

Review

Not peer-reviewed version

Point-of-Care Ultrasound in Airway Management: An Expert Review

[Daniele Salvatore Paternò](#) , [Luigi La Via](#) , [Emilia Concetta Lo Giudice](#) , [Mario Lentini](#) , [Antonino Maniaci](#) ,
Antoinette Marie Bonaccorso , Rossella Moltisanti , Antonio Putaggio , Federico Pappalardo ,
[Massimiliano Sorbello](#) *

Posted Date: 9 March 2026

doi: 10.20944/preprints202603.0644.v1

Keywords:

airway management; ultrasound; POCUS; difficult airway; cricothyrotomy; artificial intelligence



Preprints.org is a free multidisciplinary platform providing preprint service that is dedicated to making early versions of research outputs permanently available and citable. Preprints posted at Preprints.org appear in Web of Science, Crossref, Google Scholar, Scilit, Europe PMC.

Copyright: This open access article is published under a [Creative Commons CC BY 4.0 license](#), which permit the free download, distribution, and reuse, provided that the author and preprint are cited in any reuse.

Disclaimer/Publisher's Note: The statements, opinions, and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions, or products referred to in the content.

Review

Point-of-Care Ultrasound in Airway Management: An Expert Review

Daniele Salvatore Paternò ¹, Luigi La Via ², Emilia Concetta Lo Giudice ^{3,4}, Mario Lentini ^{5,6}, Antonino Maniaci ^{5,6}, Antoinette Marie Bonaccorso ⁷, Rossella Moltisanti ¹, Antonio Putaggio ¹, Federico Pappalardo ^{4,8} and Massimiliano Sorbello ^{1,4,*}

- 1 Department of Anaesthesia and Intensive Care, “Giovanni Paolo II” Hospital, Ragusa, Italy
- 2 Department of General Surgery and Medical-Surgical Specialties, University of Catania, Catania, Italy
- 3 Department of Anaesthesia and Intensive Care, “Umberto I” Hospital, Enna, Italy
- 4 School of Anaesthesia and Intensive Care, “Kore” University, Enna, Italy
- 5 Department of Ear, Nose and Throat Surgery, “Maggiore” Hospital, Modica, Italy
- 6 School of Ear, Nose and Throat Surgery, “Kore” University, Enna, Italy
- 7 Department of General Surgery, “Giovanni Paolo II” Hospital, Ragusa, Italy
- 8 Department of Anaesthesia and Intensive Care, “Morgagni” Clinic, Catania, Italy
- * Correspondence: massimiliano.sorbello@unikore.it

Abstract

Background: Unanticipated difficult airways remain a leading cause of anesthesia-related morbidity and mortality, with traditional bedside predictors demonstrating limited sensitivity. Point-of-Care Ultrasound (POCUS) has emerged as a non-invasive adjunct offering real-time visualization and quantitative measurement of airway anatomy. This narrative review, structured according to the Scale for the Assessment of Narrative Review Articles (SANRA), synthesizes current evidence on Point-of-Care Ultrasound (POCUS) as an adjunct for airway evaluation. We explore the sonoanatomy of the upper airway, the utility of ultrasound in predicting difficult laryngoscopy and intubation, its critical role in emergency front-of-neck access (FONA), and the verification of endotracheal tube placement. Furthermore, we discuss the integration of Artificial Intelligence (AI) in image interpretation and the necessity of standardized training curricula. **Methods:** We systematically searched PubMed/MEDLINE, Scopus, and Web of Science for English-language peer-reviewed studies addressing sonographic airway assessment, including sonoanatomy, prediction of difficult laryngoscopy/intubation, guidance for emergency front-of-neck access (FONA) and endotracheal tube confirmation. **Results:** POCUS enhances visualization of critical anatomical structures, improves predictive accuracy when combined with clinical assessment, and provides real-time guidance during emergency procedures. Integration of Artificial Intelligence shows promise for automated image interpretation. **Conclusions:** Airway ultrasound represents a paradigm shift toward personalized, safer airway management. However, standardized training protocols and validation in diverse clinical settings remain essential. Future research should focus on developing evidence-based algorithms integrating POCUS into airway management guidelines.

Keywords: airway management; ultrasound; POCUS; difficult airway; cricothyrotomy; artificial intelligence

1. Introduction

Airway management remains a critical task in anesthesia, critical care, and emergency medicine. While most endotracheal intubations proceed uneventfully, the occurrence of an unanticipated difficult airway can result in life-threatening incidents and serious complications [1], including hypoxemia, hemodynamic collapse, or even death, particularly in fragile and critically ill patients [2].

Despite advances in airway devices and techniques, difficult airway-related morbidity persists as a leading cause of anesthesia-related adverse events, underscoring the paramount importance of accurate pre-procedural risk assessment.

Airway management planning may reduce complications through careful and meticulous preoperative assessment [3]. Traditional bedside predictors (e.g., the Mallampati score, thyromental distance, neck extension, jaw mobility) have long served as the initial screening tools, yet their diagnostic performance is modest, with pooled sensitivity values typically ranging from 38% to 52% [4]. Consequently, a meaningful proportion of difficult intubations remain unpredicted. Difficult airway management derives from the combination of different anatomical, physiological, environmental, and team-related factors, resulting in the fact that each difficult airway exhibits a specific individual pattern [5]. In this perspective, the use of ultrasound (US) as a tool for airway evaluation has emerged as a promising adjunct to standard clinical assessment, given its potential to provide precise and quantitative measurements of anatomical parameters associated with difficult airways [6].

In recent years, point-of-care ultrasound (POCUS) has been increasingly deployed at the bedside for a variety of procedural and diagnostic applications. Its appeal in airway management arises from its non-invasive nature, ability to visualize soft-tissue structures in real time, and capacity to provide quantitative measurements of anatomical parameters relevant to intubation difficulty [7]. Sonographic measurements such as the distance from skin to epiglottis (DSE), skin to vocal-cord depth, thickness of anterior neck soft tissues, hyomental distance (HMD), and related ratios have been investigated as objective correlates of difficult laryngoscopy and intubation [8,9].

Applications of ultrasound in airway management have been recently extended [10], including assistance in locating the cricothyroid membrane for emergency front-of-neck access (FONA), two-point confirmation of correct endotracheal intubation (laryngeal/esophageal findings and symmetric lung sliding) [11], assessment of supraglottic airway device positioning [12], and gastric content and fasting status evaluation [13]. These diverse applications reflect the versatility of ultrasound as a comprehensive airway assessment tool across the peri-intubation continuum.

Despite this momentum, the incorporation of airway ultrasound into routine practice remains variable. Challenges include the absence of universally accepted scanning protocols, heterogeneity in measurement cut-offs across studies, dependence on operator skill and experience, and limited data linking sonographic predictors to meaningful clinical outcomes such as first-pass intubation success or complication rates. Moreover, while many investigations explore pre-intubation assessment in elective settings, fewer have addressed emergency scenarios or anatomical variations (e.g., morbid obesity, cervical pathology, head and neck masses). The literature thus presents promising but not yet definitive evidence for ultrasound-guided airway assessment [14]. It is worth emphasizing that even with the best-performing clinical screening tools, the prevalence of unanticipated difficult airways remains substantial [15], highlighting the urgent need for adjunctive methods that may improve pre-intubation preparedness and patient safety.

In the evolving landscape of airway management, the technological proliferation of handheld ultrasound probes and their accessibility at the bedside are critically enabling factors. As the concept of ultrasound as a "fifth pillar" of the physical examination—alongside inspection, palpation, percussion, and auscultation—gains acceptance, the role of ultrasound in airway assessment becomes increasingly viable [16]. In a domain where seconds can determine outcomes and where failure to secure an airway may lead to catastrophic consequences, the integration of ultrasound into airway assessment represents not merely an incremental advance, but a potential paradigm shift in avoiding airway-related life-threatening complications. This transition from subjective clinical evaluation to objective, image-guided risk stratification enables quantifiable anatomical measurements—such as DSE, hyomental distance ratio (HMDR), and anterior neck soft-tissue thickness—that demonstrate superior diagnostic accuracy in multiple validation studies [8,9].

The objective of this narrative review is multifaceted. First, we aim to provide an updated and critical synthesis of the evidence on ultrasound-guided prediction of difficult intubation and

ultrasound-based identification of the cricothyroid membrane (CTM). Second, we will reflect on how these techniques could be integrated into clinical workflows—highlighting practical considerations, training implications, limitations, and future research directions. Specifically, this review aims to: (1) synthesize current evidence on ultrasound-based prediction of difficult intubation; (2) evaluate the role of ultrasound in emergency front-of-neck access; (3) critically appraise limitations including operator dependency and lack of standardization; (4) explore emerging technologies such as artificial intelligence in image interpretation; and (5) propose training frameworks for clinical implementation. In accordance with the Scale for the Assessment of Narrative Review Articles (SANRA) framework [17], we outline our methodology, discuss strengths and weaknesses of existing literature, and delineate implications for clinical practice.

2. Materials and Methods

This narrative review was developed in accordance with the Scale for the Assessment of Narrative Review Articles (SANRA) guidelines [17].

2.1. Literature Search Strategy and Inclusion Criteria

A structured, comprehensive search of the literature was performed across three major databases: PubMed/MEDLINE, Scopus, and Web of Science. The search strategy combined controlled vocabulary (MeSH) and free-text terms related to airway management and ultrasonography. The main search terms included: “airway ultrasound,” “sonographic airway assessment,” “difficult intubation,” “laryngoscopy,” “cricothyroid membrane,” “ultrasound-guided cricothyrotomy,” and “ultrasound prediction of difficult airway.” Boolean operators (AND, OR) were used to expand or narrow the search scope as appropriate.

Only peer-reviewed English-language articles were considered. Eligible publications included clinical trials, prospective or retrospective cohort studies, diagnostic accuracy studies, meta-analyses, and narrative or systematic reviews that addressed the use of US in airway assessment or front-of-neck access. Case reports, editorials without primary data, non-English manuscripts, and conference abstracts without full text were excluded.

2.2. Selection and Synthesis Approach

After de-duplication, all titles and abstracts were screened independently by two reviewers for relevance to airway US. Full texts of potentially eligible studies were retrieved and assessed for inclusion. Data were extracted concerning study design, patient population, US methodology (probe type, scanning planes, measurement variables), main outcomes, and reported accuracy metrics (sensitivity, specificity, AUC). Given the narrative nature of the review, no formal quantitative synthesis or meta-analysis was conducted.

Instead, a qualitative synthesis was performed, highlighting recurring findings, methodological consistencies and discrepancies, and the evolution of evidence across different clinical contexts (elective, emergent, obese or anatomically distorted airways). Where available, comparative results between US-based and conventional predictive methods were summarized to contextualize diagnostic performance. Emphasis was placed on reproducibility, operator dependency, and translational potential into routine airway evaluation.

2.3. Evidence Level and Bias Considerations

Following SANRA principles [17], we critically appraised the methodological strength and potential bias of included studies. Most available data derive from single-center observational or diagnostic accuracy designs, often with limited sample sizes and heterogeneous definitions of “difficult intubation.” Few studies employed blinded assessment or standardized sonographic protocols, introducing potential selection and observer bias. The absence of uniform measurement thresholds (eg, for skin-to-epiglottis distance) complicates inter-study comparability.

To mitigate these limitations, findings were discussed in relation to study quality and context rather than pooled. Where systematic reviews or meta-analyses were available, their conclusions were integrated to strengthen the synthesis. Throughout the manuscript, claims were proportionate to the robustness of evidence, and potential confounders—such as operator experience, patient body-mass index, and airway pathology—were explicitly considered.

Finally, this review adhered to SANRA recommendations for transparency and structure, ensuring clear articulation of aims, justification of topic relevance, balanced interpretation of findings, and comprehensive referencing of current literature. The purpose of this methodological rigor is to provide a credible, educationally valuable synthesis that may guide both clinical practice and future research design.

3. Results

3.1. Ultrasonographic Anatomy of the Upper Airway

A systematic and reproducible knowledge of the anatomical relationships between the tongue, epiglottis, hyoid bone, laryngeal cartilages, vocal cords, and trachea enables clinicians to identify critical landmarks for intubation, ventilation, and emergency front-of-neck access. Over the past decade, high-frequency US has become increasingly used to delineate these structures in both normal and difficult airways, allowing real-time assessment of dynamic changes during respiration and airway manipulation [18] (Figure 1).

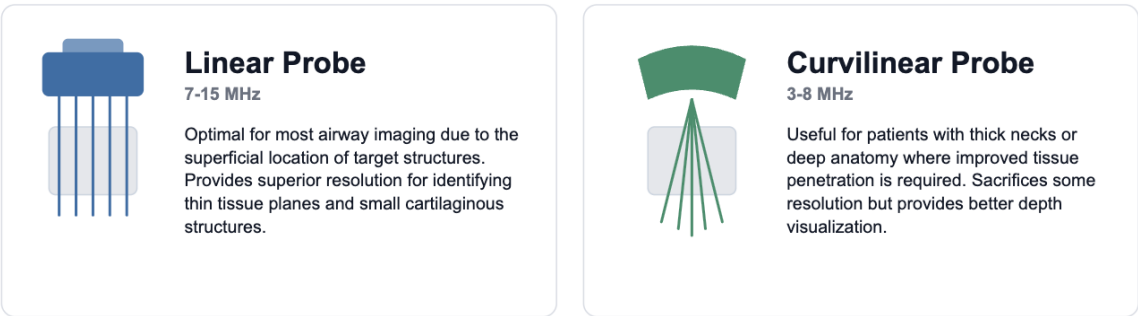


Figure 1. Comparison of ultrasound probe types used for airway assessment. On the left the linear probe (7–15 MHz) and on the right the curvilinear probe (3–8 MHz).

3.1. Tongue and Floor of the Mouth

The tongue is best visualized using a curvilinear probe placed in the submental region with the patient in the supine position and mouth closed. In the sagittal (midline) plane, the geniohyoid and mylohyoid muscles appear as paired hypoechoic bands separated by a hyperechoic midline raphe. The intrinsic musculature of the tongue forms a heterogeneous echotexture anterior to the hyoid bone (Figure 2). Measurements such as the HMD and the hyomental distance ratio (HMDR)—the ratio of HMD in neutral versus extended neck positions—have been proposed as sonographic predictors of difficult laryngoscopy [19,20]. These metrics provide an objective quantification of anterior neck soft-tissue compliance and have demonstrated moderate correlation with Cormack-Lehane laryngoscopic grades.



Figure 2. Tongue and floor of the mouth in sagittal plane with curvilinear probe.

3.2. Epiglottis and Pre-Epiglottic Space

The epiglottis can be imaged by placing the linear probe transversely over the thyrohyoid membrane, just superior to the thyroid cartilage. It appears as a curved hypoechoic structure with a bright posterior border, representing the air–mucosa interface of the epiglottic surface [21]. The DSE—a parameter measured from the skin surface to the midpoint of the epiglottic shadow—has gained attention as a reliable predictor of difficult laryngoscopy, with thresholds between 2.3 and 2.5 cm showing acceptable diagnostic accuracy [22].

The pre-epiglottic space (PES), filled with adipose tissue, appears hypoechoic, and its thickness may influence epiglottic mobility during laryngoscopy. Evaluating the PES also assists in differentiating normal from pathological conditions, such as epiglottic edema or neoplastic infiltration, which can affect intubation safety

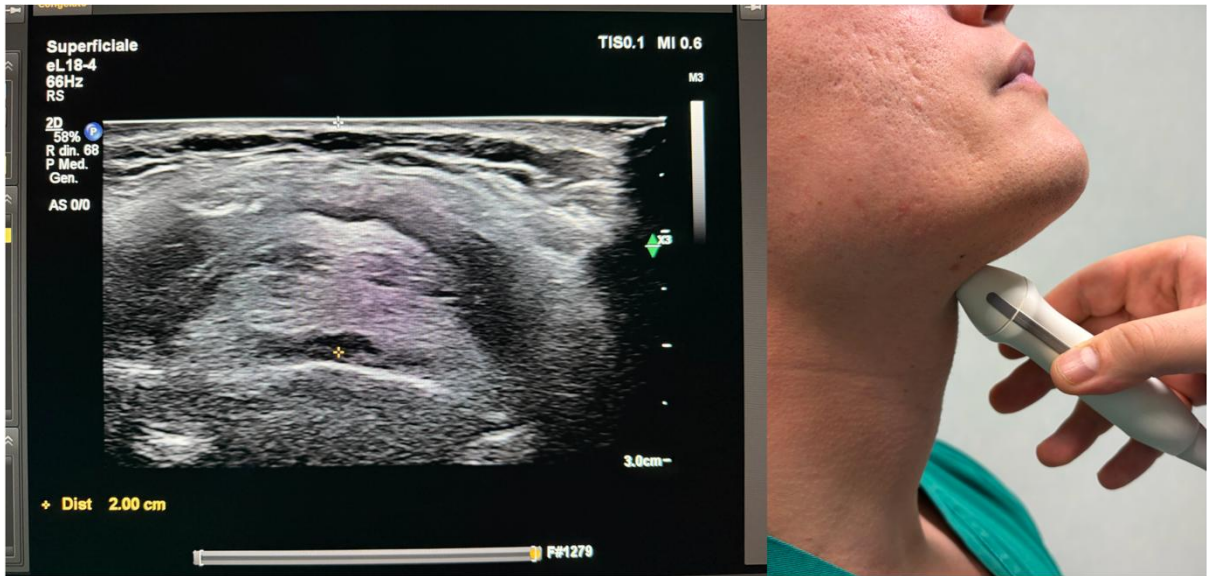


Figure 3. DSE measured in trasverse plane with linear probe at the epiglottic level.

3.3. Hyoid Bone and Laryngeal Cartilages

The hyoid bone presents as a bright, curved echogenic line casting a posterior acoustic shadow. Its visualization is essential for orienting the examiner during longitudinal and transverse scans, acting as a landmark that separates the suprahyoid and infrahyoid compartments [23]. The thyroid cartilage appears as a paired hypoechoic structure with an intervening midline notch, while the cricoid cartilage is more circular and produces a stronger posterior acoustic shadow due to its complete ring morphology [24]. With age, ossification of these cartilages increases, altering echogenicity and sometimes complicating image interpretation. Nevertheless, recognition of the laryngeal framework provides guidance for identifying the CTM and tracheal rings.

3.4. Vocal Cords and Glottic Structures

Sonographic evaluation of the vocal cords can be achieved using either a transverse scan through the thyroid cartilage or a longitudinal midline approach through the cricothyroid membrane. The true cords appear as paired hypoechoic linear structures that move symmetrically during phonation, while the false cords demonstrate less mobility and greater echogenicity [25]. Dynamic US allows visualization of cord motion, useful in assessing recurrent laryngeal nerve palsy or verifying endotracheal tube placement. The air–mucosa interface beneath the cords produces a distinct hyperechoic line, aiding identification even when direct visualization is difficult [26].

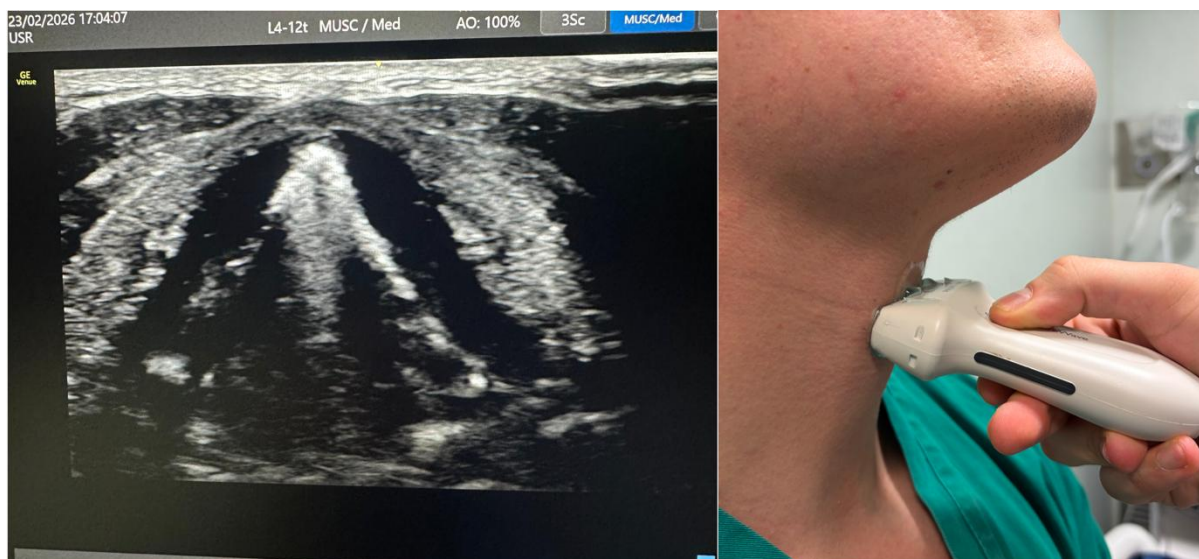


Figure 4. Vocal cords visualization in transverse plane with linear plane.

3.5. Trachea and Subglottic Region

Below the CTM, the trachea appears as a series of hypoechoic cartilaginous rings surrounding a central air column that generates posterior reverberation artifacts. The tracheal midline is verified by symmetric visualization of the lateral lobes of the thyroid gland, an important step during pre-intubation airway assessment and percutaneous tracheostomy planning, with special emphasis in head and neck surgery [27]. US may also help identifying abnormal tracheal anatomy or pathologic status of tracheal cartilaginous rings [28]. The distance from skin to anterior tracheal wall can be measured to anticipate challenges in surgical or needle cricothyrotomy, particularly in obese patients or those with cervical swelling [29].

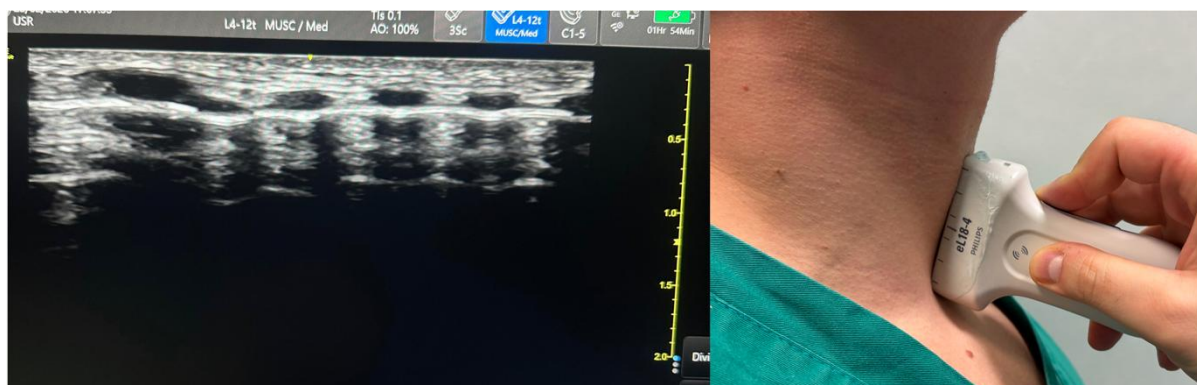


Figure 6. Longitudinal midline view of the trachea, illustrating the tracheal cartilaginous rings.

4. Sonographic Predictors of Difficult Intubation

The quest to reliably predict a difficult intubation remains one of the most persistent challenges in anesthesiology and airway management. Traditional bedside tests—such as the Mallampati classification, thyromental distance, and upper lip bite test—suffer from limited sensitivity and specificity, with many difficult airways occurring unexpectedly despite apparently favourable assessments [3,30–32]. In recent years, US has emerged as a powerful, non-invasive adjunct capable of quantifying airway anatomy and tissue compliance in real time. Sonographic evaluation provides both quantitative and qualitative information that can refine preoperative risk stratification and augment conventional clinical predictors.

4.1. Quantitative Parameters

4.1.1. Anterior Neck Soft-Tissue Thickness

Anterior neck soft-tissue thickness (ANS) represents one of the most extensively studied quantitative predictors. It is typically measured as the distance from the skin surface to the anterior aspect of the airway structures, such as the hyoid bone, epiglottis, or vocal cords. In a landmark study, Ezri et al. demonstrated that a greater distance between the skin and the epiglottis was strongly correlated with difficult laryngoscopy [33]. The DSE, measured in the mid-sagittal plane at the thyrohyoid membrane, has since become one of the most validated parameters. Thresholds between 2.3 and 2.5 cm have been proposed as predictive cut-offs, with pooled sensitivity and specificity of approximately 75% and 86%, respectively [34].

The pretracheal depth—defined as the distance between the skin and the anterior tracheal wall at the level of the suprasternal notch—has also been evaluated, particularly in obese patients. Thick pretracheal soft tissue (>28 mm) increases the risk of failed visualization of the vocal cords and difficult intubation [35]. These findings are consistent with the notion that excessive anterior neck adiposity impairs laryngoscopic alignment of oral, pharyngeal, and laryngeal axes.

4.1.2. Hyomental Distance and Ratio

The HMD is the linear measurement between the hyoid bone and the mentum, typically obtained in the midline sagittal view. This distance shortens in patients with anterior larynx positioning or reduced mandibular mobility—both known contributors to intubation difficulty [9]. However, because absolute HMD values vary by sex, height, and ethnicity, the HMDR was introduced as a more standardized metric. An HMDR < 1.2 has been associated with difficult laryngoscopy, reflecting limited cervical extension or soft-tissue compliance [36]. These quantitative indices offer an objective alternative to subjective clinical estimates of airway flexibility.

4.1.3. Composite Ultrasound Scores

Recent efforts have explored multivariate US indices combining several parameters (DSE, pretracheal depth, and HMDR). De Luis-Cabezón et al. proposed a composite “Airway US Score” integrating three sonographic predictors with two clinical variables, improving overall predictive accuracy compared with any single measurement [14]. Although not yet universally validated, such integrated models illustrate the potential of US-based scoring systems to augment traditional airway algorithms.

4.2. Qualitative Markers

Beyond quantitative measures, qualitative sonographic findings provide contextual insight into airway configuration. The visibility of the epiglottis, for example, is a qualitative surrogate for anatomical accessibility during laryngoscopy. In well-visualized airways, the epiglottis appears as a distinct hypoechoic arc with posterior reverberation; in contrast, blurred or absent visualization often correlates with deep-seated or anteriorly displaced laryngeal structures [37]. Similarly, the hyoid–mandible position—reflected in the relative orientation of the hyoid bone to the mandibular symphysis—can signal potential difficulty when the hyoid lies unusually posterior or inferior, indicating a reduced mandibular space [38].

In certain populations, such as patients with obstructive sleep apnea (OSA) or obesity, these qualitative patterns are accentuated by fatty infiltration and redundant soft tissue, further supporting the role of sonography as a dynamic anatomical mapping tool [39]. Moreover, US visualization of the tongue base, vallecula, and epiglottic edge can help identify patients in whom direct laryngoscopy may fail, guiding early use of video-assisted or fiberoptic techniques.

4.3. Diagnostic Accuracy Compared with Clinical Prediction Scores

Multiple studies and meta-analyses have compared sonographic parameters with standard clinical predictors. In general, US-derived measurements outperform individual bedside tests in terms of both sensitivity and specificity. For instance, Anushaprasath et al. reported that DSE had an area under the ROC curve (AUC) of 0.87 compared to 0.68 for the Mallampati score [40]. Similarly, the HMDR demonstrated greater predictive value than thyromental distance alone, highlighting the advantage of dynamic, anatomically grounded measurements.

Nevertheless, combining US with conventional predictors yields the best diagnostic performance. A prospective trial found that integrating sonographic DSE with the modified Mallampati and upper lip bite tests increased the positive predictive value for difficult laryngoscopy from 48% to 86% [8]. Such evidence reinforces the concept that US should complement—not replace—clinical assessment.

Despite these promising results, several caveats remain. First, operator dependency and the absence of standardized measurement protocols introduce variability in reported cut-offs. Second, many studies have small sample sizes or selective inclusion criteria, limiting generalizability. Finally, diagnostic accuracy studies often use Cormack-Lehane grade ≥ 3 as a surrogate for difficult intubation, which may not fully capture real-world airway challenges. Larger, multicentre trials with standardized definitions are required to confirm the clinical utility of these parameters [9,41].

5. Comparative Evidence: US vs Conventional Predictive Tools

In the evolving landscape of airway management, the comparative performance of US-based assessment versus traditional clinical screening is a critical area of investigation. We compared the available evidence from meta-analyses and prospective trials, considering the strengths and limitations of ultrasonographic predictors, and how exploring these tools may be integrated into preoperative screening workflows while noting gaps and caveats.

5.1. Meta-analyses and Prospective Trials Comparing US and Clinical Assessments

Several systematic reviews and meta-analyses have evaluated the diagnostic accuracy of US-derived airway parameters compared with conventional bedside tests. For example, one meta-analysis found that US metrics across three domains – anterior tissue thickness, anatomical position, and oral space—yielded a pooled sensitivity of 76 % (95 % CI 71–81 %) and specificity of 77 % (95 % CI 72–81 %) for anterior tissue thickness, and an AUROC of 0.83, whereas the anatomical position domain yielded even higher specificity (86 %) and AUROC (0.87) [8].

Prospective trials have further demonstrated that US measurements are significantly different between patients with easy versus difficult direct laryngoscopy. For instance, one study reported mean differences in DSE of 0.38 cm (95% CI 0.17–0.58), DSVC (distance skin to vocal cords) of 0.18 cm (95% CI 0.01–0.35) and DSHB (distance skin to hyoid bone) of 0.23 cm (95% CI 0.08–0.39) in difficult vs easy groups [42]. These findings suggest that US may provide a more sensitive anatomical assessment than observation of external landmarks alone (Table 1).

Table 1. Key strengths and weaknesses of ultrasonographic airway assessment derived from recent meta-analyses and diagnostic accuracy studies.

Domain	Key Findings	Clinical Impact	Evidence Base
STRENGTHS			
Objective, Dynamic Assessment	Provides real-time visualization of airway structures (tongue, epiglottis, hyoid, larynx, vocal cords) with quantifiable anatomical measurements during positioning and breathing	• Eliminates inter-observer variability inherent to subjective clinical tests (e.g., Mallampati) • Captures dynamic changes in neck position and tissue compliance not detectable by static bedside examination	High-frequency US enables real-time assessment; contrast with Mallampati's static, subjective grading
Superior Diagnostic Performance	Higher sensitivity (76–86%) and comparable specificity (77–86%) versus conventional predictors; Area Under ROC Curve (AUROC) 0.83–0.87 for key parameters (DSE, HMDR)	• Improves detection of at-risk airways compared to traditional tests (Mallampati sensitivity ~38–52%) • May reduce unanticipated difficult intubations when integrated with clinical assessment	Multiple meta-analyses; superior sensitivity over Mallampati, thyromental distance, upper lip bite test
Practical Accessibility	Non-invasive, portable, bedside technique requiring no ionizing radiation or patient transport	• Enables rapid point-of-care decision-making in preoperative, emergency, and critical care settings • Compact POCUS devices facilitate immediate airway evaluation	Widespread availability of handheld US; proven feasibility in ED and OR settings
LIMITATIONS			
Lack of Standardization	Marked heterogeneity in:	• Prevents direct comparison across studies	Systematic reviews

Domain	Key Findings	Clinical Impact	Evidence Base
	probe type (linear vs. curvilinear), scanning planes (transverse vs. sagittal), measurement definitions (e.g., DSE cut-offs range 1.6–2.75 cm), and patient populations (elective vs. emergency, obese vs. non-obese)	• Precludes definitive meta-analytic conclusions • Hinders development of universal clinical protocols and guidelines	highlight inconsistent methodology; no consensus on optimal scanning protocol or thresholds
Operator Dependence	Image quality and measurement accuracy strongly influenced by: user experience, probe pressure/angle, technique, and patient anatomy (obesity, short neck, pathology)	• Requires specialized training with steep learning curve • Inter-operator reliability varies without standardized competency assessment • Reduced accuracy in anatomically challenging patients	Inter-rater ICC ranges from 0.57–0.88; inexperienced operators yield unreliable data
Population Variability	Performance of certain parameters (e.g., anterior neck soft-tissue thickness) inconsistent across demographic groups (sex, BMI, ethnicity) and clinical contexts	• Measurement thresholds validated in one population may not generalize to others • Limited data in emergency, distorted anatomy, or pediatric airways	Few studies include obese, emergency, or anatomically variant cohorts; most focus on elective adult populations
Limited Outcome Evidence	Most studies use surrogate endpoints (Cormack–Lehane grade ≥ 3) rather than patient-centered outcomes (intubation success, complications, hypoxemia, mortality)	• Unclear whether improved prediction translates to better clinical outcomes • Small sample sizes (<200 patients in most trials) limit external validity • Few multicenter or emergency airway datasets	Evidence base dominated by single-center observational studies; lack of outcome-driven RCTs

Comparisons with clinical prediction tools consistently show that traditional tests (e.g., Mallampati classification, thyromental distance, upper lip bite test) display high specificity but disappointingly low sensitivity. For example, a large meta-analysis on these clinical methods found sensitivities around 0.38–0.52 with specificities of approximately 0.83–0.86 [41]. In contrast, US appears to deliver higher sensitivity while retaining similar specificity in many studies, suggesting potential for improved detection of at-risk airways.

5.2. Integration into Preoperative Screening

US may be viewed not as a replacement for clinical evaluation, but as a complementary tool. A practical workflow could involve initial clinical screening (Airway history, Mallampati, thyromental distance, neck mobility, interincisal distance and upper lip bite test), followed by targeted US in patients with equivocal or borderline findings, significant risk factors (obesity, cervical pathology, prior difficult airway) or anatomical uncertainty.

Practical implementation of airway US within clinical workflows requires a structured, multidisciplinary approach. The first step is the development of standardized protocols that clearly define which sonographic parameters—such as the DSE, HMDR, and anterior neck soft-tissue thickness—should be measured, alongside institution-specific cut-offs validated in local populations. Adequate training is equally essential: anesthesiologists and airway teams must acquire the skills to obtain reproducible scans, accurately interpret images, and contextualize findings within each patient's airway profile. US results should then be incorporated into preoperative airway risk charts, categorizing patients by risk level (for example, green for low risk, amber for moderate risk where video laryngoscopy may be advisable, and red for high risk requiring awake intubation planning). These findings should also be linked to specific clinical decision pathways, triggering the use of advanced airway strategies or ensuring the immediate availability of surgical airway equipment in high-risk cases. Finally, continuous audit and feedback mechanisms are vital—tracking metrics such as first-pass success, incidence of unexpected difficult intubations, and complications—to refine institutional thresholds and ensure ongoing quality improvement.

However, integration must remain pragmatic. In emergent situations or resource-limited settings, reliance on quick clinical assessment remains essential; US should not delay urgent airway management. Further, institutions must validate US thresholds locally, since differences in operator practice and population anatomy may affect generalizability.

Lastly, future research must move beyond diagnostic accuracy to evaluate outcome-based endpoints: does adding US reduce unexpected difficult intubations, decrease complications, or improve first-pass success? Without outcome data, widespread adoption remains aspirational.

6. US-Guided Cricothyroid Membrane Identification

Concurrently, US has gained traction in the setting of “front-of-neck access” (FONA), particularly for the identification of the CTM in cases where anatomical landmarks are obscured by obesity, neck mass or trauma [29,43]. Several studies have demonstrated that US outperforms manual palpation in locating the CTM, thereby facilitating preparation for emergency cricothyrotomy [44,45].

The ability to rapidly and accurately identify the CTM is a pivotal element in airway management, especially in “cannot intubate, cannot oxygenate” (CICO) scenarios. Traditional palpation of surface landmarks often fails in obese or anatomically distorted patients, contributing to high failure rates in emergency FONA. US-guided identification of the CTM has therefore garnered significant interest as a technique to enhance anatomical accuracy and improve procedural safety in both elective and emergent airway settings. Studies [46] and a recent systematic review [47] showed that US is superior to conventional palpation for identification of the cricothyroid membrane, hence such technique should be considered during pre-procedural airway assessment.

6.1. Techniques and Scanning Protocols

US approaches to CTM identification primarily employ either the transverse (short-axis) or longitudinal (sagittal/paramedian) plane. In the transverse approach, a high-frequency linear probe is placed at the level of the thyroid cartilage notch, scanning caudally until the hyperechoic air-mucosa interface of the trachea is visualised and the CTM is identified between the thyroid and cricoid cartilages. In contrast, the longitudinal “string-of-pearls” technique aligns the probe in the sagittal midline, allowing the examiner to track the cricoid and tracheal rings as a series of hypoechoic

beads, thereby localising the CTM as the echoless gap between thyroid and cricoid. A systematic review found that although the transverse technique was faster on average, accuracy between the two methods was comparable [9].

In practice, probe choice and scanning technique must be tailored to the patient's anatomy. A high-frequency linear transducer (10–15 MHz) is ideal for superficial neck structures; however, in obese or thick-necked patients deeper penetration may require a lower-frequency curvilinear probe to identify landmarks reliably. Achieving the correct neck position—neutral or slightly extended—is also essential to optimise acoustic windows and reduce distortions in sonoanatomy.

6.2. Accuracy in Normal and Difficult Neck Anatomy

The evidence consistently demonstrates that US significantly outperforms palpation in identifying the CTM across a range of anatomical scenarios. A landmark randomized trial in 223 subjects with difficult neck anatomy compared US versus palpation, finding accurate localisation within 5 mm of a CT scan reference point in 81% of US attempts versus only 8% of palpation attempts ($P < 0.0001$) [9].

Similarly, in a cohort of obese obstetric patients, US localisation yielded correct CTM identification in 71% of cases compared to 39% with landmark palpation ($P = 0.015$), although the US technique required slightly more time (23.5 s vs 16.9 s) and was rated as somewhat more technically challenging [16]. Moreover, a recent systematic review of 14 studies concluded that US offers superior accuracy for CTM localisation—especially in patients with difficult anatomy—and objectively defines neck landmarks more reliably than palpation [47].

It is worth noting that although promising, US identification of the CTM has not yet been definitively shown to improve clinical outcomes (e.g., first-attempt success of cricothyrotomy or reduced complications), as most studies remain observational or cadaveric in nature. The adoption of US for CTM marking, however, is increasingly recommended as part of a pre-intubation “double-set-up” in anticipated difficult airway cases [4,29].

6.3. Role in Emergency Airway Access, Decision-Making

In the algorithm of difficult airway management, especially when emergency FONA is a potential step, pre-procedural US marking of the CTM provides several strategic advantages. First, it enables pre-emptive planning: if the site of cricothyroidotomy is identified and marked before induction of anaesthesia, the operative window in a CVCO crisis is narrowed and anatomical surprises are reduced. Secondly, it enhances procedural confidence: multiple studies report that anesthesiologists who mark the CTM under US are more likely to feel prepared for emergency airway access than those relying on palpation alone. For instance, post-training survey data revealed that 79% of emergency medicine residents reported that focused US training significantly improved their comfort level with CTM identification [49].

However, US is not recommended once a CICO scenario is ongoing and the airway is already lost, because the time required to set up the probe and scan may delay airway access. Instead, the technique is best applied in the pre-induction phase when there is anticipated airway risk and time for planning [50,51].

Proper technique is essential to ensure accurate sonographic identification of the cricothyroid membrane. A generous amount of gel should be applied to minimize compression artifacts in the anterior neck, and the probe must be placed gently to avoid distortion of surrounding soft tissues. During scanning, the operator should clearly recognize key anatomical landmarks—the thyroid cartilage, appearing as a triangular hyperechoic ridge; the cricoid cartilage, visible as a circumferential hypoechoic ring; and the tracheal rings, forming the characteristic “string-of-pearls” pattern. The CTM is located in the interval between the thyroid and cricoid cartilages. Optimal patient positioning involves a slight neck extension, or a ramped position if necessary, to improve visibility while avoiding excessive extension that may distort US windows. Once the CTM is visualized, pre-marking the site with a sterile skin marker facilitates immediate recognition during airway

emergencies. Documentation of the US image and the marked location is recommended for clinical records and teaching purposes. Finally, structured, short-duration training sessions—such as in-house airway US workshops—have been shown to promote rapid acquisition and durable retention of CTM identification skills even among non-radiologists [49].

7. Clinical Applications and Training Implications

The incorporation of airway US into everyday clinical practice—spanning anesthesiology, emergency medicine, and critical care—represents a significant shift toward image-guided airway management. At the same time, the successful deployment of these techniques hinges on structured training programs, simulation-based education, and credentialing frameworks to ensure competence, reduce variability, and mitigate operator-dependence [52].

7.1. Incorporation in Anesthesiology, Emergency Medicine, and Critical Care Practice

In the perioperative arena, US of the upper airway is increasingly used for multiple applications: pre-intubation screening for difficult anatomy, confirmation of endotracheal tube placement, localisation of the cricothyroid membrane, and dynamic monitoring of airway changes (eg, tongue base swelling, oedema). In emergency departments and critical care units, portable POCUS allows rapid bedside assessment when physical anatomy is distorted, and may guide decision-making in difficult airway scenarios. One review highlighted that airway POCUS may improve first-pass success rates and reduce unanticipated difficult intubations, especially when used in tandem with clinical assessment [53].

Further applications of US in modern airway management include a two points confirmation approach to exclude unrecognized esophageal intubation (laryngeal/esophageal findings and symmetric lung sliding), which remains of paramount importance in reducing critical airway accidents, with US aimed to substitute old stethoscopes while contributing in reduction of cognitive biases [54–56]. Despite the theoretically limited benefit of assessing supraglottic airway devices positioning (bronchoscopic assessment or recent video-laryngeal masks may provide better performance and address correcting manoeuvres [57]). Nevertheless, US may be used to assess the amount of secretions or blood just above the cuff of endotracheal tubes or supraglottic devices [58]. US may be used also for lung separation/exclusion procedures for either tracheal and bronchial measurements and to assess correct positioning of bronchial blockers and double lumen tubes [59]. Last but not least, US may be used also assessment of quantity and quality of gastric content and fasting status, with implications on anesthetic techniques, particularly during rapid sequence induction-intubation [60].

Experience from the COVID-19 pandemic showed that US may be versatile and prompt implementations in the airway cart, providing valuable support for different airway manoeuvres [61]. Out of infectious transmissible diseases, and considering evolution of machines with consequential cost reduction and increased availability, we may foresee a next future where US may substitute the stethoscope on the airway cart, with further benefits and uses.

Despite the promise, actual adoption remains inconsistent. A recent survey of anesthesiology residency programs in the U.S. found that only 21% had a formal airway US curriculum, and airway US was ranked least among POCUS topics in terms of training emphasis [62]. Barriers included a lack of faculty trained in airway sonography, limited dedicated time for instruction, and absence of standardised competency assessment. As such, while airway US is clinically feasible and beneficial, translation into everyday practice requires organisational commitment, equipment availability, and integration into airway algorithms.

7.2. Simulation-Based Education and Credentialing Models

Simulation offers a structured, safe, and reproducible environment to teach airway US before real-world patient application. Hybrid airway models, high-fidelity mannequins, and virtual reality platforms allow learners to visualise sonoanatomic landmarks, practice probe manipulation, perform measurements, and interpret images under guided supervision. A recent low-cost hybrid airway model for nursing students showed high feasibility and learner satisfaction in training basic airway sonography skills [63–65]. These educational modalities support deliberate practice, feedback, and error correction without patient risk.

Credentialing frameworks and direct assessment of competence are increasingly recognised as vital. The surveyed anesthesiology programs reported relying on combinations of hands-on skills assessment, written exams, image review and minimum scan numbers—but 60% of programs lacked formal competency assessment for airway US [66]. This gap underscores the need for standardised curricula. For example, the American Society of Regional Anesthesia and Pain Medicine (ASRA) expert panel recommended minimum study volumes: 30 airway exams, 30 lung scans, and 20 gastric scans in a broader POCUS curriculum [67–69]. While not airway-specific, this provides a useful benchmark.

In addition, embedding US findings into institutional airway protocols (e.g., marking high-risk patients, prompting video laryngoscope or awake intubation) fosters translation into decision-making workflows and promotes sustained use. Combining simulation, credentialing and clinical integration supports the transition from technical skill to cognitive decision-making in airway management.

8. Limitations and Controversies

While the adoption of US in airway management promises significant benefits, it is essential to critically examine persistent limitations, emerging controversies, and the future-oriented avenues—such as artificial intelligence (AI) and automated analysis—that may overcome current hurdles.

8.1. Operator Variability and Lack of Standardization

One of the most consistently cited weaknesses of airway US is operator dependence. Imaging acquisition, landmark identification, probe pressure, and measurement techniques vary among practitioners, contributing to significant inter-observer and intra-observer variability [70]. For example, one feasibility study in an emergency department setting found inter-rater intraclass correlation coefficients (ICCs) ranging from 0.76 to 0.88 for various upper airway measurements—but only 0.57 for epiglottic thickness, indicating that even in controlled settings variability remains [71]. Multi-institutional studies confirm that inter-rater reliability improves significantly when standardized measurement protocols and structured reporting templates are employed [72]. However, real-world adoption of such protocols remains limited outside academic centers [73].

Compounding this is the absence of standardized scanning protocols for airway assessment. Despite meta-analyses demonstrating promising values for parameters such as DSE or HMDR [9], heterogeneity among studies in head position, measuring plane, probe frequency, patient population (elective vs emergency vs obese) and cut-off values limits generalizability [47]. As one recent systematic review concluded: “high clinical and methodological heterogeneity has been found between studies ... it is not currently possible to reach a definitive conclusion before better standardization of US assessment” [9].

The lack of consensus on measurement definitions and thresholds also means that clinical implementation is inconsistent. For instance, DSE cut-offs vary widely (from 1.6 cm to 2.75 cm) across studies, making institution-specific calibration essential prior to routine use [46]. Therefore, despite promising diagnostic accuracy metrics, routine adoption remains hindered by these standardization gaps.

8.2. Technological Challenges (Portable Devices, AI-Based Measurement)

Emerging technology brings new promise but also new challenges. The proliferation of portable and handheld US devices gives broader access, but device-based variability—including probe frequency, image resolution, gel quality, user interface and built-in measurement tools—can influence the accuracy of airway scans. Some studies point out that suboptimal US windows (e.g., in patients with subcutaneous emphysema, thick necks or anterior neck masses) remain a barrier to consistent imaging [7].

In recent years, AI and automated measurement tools have begun to enter the POCUS space. In lung US, AI guidance has enabled non-experts to acquire diagnostic-quality images with success rates over 98% [74]. Though airway-specific AI work is still nascent, a narrative review of AI in difficult airway assessment concluded that deep-learning models using images plus clinical data offer promising gains but are “limited by data-quality, class imbalance, and generalizability” [30]. A recent article describes deep-learning workflows for airway landmark detection in neck US, noting that synthetic image-generation methods may help remedy class imbalance but clinical deployment remains some distance off [74].

9. Conclusions

US has evolved from a supplementary diagnostic modality into a transformative tool for airway evaluation and management. By providing real-time visualization of key upper airway structures, quantifiable predictive parameters, and accurate localization of the cricothyroid membrane, it enhances both pre-intubation planning and procedural safety. Compared with traditional bedside predictors, ultrasonography offers superior sensitivity and objectivity, although its performance is still influenced by operator skill, equipment variability, and lack of standardized protocols.

Future integration of airway US into routine anesthetic, emergency, and critical care workflows will depend on structured training programs, evidence-based credentialing, and outcome-driven research. Technological advances—particularly AI, automated measurement, and portable high-resolution devices—hold the potential to mitigate current limitations and democratize access to airway imaging. Ultimately, as standardization and clinical validation progress, airway US may redefine difficult airway prediction from an art of anticipation to a science of precision, improving safety and decision-making across all critical care settings.

Author: Contributions: Conceptualization: M.S. conceived and designed the scope of this narrative review. Methodology: D.S.P. and L.L.V. established the literature search strategy and selection criteria in accordance with the SANRA framework. Investigation: E.L.G, M.R. and A.P. conducted the comprehensive literature search and data extraction. Writing—Original Draft Preparation: E.L.G, A.M.B., M.R. and A.P. drafted the initial manuscript sections. Writing—Review and Editing: D.SP., L.L.V., M.L., A.M. critically reviewed, revised, and refined the manuscript for intellectual content and clarity. Visualization: E.L.G, M.R. and A.P. created figures, tables, and graphical representations of ultrasound techniques and measurement protocols. Supervision: M.S. and F.P. provided overall guidance, mentorship, and final approval of the manuscript. Project Administration: M.S. coordinated the review process and managed manuscript revisions. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding. This work was conducted without financial support from governmental, commercial, or not-for-profit funding agencies.

Institutional Review Board Statement: Not applicable. This is a narrative review article based exclusively on previously published literature. No primary data collection, human subjects research, or animal studies were conducted. Therefore, ethical approval and informed consent were not required.

Informed Consent Statement: Not applicable. This narrative review does not involve primary data collection from human participants.

Data Availability Statement: This narrative review synthesizes previously published literature. No new datasets were generated. All cited studies are publicly accessible through their respective journal publications and are listed in the References section.

Conflicts of Interest: The authors declare no conflicts of interest. No financial relationships, consulting arrangements, stock ownership, patent holdings, or other potential sources of bias exist that could inappropriately influence this work. The authors have no commercial associations that might pose a conflict of interest in connection with the submitted manuscript.

Abbreviations

- AI Artificial Intelligence
- ANS Anterior Neck Soft-tissue Thickness
- ASRA American Society of Regional Anesthesia and Pain Medicine
- AUC Area Under the Curve
- BMI Body Mass Index
- CICO Cannot Intubate, Cannot Oxygenate
- CTM Cricothyroid Membrane
- CVCO Cannot Ventilate, Cannot Oxygenate
- DSE Distance from Skin to Epiglottis
- DSHB Distance Skin to Hyoid Bone
- DSVC Distance Skin to Vocal Cords
- ED Emergency Department
- FONA Front-of-Neck Access
- HMD Hyomental Distance
- HMDR Hyomental Distance Ratio
- ICC Intraclass Correlation Coefficient(s)
- OR Operating Room
- OSA Obstructive Sleep Apnea
- POCUS Point-of-Care Ultrasound
- PES Pre-Epiglottic Space
- SANRA Scale for the Assessment of Narrative Review Articles
- US Ultrasound

References

1. Cook TM, Woodall N, Frerk C, Fourth National Audit Project. Major complications of airway management in the UK: results of the Fourth National Audit Project of the Royal College of Anaesthetists and the Difficult Airway Society. Part 1: anaesthesia. Br J Anaesth. 2011;106(5):617-31. doi: 10.1093/bja/aer058
2. Russotto V, Sorbello M. Airway management in critically ill patients. BJA Educ. 2025;25(9):375-81. doi: 10.1016/j.bjae.2025.05.003
3. Lamperti M, Romero CS, Guarracino F, Cammarota G, Vetrugno L, Tufegdzcic B, et al. Preoperative assessment of adults undergoing elective noncardiac surgery: updated guidelines from the European Society of Anaesthesiology and Intensive Care. Eur J Anaesthesiol. 2025;42(1):1-35. doi: 10.1097/EJA.0000000000002069
4. Heidegger T, Pandit JJ. Difficult airway management: from the power of prediction to the art of management. Anesth Analg. 2025;140(2):290-4. doi: 10.1213/ANE.0000000000007202
5. Pandit JJ, Heidegger T. Putting the 'point' back into the ritual: a binary approach to difficult airway prediction. Anaesthesia. 2017;72(3):283-8. doi: 10.1111/anae.13720
6. Sorbello M, Falcetta S. Time to include ultrasounds in pre-procedural airway evaluation? Trends Anaesth Crit Care. 2021;22:45-55. doi: 10.1016/j.tacc.2021.02.006

7. Lin J, Bellinger R, Shedd A, Wolfshohl J, Walker J, Healy J, et al. Point-of-care ultrasound in airway evaluation and management: a comprehensive review. *Diagnostics (Basel)*. 2023;13(9):1541. doi: 10.3390/diagnostics13091541
8. Soni VM, Pappu A, Zarabi S, Khalil C, You-Ten KE, Siddiqui N, et al. Point-of-care ultrasound of the upper airway in difficult airway management: a systematic review and meta-analysis. *Anaesthesia*. 2025;80(12):1556-67. doi: 10.1111/anae.16751
9. Carsetti A, Sorbello M, Adrario E, Donati A, Falcetta S. Airway ultrasound as predictor of difficult direct laryngoscopy: a systematic review and meta-analysis. *Anesth Analg*. 2022;134(4):740-50. doi: 10.1213/ANE.0000000000005839
10. Riveros-Perez E, Avella-Molano B, Rocuts A. Airway ultrasound: a narrative review of present use and future applications in anesthesia. *Healthcare (Basel)*. 2025;13(13):1502. doi: 10.3390/healthcare13131502
11. Chrimes N, Higgs A, Hagberg CA, Baker PA, Cooper RM, Greif R, et al. Preventing unrecognised oesophageal intubation: a consensus guideline from the Project for Universal Management of Airways and international airway societies. *Anaesthesia*. 2022;77(12):1395-415. doi: 10.1111/anae.15817
12. Amina S, Rajasree O, Balakrishnan M, Philip FA, George PS. Efficacy of ultrasound versus video-bronchoscopy in confirming correct placement of i-gel®: a prospective observational study. *Indian J Anaesth*. 2025;69(11):1214-20. doi: 10.4103/ija.ija_150_25
13. Pai SL, Nimma SR, Beam WB, VanderWielen BA, Kalagara HK, Bettini LM, et al. Assessment of gastric content using gastric ultrasound in patients on glucagon-like peptide-1 receptor agonists before anesthesia. *Anesth Analg*. 2025 Oct 1. doi: 10.1213/ANE.0000000000007764 [Epub ahead of print]
14. De Luis-Cabezón N, Ly-Liu D, Renedo-Corcostegui P, Santaolalla-Montoya F, Zabala-Lopez de Maturana A, Herrero-Herrero JC, et al. A new score for airway assessment using clinical and ultrasound parameters. *Front Med (Lausanne)*. 2024;11:1334595. doi: 10.3389/fmed.2024.1334595
15. Yang IT, Tung A, Flores KS, Berenhaut KS, Choi JA, Bryan YF. Clinical decision-making and process complications during anticipated difficult airway management for elective surgery. *Anesth Analg*. 2025;140(2):295-305. doi: 10.1213/ANE.0000000000007049
16. Nakazawa H, Uzawa K, Tokumine J, Lefor AK, Motoyasu A, Yoroazu T. Airway ultrasound for patients anticipated to have a difficult airway: perspective for personalized medicine. *World J Clin Cases*. 2023;11(9):1951-62. doi: 10.12998/wjcc.v11.i9.1951
17. Baethge C, Goldbeck-Wood S, Mertens S. SANRA—a scale for the assessment of narrative review articles. *Res Integr Peer Rev*. 2019;4:5. doi: 10.1186/s41073-019-0064-8
18. Nair AR, Eltohamy A, Krishnakumar N. Ultrasound-guided evaluation of airway difficulty in morbid obesity: comparative predictive parameters. *Bioinformation*. 2025;21(8):2537-42. doi: 10.6026/973206300212537
19. Hui CM, Tsui BC. Sublingual ultrasound as an assessment method for predicting difficult intubation: a pilot study. *Anaesthesia*. 2014;69(4):314-9. doi: 10.1111/anae.12598
20. Giordano G, Alessandri F, Zulian A, Bilotta F, Pugliese F. Pre-operative ultrasound prediction of difficult airway management in adult patients: a systematic review of clinical evidence. *Eur J Anaesthesiol*. 2023;40(5):313-25. doi: 10.1097/EJA.0000000000001800
21. Gottlieb M, Holladay D, Burns KM, Nakitende D, Bailitz J. Ultrasound for airway management: an evidence-based review for the emergency clinician. *Am J Emerg Med*. 2020;38(5):1007-13. doi: 10.1016/j.ajem.2019.12.019
22. Parameshwar SK, Karna ST, Waindeskar V, Kumar H, Singh P, Saigal S. Accuracy of sonographic airway parameters in difficult laryngoscopy prediction: a prospective observational cohort study from Central India. *Turk J Anaesthesiol Reanim*. 2023;51(5):434-42. doi: 10.4274/TJAR.2023.231217
23. Wojtczak JA. Submandibular sonography for airway management. *J Ultrasound Med*. 2012;31(4):523-31. doi: 10.7863/jum.2012.31.4.523
24. Nkwocha O, Enwerem CJ, Adeniyi M, Alambrouk T, Jawad U, Javed S, et al. Role of ultrasound in tracheotomy and cricothyrotomy: a research study of midline cervical vasculature in healthy individuals. *Cureus*. 2025;17(9):e92711. doi: 10.7759/cureus.92711

25. Rai S, Tiku A, Menon A, Seth D, Bajaj G. Ultrasonographic measurement of glottal area: a potential biomarker study in young normophonic adults. *Eur Arch Otorhinolaryngol.* 2025;282(12):6335-45. doi: 10.1007/s00405-025-09739-5
26. Falcetta S, Sorbello M. Bats, Dracula and Batman: the sixth sense in airway management. *Minerva Anesthesiol.* 2021 Feb 16. doi: 10.23736/S0375-9393.21.15577-4 [Epub ahead of print]
27. Falcetta S, Ahmad I, Paternò DS, Sorbello M. Anesthesia management in thyroid surgery. *Curr Opin Anaesthesiol.* 2025;38(6):852-60. doi: 10.1097/ACO.0000000000001569
28. Richardson CM, Lam AS, Nicholas GE, Wang X, Sie KC, Perkins JA, et al. Tracheal ultrasound for diagnosis of tracheal cartilaginous sleeve in patients with syndromic craniosynostosis. *Otolaryngol Head Neck Surg.* 2025;172(1):307-12. doi: 10.1002/ohn.967
29. Onrubia X, Frova G, Sorbello M. Front of neck access to the airway: a narrative review. *Trends Anaesth Crit Care.* 2018;22:45-55. doi: 10.1016/j.tacc.2018.06.001
30. Mika S, Gola W, Gil-Mika M, Wilk M, Misiołek H. Overview of artificial intelligence in point-of-care ultrasound. *New horizons for respiratory system diagnoses. Anaesthesiol Intensive Ther.* 2024;56(1):1-8. doi: 10.5114/ait.2024.136784
31. La Via L, Maniaci A, Gage D, Cuttone G, Misseri G, Lentini M, et al. Exploring the potential of artificial intelligence in airway management. *Trends Anaesth Crit Care.* 2024;59:101512. doi: 10.1016/j.tacc.2024.101512
32. Detsky ME, Jivraj N, Adhikari NK, Friedrich JO, Pinto R, Simel DL, et al. Will this patient be difficult to intubate? The rational clinical examination systematic review. *JAMA.* 2019;321(5):493-503. doi: 10.1001/jama.2018.21413
33. Ezri T, Gewürtz G, Sessler DI, Medalion B, Szmuk P, Hagberg C, et al. Prediction of difficult laryngoscopy in obese patients by ultrasound quantification of anterior neck soft tissue. *Anaesthesia.* 2003;58(11):1111-4. doi: 10.1046/j.1365-2044.2003.03412.x
34. Gomes SH, Simões AM, Nunes AM, Pereira MV, Teoh WH, Costa PS, et al. Useful ultrasonographic parameters to predict difficult laryngoscopy and difficult tracheal intubation—a systematic review and meta-analysis. *Front Med (Lausanne).* 2021;8:671658. doi: 10.3389/fmed.2021.671658
35. Saha S, Rattansingh A, Viswanathan K, Saha A, Martino R, Yadollahi A. Ultrasonographic measurement of pharyngeal-airway dimension and its relationship with obesity and sleep-disordered breathing. *Ultrasound Med Biol.* 2020;46(11):2998-3007. doi: 10.1016/j.ultrasmedbio.2020.07.007
36. Petrișor C, Szabo R, Constantinescu C, Prie A, Trancă S, Hagău N. The performance of ultrasound-based quantification of the hyomental distance ratio in predicting difficult airway in anaesthesia: a STARD-compliant prospective diagnostic study. *Eur J Anaesthesiol.* 2018;35:627-8. doi: 10.1097/EJA.0000000000000849
37. Yao W, Wang B. Can tongue thickness measured by ultrasonography predict difficult tracheal intubation? *Br J Anaesth.* 2017;118(4):601-9. doi: 10.1093/bja/aex051
38. Wang B, Yao W, Xue Q, Wang M, Xu J, Chen Y, et al. Nomograms for predicting difficult airway based on ultrasound assessment. *BMC Anesthesiol.* 2022;22(1):23. doi: 10.1186/s12871-022-01567-y
39. Bellizzi MG, Pace A, Iannella G, Maniaci A, Paternò DS, Tutino S, et al. Airway management in obstructive sleep apnea: a comprehensive review of assessment strategies, techniques, and technological advances. *Healthcare (Basel).* 2025;13(15):1823. doi: 10.3390/healthcare13151823
40. Anushaprasath U, Kumar M, Kamal M, Bhatia P, Kaloria N, Paliwal B, et al. Evaluation and comparison of sonographic difficult airway assessment parameters with clinical airway predictors. *J Anaesthesiol Clin Pharmacol.* 2024;40(3):422-31. doi: 10.4103/joacp.joacp_181_23
41. Benavides-Zora D, Jaramillo MC, Townsley MM, Franco V, González S, Hoyos C, et al. Diagnostic performance of airway ultrasound for the assessment of difficult laryngoscopy: a systematic review and meta-analysis. *J Cardiothorac Vasc Anesth.* 2023;37(7):1101-9. doi: 10.1053/j.jvca.2023.02.036
42. Bhargava V, Rockwell NA, Tawfik D, Haileselassie B, Petrisor C, Su E. Prediction of difficult laryngoscopy using ultrasound: a systematic review and meta-analysis. *Crit Care Med.* 2023;51(1):117-26. doi: 10.1097/CCM.0000000000005711

43. Maniaci A, Lentini M, Vaira L, Lavalle S, Ronsivalle S, Rubulotta FM, et al. The global burden of maxillofacial trauma in critical care: a narrative review of epidemiology, prevention, economics, and outcomes. *Medicina (Kaunas)*. 2025;61(5):915. doi: 10.3390/medicina61050915
44. Okano H, Uzawa K, Watanabe K, Motoyasu A, Tokumine J, Lefor AK, et al. Ultrasound-guided identification of the cricothyroid membrane in a patient with a difficult airway: a case report. *BMC Emerg Med*. 2018;18(1):5. doi: 10.1186/s12873-018-0156-7
45. Kristensen MS, Teoh WH. Ultrasound identification of the cricothyroid membrane: the new standard in preparing for front-of-neck airway access. *Br J Anaesth*. 2021;126(1):22-7. doi: 10.1016/j.bja.2020.10.004
46. Siddiqui N, Yu E, Boulis S, You-Ten KE. Ultrasound is superior to palpation in identifying the cricothyroid membrane in subjects with poorly defined neck landmarks: a randomized clinical trial. *Anesthesiology*. 2018;129(6):1132-9. doi: 10.1097/ALN.0000000000002454
47. Rai Y, You-Ten E, Zasso F, De Castro C, Ye XY, Siddiqui N. The role of ultrasound in front-of-neck access for cricothyroid membrane identification: a systematic review. *J Crit Care*. 2020;60:161-8. doi: 10.1016/j.jcrc.2020.07.030
48. Lavelle A, Drew T, Fennessy P, McCaul C, Shannon J. Accuracy of cricothyroid membrane identification using ultrasound and palpation techniques in obese obstetric patients: an observational study. *Int J Obstet Anesth*. 2021;48:103205. doi: 10.1016/j.ijoa.2021.103205
49. Adhikari S, Situ-LaCasse E, Acuña J, Ray A, Godwin M, Blaivas M. Integration of pre-intubation ultrasound into an airway management course: a novel training program. *Indian J Crit Care Med*. 2020;24(3):179-83. doi: 10.5005/jp-journals-10071-23370
50. Sorbello M, Parrinello L, Petrini F, Frova G. Ultrasound: not the best 'soundtrack' for a 'cannot ventilate - cannot intubate' scenario. *Eur J Anaesthesiol*. 2012;29(6):295. doi: 10.1097/EJA.0b013e32834de24a
51. Alerhand S. Ultrasound for identifying the cricothyroid membrane prior to the anticipated difficult airway. *Am J Emerg Med*. 2018;36(11):2078-84. doi: 10.1016/j.ajem.2018.07.027
52. Baker PA, Dua G, Iliff HA. Education in airway management: a narrative review. *Br J Anaesth*. 2026;136(1):308-16. doi: 10.1016/j.bja.2025.10.009
53. Edwards J, Ahn D, Alcaraz D, Chiles C, Khuu T, Soni NJ, et al. Point-of-care ultrasound training among anesthesiology residency programs in the United States. *BMC Anesthesiol*. 2025;25(1):105. doi: 10.1186/s12871-025-02929-y
54. Sorbello M, De Jong A, De Robertis E, Greif R. Dubito ergo sum. From philosophy towards prevention of unrecognised oesophageal intubation. *Eur J Anaesthesiol*. 2023;40(5):310-2. doi: 10.1097/EJA.0000000000001822
55. Gottlieb M, Alerhand S, Long B, Wiant A. Ultrasound education in emergency medicine residency programs: a national survey. *J Ultrasound Med*. 2020;39(5):1013-9. doi: 10.1002/jum.15187
56. Dinh VA, Dukes WS, Prigge J, Avila M. Ultrasound integration in undergraduate medical education: comparison of ultrasound proficiency between trained and untrained medical students. *J Ultrasound Med*. 2015;34(10):1819-24. doi: 10.7863/ultra.15.14.12045
57. Jiang Y, Xing F, Wu Q, Gao Y, Chen G, Li C. Comparison of patient outcomes between video and non-video laryngeal mask airway insertion performed by novices: a prospective randomized controlled study. *Front Med (Lausanne)*. 2025;12:1667040. doi: 10.3389/fmed.2025.1667040
58. Bianchini A, Felicani C, Zangheri E, Bianchin M, Siniscalchi A. Point-of-care airway US: a valuable tool in the management of occult over the cuff bleeding and secretions. *Ultrasound J*. 2023;15(1):5. doi: 10.1186/s13089-022-00300-7
59. El Tahan MR, Tschernko E, Végh T, Mourisse J, Sentürk M, Lenartova K, et al. Monitoring in thoracic anesthesia: EACTAIC consensus document. *J Cardiothorac Vasc Anesth*. 2025 Dec 18:S1053-0770(25)01129-2. doi: 10.1053/j.jvca.2025.11.003 [Epub ahead of print]
60. Sorbello M, Paternò DS, Zdravkovic I, La Via L. Pharmacological approach to rapid sequence induction/intubation: a contemporary perspective. *Curr Opin Anaesthesiol*. 2025;38(4):369-74. doi: 10.1097/ACO.0000000000001528
61. Sorbello M, Morello G, Pintaudo S, Cataldo R. COVID-19: intubation kit, intubation team, or intubation spots? *Anesth Analg*. 2020;131(2):e128-30. doi: 10.1213/ANE.0000000000004970

62. Park S, Lee S, Do HH, Kim JS, Seo JS. Effectiveness of limited airway ultrasound education for medical students: a pilot study. *Clin Exp Emerg Med*. 2019;6(3):257-63. doi: 10.15441/ceem.18.061
63. Hauglum SD, Crenshaw NA, Gattamorta KA, Mitzova-Vladinov G. Evaluation of a low-cost, high-fidelity animal model to train graduate advanced practice nursing students in the performance of ultrasound-guided central line catheter insertion. *Simul Healthc*. 2018;13(5):341-7. doi: 10.1097/SIH.0000000000000337
64. Sites BD, Gallagher JD, Cravero J, Lundberg J, Blike G. The learning curve associated with a simulated ultrasound-guided interventional task by inexperienced anesthesia residents. *Reg Anesth Pain Med*. 2004;29(6):544-8. doi: 10.1016/j.rapm.2004.04.002
65. Shokoohi H, Armstrong P, Tansek R. Emergency department ultrasound improves skillset and knowledge base of internal medicine residents. *Cureus*. 2015;7(8):e302. doi: 10.7759/cureus.302
66. Haskins SC, Bronshteyn Y, Perlas A, El-Boghdady K, Zimmerman J, Silva M, et al. American Society of Regional Anesthesia and Pain Medicine expert panel recommendations on point-of-care ultrasound education and training for regional anesthesiologists and pain physicians—part II: recommendations. *Reg Anesth Pain Med*. 2021;46(12):1048-60. doi: 10.1136/rapm-2021-102561
67. Quinn L, Tryposkiadis K, Deeks J, De Vet HCW, Mallett S, Mookink LB, et al. Interobserver variability studies in diagnostic imaging: a methodological systematic review. *Br J Radiol*. 2023;96(1148):20220972. doi: 10.1259/bjr.20220972
68. Schnitterger T, Breckwoldt J, Schilling T, Hinkelbein J. Ultrasound in anaesthesia: European perspective and training recommendations. *Eur J Anaesthesiol*. 2020;37(8):633-41. doi: 10.1097/EJA.0000000000001238
69. Ramsingh D, Rinehart J, Kain Z, Strom S, Canales C, Alexander B, et al. Impact assessment of perioperative point-of-care ultrasound training on anesthesiology residents. *Anesthesiology*. 2015;123(3):670-82. doi: 10.1097/ALN.0000000000000776
70. Hall EA, Showaihi I, Shofer FS, Panebianco NL, Dean AJ. Ultrasound evaluation of the airway in the ED: a feasibility study. *Crit Ultrasound J*. 2018;10(1):3. doi: 10.1186/s13089-018-0083-6
71. Baloesu C, Bailitz J, Cheema B, Gorenstein L, Hetherington T, Shah P, et al. Artificial intelligence-guided lung ultrasound by nonexperts. *JAMA Cardiol*. 2025;10(3):245-53. doi: 10.1001/jamacardio.2024.4991
72. Tessaro MO, Salant EP, Arroyo AC, Haines LE, Dickman E. Tracheal rapid ultrasound saline test (TRUST) for confirming correct endotracheal tube depth in children. *Resuscitation*. 2015;89:8-12. doi: 10.1016/j.resuscitation.2014.12.032
73. Lakhal K, Delplace X, Cottier JP, Tranquart F, Sauvagnac X, Mercier C, et al. The feasibility of ultrasound to assess subglottic diameter. *Anesth Analg*. 2007;104(3):611-4. doi: 10.1213/01.ane.0000260136.53694.fe
74. Varaganti M, Vankayalapati A, Awad N, Dion GR, Brattain LJ. T2ID-CAS: diffusion model and class aware sampling to mitigate class imbalance in neck ultrasound anatomical landmark detection. *Annu Int Conf IEEE Eng Med Biol Soc*. 2025;2025:1-6. doi: 10.1109/EMBC58623.2025.11254047

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.