual tests have imperfect diagnostic performance [6,7]. This supports the use of a structured combination of history and examination rather than reliance on Mallampati class or thyromental distance alone.

Airway ultrasound offers a complementary perspective by visualizing soft tissues and landmarks that are difficult to assess externally. The 2022 meta-analysis found moderate-to-good pooled diagnostic performance for selected tissue-thickness and anatomical-position indices, while also reporting heterogeneity in ultrasound protocols [8]. The 2025 systematic review included a larger evidence base and reported promising diagnostic performance for selected measurements, but emphasized the need for standardized methods and combined clinical-ultrasound assessment [11].

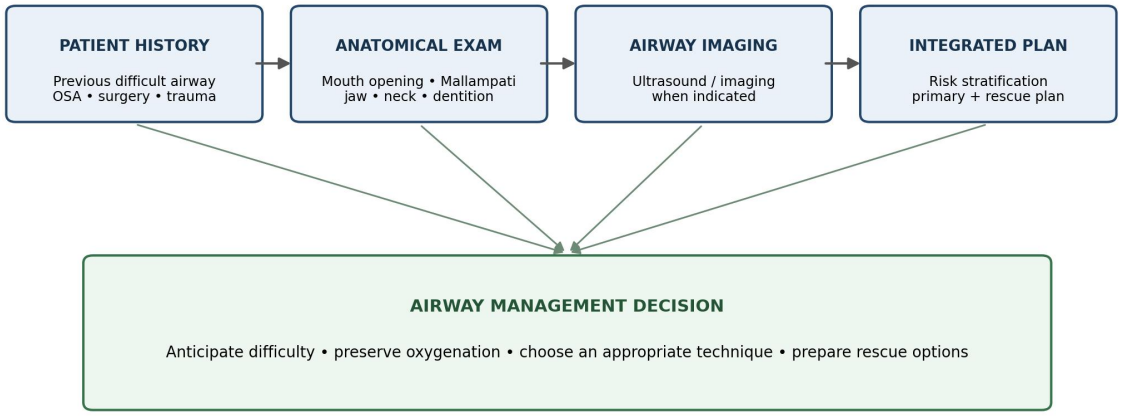
These findings should not be overinterpreted. Diagnostic accuracy estimates from selected study populations may not transfer directly to emergency departments, intensive care units, obstetric patients, or patients with major head and neck pathology. Ultrasound cutoffs may also vary with sex, body habitus, ethnicity, head position, probe pressure, and operator technique. Multicenter prospective validation is needed before any single ultrasound threshold can be adopted as a universal rule.

The clinical value of anatomical prediction lies in preparation rather than labeling. Identifying a potentially difficult airway allows the clinician to select an appropriate technique, optimize positioning and oxygenation, request experienced assistance, and prepare rescue devices. The 2022 ASA guideline and DAS recommendations emphasize that prediction must be linked to an actionable airway strategy [1,2].

For anatomy education, this topic illustrates the direct clinical relevance of regional and topographic anatomy. Students should understand the relationship between mandibular dimensions, tongue position, hyoid and laryngeal levels, cervical mobility, and the airway axis. Integrating surface examination with ultrasound anatomy may improve the translation of anatomical knowledge into safe clinical decision-making.

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ISSN: 2058-5519|Impact factor-15.9
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Figure 1. Integrated framework for anatomical assessment and prediction of difficult endotracheal intubation



Source: author-developed conceptual diagram based on the reviewed literature.

CONCLUSION

Individual anatomical characteristics of the upper airway have a substantial influence on the technical conditions required for endotracheal intubation. Restricted mouth opening, reduced mandibular protrusion, relative macroglossia, short thyromental or hyomental distance, limited cervical extension, increased anterior neck soft-tissue thickness, and distorted airway anatomy may contribute to difficult laryngoscopy or tube passage.

Conventional bedside tests are useful but have limited predictive accuracy when applied individually. A structured assessment that combines patient history, external anatomical examination, multiple measurements, and selective airway ultrasound provides a more comprehensive description of risk. Ultrasound is a promising adjunct, but its protocols and thresholds require further standardization and validation.

The ultimate purpose of preoperative airway assessment is not simply to predict difficulty, but to enable an appropriate airway strategy that preserves oxygenation, minimizes repeated attempts, and ensures timely access to rescue techniques.

PRACTICAL RECOMMENDATIONS

- Review previous anesthesia records and ask specifically about prior difficult mask ventilation, laryngoscopy, and intubation.
- Assess mouth opening, mandibular protrusion, dentition, Mallampati class, thyromental distance, neck circumference, and cervical mobility.
- Consider anatomical distortion from obesity, obstructive sleep apnea, tumor, trauma, infection, previous surgery, or radiotherapy.
- Do not use a single bedside test as a definitive rule-in or rule-out test.

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ISSN: 2058-5519|Impact factor-15.9
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- Use airway ultrasound selectively to assess anterior neck soft tissue, hyomental distance, tongue dimensions, and relevant landmarks when trained personnel and equipment are available.
- Document the anticipated difficulty separately for mask ventilation, supraglottic airway placement, laryngoscopy, tracheal tube passage, and front-of-neck access.
- Link risk assessment to a documented primary plan, backup plan, rescue equipment, and team communication.

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