The Egyptian Journal of Hospital Medicine (April 2025) Vol. 99, Page 2333-2343

Airway Ultrasound as a Method of Airway Assessment: Review Article

Ahmed Mohamed Ali Ismail, Abdel Rahman Hassan Abdel Rahman, Meril Nassry Saleeb*, Mohammed Ahmed Mahmoud

Department of Anesthesia, Intensive Care and Pain Management,
Faculty of Medicine, Sohag University, Sohag, Egypt

***Corresponding author:** Meril Nassry Saleeb, **Mobile:** (+20)01287178283, **Email:** merelnassry@gmail.com

ABSTRACT

Background: Unanticipated and challenging endotracheal intubation continues to pose a significant clinical challenge, particularly when accompanied by difficulty in ventilation. It is linked to serious complications, including airway trauma, laryngospasm, hypoxemia, and cardiac arrhythmias. Despite the availability of various clinical screening tools, a subset of patients initially assessed as having an uncomplicated airway may still experience unforeseen difficulties. Ultrasound (US) imaging is a simple, portable, non-invasive tool that can aid in rapid assessment of airway anatomy not only in the operating theatre but also in the intensive care unit and emergency department.

Objective: This review aimed to evaluate the value of airway US in the assessment and prediction of difficult intubation in adult patients undergoing general anaesthesia.

Conclusions: Although no single US measurement has been universally accepted, several indices, such as increased tongue thickness (> 6.1 mm), skin-to-epiglottic distance (> 2.54 cm), and pre-epiglottic area (> 5.04 cm), demonstrated high sensitivity and specificity for predicting difficult airways. US also assisted in evaluating tracheal size, identifying pathological changes (e.g., tumors or goitres), verifying endotracheal tube placement, and assessing cuff-related tracheal wall pressure. The advent of point-of-care airway US can enhance patient safety by uncovering anatomical modifications that impede ventilation or intubation. To maximize its utility, standardized protocols and training are needed so that airway becomes an accessible, reliable component of perioperative and critical care practice.

Keywords: Airway ultrasound, Difficult intubation, Tongue thickness, Skin-to-epiglottic distance, Pre-epiglottic area, Perioperative airway assessment.

INTRODUCTION

Unanticipated difficulty in performing endotracheal intubation remains a persistent clinical concern, particularly when accompanied by challenges in ventilation. Such difficulty is associated with numerous serious and potentially life-threatening complications, including airway trauma, laryngospasm, reduced oxygen saturation, cardiac arrhythmias, and in extreme cases, cardiac arrest. Accordingly, a thorough preoperative evaluation aimed at identifying potentially challenging airways is of critical importance [(1)].

A variety of screening assessments are routinely employed in clinical settings to detect patients who may be at increased risk for airway management difficulties. However, despite the clinical utility and reported accuracy of these assessments, a subset of individuals deemed to have an uncomplicated airway may nonetheless present with unforeseen intubation challenges. Accurately forecasting a difficult airway remains a complex task across all patient profiles [(2)].

Ultrasound (US) imaging has emerged as a straightforward, mobile, and noninvasive modality that can aid significantly in both airway evaluation and procedural management. Recent literature has highlighted the expanding role of US in airway-related applications. It facilitates expedited visualization of anatomical structures and is beneficial not only within operating theatres but also across intensive care and emergency settings [(3)].

US has been applied to several upper airway clinical scenarios, including confirmation of endotracheal tube (ETT) positioning, guidance during percutaneous tracheostomy and cricothyroidotomy procedures, identification of subglottic narrowing, and prediction of difficult intubation and post-extubation airway obstruction. Furthermore, it assists in selecting appropriately sized pediatric ETTs and double-lumen tubes (DLTs) [(4)].This review aimed to assess the utility of airway US in evaluating and anticipating difficult intubation scenarios.

UPPER AIRWAY ANATOMY

The "airway" generally pertains to the upper segment of the respiratory tract, which comprises non-respiratory conduits. Anatomically, it includes the nasal and oral cavities, pharynx, larynx, trachea, and major bronchi. During the induction and maintenance phases of general anesthesia, neural regulation of respiratory activity is suppressed, rendering the airway functionally passive. Competent respiratory care necessitates a comprehensive understanding of both airway anatomy and its physiological regulation [(5)].

❖ Nose

The nasal cavity is anatomically defined by a roof, floor, medial wall, and lateral wall. It is partitioned into two channels by the nasal septum, each extending anteriorly to the external environment via the nares and posteriorly to the nasopharynx via the choanae. Arterial perfusion is supplied by the anterior and posterior ethmoidal arteries, maxillary artery, and superior labial artery. Venous return occurs through the sphenopalatine, facial, and ophthalmic veins. Neural innervation is provided by the olfactory and trigeminal nerves [(6)].

Received: 07/01/2025
Accepted: 09/03/2025

❖ Mouth and palate

The oral cavity consists of two primary components: The vestibule and the mouth proper. These compartments are interconnected at the oral commissure. The vestibule is enclosed by the lips, cheeks, gingiva, and dentition. The main oral cavity is anteriorly bordered by the alveolar arches and teeth, superiorly by the palatal structures, inferiorly by the anterior segment of the tongue, and posteriorly by the oropharynx. The palate is anatomically divided into two regions: The hard palate, composed of bone, and the soft palate, a muscular extension of the posterior hard palate. The central portion of the soft palate terminates in the uvula and laterally blends with the pharyngeal wall. Five distinct muscles contribute to palatal function: tensor veli palatini, levator veli palatini, palatoglossus, palatopharyngeus, and musculus uvulae. These muscles are primarily responsible for sealing the nasopharyngeal passage during the acts of deglutition and phonation [(7)].

❖ Pharynx

The pharynx serves as a shared conduit for both the respiratory and digestive systems and is divided into three anatomical regions: The nasopharynx, oropharynx, and laryngopharynx. The nasopharynx is positioned posterior to the nasal cavity and superior to the soft palate, communicating with the oropharynx via the pharyngeal isthmus. Key anatomical landmarks within the nasopharynx include the auditory (Eustachian) tube opening, the adenoid tissue, and the fossa of Rosenmüller. The musculature of the pharynx is composed of the superior, middle, and inferior constrictor muscles, as well as the stylopharyngeus, salpingopharyngeus, and palatopharyngeus muscles. The laryngopharynx constitutes the terminal segment of the pharynx, extending from the superior margin of the epiglottis to the level of the sixth cervical vertebra (C6), and contains the pyriform sinuses [(5)].

❖ Larynx

The larynx, positioned anterior to the vertebral bodies of C4 to C6, marks the gateway to the lower respiratory tract. It is a robust, musculocartilaginous structure primarily functioning as a protective valve. Its secondary evolution as the anatomical basis of phonation has earned it the designation "voice box". Structurally, the larynx comprises nine cartilaginous elements joined by ligaments and mobilized by muscular attachments. These include three unpaired cartilages, cricoid, thyroid, and epiglottic, and three paired sets, arytenoid, cuneiform, and corniculate cartilages. The arytenoid cartilages, pyramid-shaped and seated on the cricoid cartilage, have posterior and lateral cricoarytenoid muscles attaching laterally and the vocal ligaments anchoring anteriorly [(6)].

The corniculate cartilages rest atop the arytenoids, while the cuneiform cartilages lie adjacent to them. Among these, the cricoid cartilage forms the only complete cartilaginous ring and serves as the principal structural base of the larynx, articulating with both thyroid and arytenoid cartilages. The thyroid cartilage, the largest, features prominent structures such as the laryngeal prominence (Adam's apple), thyroid notch, and superior and inferior cornua. The epiglottic cartilage, leaf-like in form, is affixed to the thyroid cartilage and connected to the arytenoids via mucosal folds. Ligamentous structures within the larynx include the thyrohyoid, cricotracheal, hyoepiglottic, and cricothyroid ligaments. The muscular system is divided into extrinsic (Sternothyroid, thyrohyoid, stylopharyngeus, palatopharyngeus) and intrinsic (Lateral and posterior cricoarytenoids, interarytenoids, aryepiglottic, thyroarytenoid, thyroepiglottic, vocalis and cricothyroid) groups. The laryngeal nerve supply is provided by the superior and recurrent branches of the vagus nerve [(8)] (Figure 1).

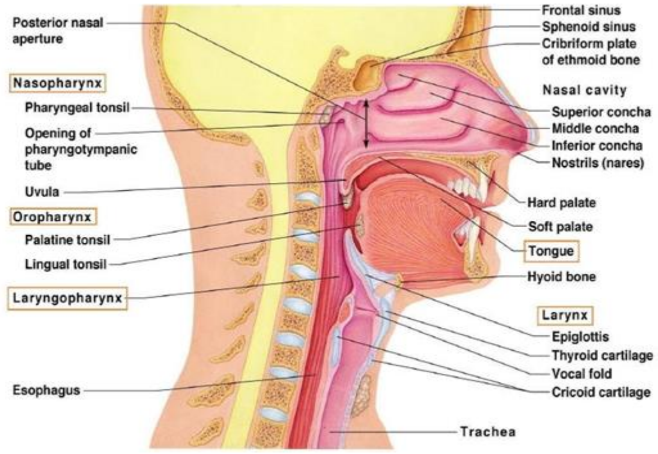

Figure (1): Anatomy of the airway [(5)].

❖ Laryngoscopic anatomy of the larynx (Figure 2)

During DL, as the laryngoscope blade advances through the oral cavity, a sequential visualization of anatomical landmarks occurs. The first structure encountered is the base of the tongue, followed by the valleculae, and then the anterior surface of the epiglottis, ultimately leading to the laryngeal inlet. Extending posteriorly from the epiglottis are thin mucosal ridges known as the aryepiglottic folds, which encase the cuneiform and corniculate cartilages at their posterior aspects. The vocal cords appear as pale, symmetrical bands which are typically positioned in an abducted state due to neuromuscular relaxation induced prior to the procedure. The space between the vocal cords is referred to as the *rima glottidis*, and through this glottic aperture, the upper tracheal cartilaginous rings become visible [(8)].

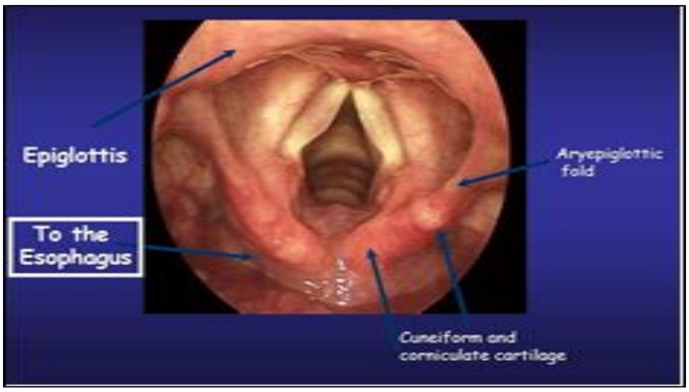

Figure (2): Laryngoscopic anatomy of the larynx [(9)] .

AIRWAY ASSESSMENT

It is essential to conduct a comprehensive preoperative airway assessment as a routine component of anesthetic planning to identify factors that may complicate face-mask ventilation, insertion of a supraglottic airway device, tracheal intubation, or access via a front-of-neck route. Although forecasting airway difficulties is inherently uncertain, it is imperative for the anesthesiologist to formulate a management strategy in advance of anesthesia induction. This strategy should be addressed during the pre-induction phase of the World Health Organization (WHO) Surgical Safety Checklist. Notably, a failure to achieve intubation on the initial attempt has been correlated with a 33% increase in the incidence of adverse outcomes such as oxygen desaturation, aspiration, trauma to soft tissues, hypotension, cardiac arrhythmias, and arrest. The likelihood of success on the first attempt is closely linked to whether the airway is classified as difficult or standard, with the former being a key indicator for procedural complications [1].

Difficult airways are estimated to represent between 10.1% and 30% of emergency airway management (EAM) cases, accounting for a considerable subset of patients. Such airways are statistically associated with reduced first-pass success rates (FSRs), averaging 82.1%, compared to 92.4% for standard airways. In certain studies, nearly half (49.7%) of intubation attempts in patients with difficult airways are unsuccessful on the first attempt. These success rates are further influenced by the choice of device used. Accordingly, the two pillars of successful intubation are a systematic preoperative evaluation and physician proficiency with appropriate airway devices [2].

The practice of securing the airway via tracheal intubation, introducing a tube through the oral cavity into the trachea, has its origins in antiquity, dating back to the Greek and Roman civilizations. The Romans reportedly employed dental mirrors for visualizing the airway, a primitive analogue to modern direct laryngoscopy (DL). Alfred Kirstein is recognized as the pioneer of modern DL, having developed a laryngoscopic device equipped with internal illumination. This innovation laid the foundation for the introduction of the Miller (straight) and Macintosh (curved) blades during World War II, both of which remain in widespread use. In the 1990s, fiber-optic cables were integrated into DL blades to enhance visualization, eventually giving rise to the video laryngoscope (VL) in the early 2000s. The VL incorporates a fiber-optic camera and light source at the blade's tip, transmitting a real-time image of the airway to a display monitor for guided intubation [10].

Meta-analyses and retrospective studies conducted in the United States have demonstrated that VL generally results in higher FSRs compared to DL across various clinical environments. VL not only facilitates quicker intubation in both standard and difficult airways but also yields higher success rates among inexperienced operators. Despite its advantages, VL is less accessible in emergency contexts, where constraints such as limited reusability, the necessity of electrical power, and higher costs limit its practicality in resource-limited settings. Furthermore, retrospective data indicate that patients intubated with VL tend to incur higher hospitalization costs relative to those managed with DL [11].

Intubation by laryngoscopy involves two essential stages: First, the visualization of the vocal cords using either DL or indirect laryngoscopy (IDL), and second, the advancement of the ETT through the glottis into the trachea. DL relies on direct visualization using a light source, whereas IDL or VL employs a fiber-optic camera integrated into the blade. Once positioned, the ETT is connected to a mechanical ventilator to provide positive-pressure ventilation, replacing spontaneous respiratory function. In the emergency department (ED), the preferred initial approach is VL. Should this fail, adjunct techniques such as the use of a Bougie, laryngeal mask airway (LMA), or surgical airway may be necessary. In most failed intubation cases, the inability to visualize the laryngeal inlet is cited as the principal obstacle [12]. Among experienced clinicians, visualization failure typically results from anatomical variations, fluid obstruction, or trauma to the airway structures. When a difficult airway is anticipated during the pre-intubation assessment, the probability of injury or failure on the initial attempt significantly increases compared to cases with typical airway features. The relevant pathologies and risk factors contributing to such intubation difficulties will be discussed further. Hence, the disparity in FSRs between difficult and typical airways highlights an opportunity to refine both technology and technique, in order to optimize success rates and reduce intubation times in emergent scenarios [1].

A comprehensive airway assessment should include several critical observations. Ideally, the inter-incisor distance in adults should allow for a minimum of two finger breadths of mouth opening. Dental examination is essential, as pronounced upper incisors or prominent canines, with or without overbite, can complicate alignment of the oral and pharyngeal axes during DL, particularly when associated with a bulky tongue base. In contrast, edentulous patients may experience easier axis alignment, although their risk of tongue-induced hypopharyngeal obstruction is elevated. Anatomical variations such as a high-arched palate, elongated or constricted oral opening, and a short, thick neck are commonly associated with intubation difficulties. Assessment should also include inspection for cervical masses, evaluation of neck extension and mobility, and the patient's capacity to assume the 'sniffing' position. Additional indicators such as hoarseness, stridor, or history of tracheostomy may signal underlying tracheal stenosis. Measurement of submental space is advised, with hyomental or thyromental distances ideally exceeding 6 cm [12].

Specific tests for the assessment of difficult intubation process included:

❖ **Mallampatti's test (Figure 3)**

Mallampati's classification is used to evaluate the anatomical relationship between the tongue and the pharyngeal space. The patient is instructed to sit upright with the head in a neutral position, mouth opened to its fullest extent, and tongue maximally protruded without phonation. Classification is based on the visibility of specific oropharyngeal structures under these standardized conditions [13]

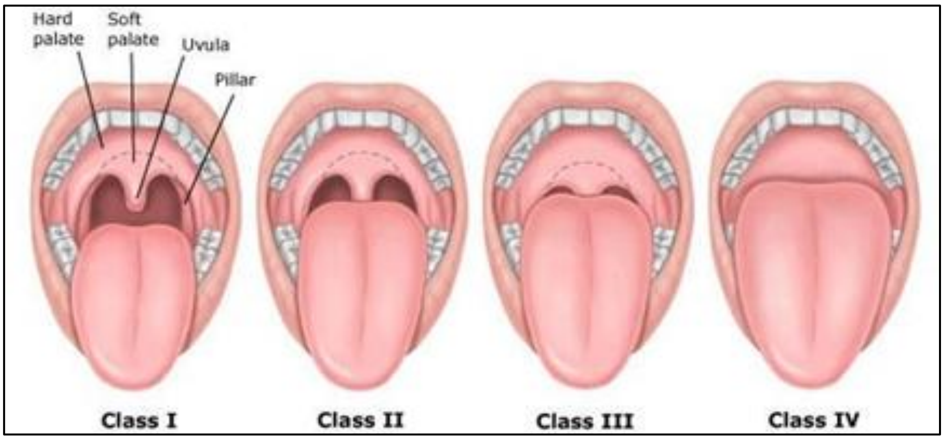

Figure (3): Mallampatti's classification [13].

❖ **Thyromental (T-M) distance (Patil's test)**

Patil's test, also referred to as the thyromental (T-M) distance assessment, measures the linear distance between the mentum (chin) and the thyroid notch with the cervical spine fully extended. This metric is indicative of how effectively the laryngeal and pharyngeal axes can align during atlanto-occipital extension. A T-M distance of less than 3 finger breadths or under 6 cm in adults correlates with increased intubation difficulty. Measurements between 6 and 6.5 cm represent intermediate difficulty, while distances exceeding 6.5 cm are typically associated with normal alignment [13].

❖ **LEMON airway assessment**

The LEMON score is a structured airway assessment tool composed of multiple criteria, with a maximum achievable score of 10. Each of the following features is assigned 1 point: presence of facial trauma, prominent upper incisors, facial hair (beard or moustache), large tongue, reduced hyomental and thyrohyoid distances, and limited inter-incisor gap. The cumulative score aids in stratifying the risk of difficult airway management [14].

❖ **Cormack –Lehane scoring system**

The Cormack–Lehane scoring system categorizes intubation difficulty according to the laryngoscopic view obtained during DL. The classification includes four grades: Grade I: complete visualization of the glottic opening; Grade II: visualization restricted to the posterior glottis; Grade III: only the epiglottis is visible; and Grade IV: only the soft palate is seen. Grades III and IV are indicative of difficult intubation [15].

❖ **Wilson Score system**

The Wilson scoring system is a pre-anesthetic evaluation method that assesses five individual factors predictive of intubation difficulty: Body weight, range of head and neck mobility, jaw movement capacity, ability to protrude the mandible, and the presence of prominent upper teeth. Each parameter is rated from 0 to 2 based on severity, and a cumulative score above 2 is considered predictive of a challenging laryngoscopic intubation [10].

❖ **El-Ganzouri Risk Index**

El-Ganzouri Risk Index integrates seven preoperative criteria, modified Mallampati classification, mouth opening measurement, T-M distance, cervical range of motion, patient body weight, prior history of difficult intubation, and ability to advance the mandible. Each criterion is scored individually, and a total score of 4 or greater is suggestive of a heightened risk for difficult tracheal intubation under general anesthesia [11].

ULTRASOUND PHYSICS

❖ **Basic principles of ultrasound**

A foundational comprehension of the physical principles governing US image formation is vital for accurate interpretation of sonographic findings. Although US is often regarded as a user-friendly bedside modality, the underlying physics can be complex. The term "US" refers to sound waves that possess frequencies above the upper threshold of human hearing. While the human auditory range spans approximately 20 hertz (Hz) to 20 kilohertz (kHz), with one hertz corresponding to one oscillation per second, the frequencies utilized in diagnostic medical imaging lie well above this, typically ranging from 1 to 10 megahertz (MHz). US imaging is based on the pulse-echo principle, in which short pulses of sound are emitted and the returning echoes, reflected from tissue interfaces, are recorded. This principle parallels the natural echolocation mechanism used by bats to navigate dark environments and locate prey [(16)].

❖ **Diagnostic ultrasound waves**

In diagnostic applications, US waves are generated and received using a device called a transducer. These transducers incorporate a piezoelectric crystal, which oscillates at extremely high frequencies when an electric current is applied. This same material can also convert received sound vibrations into electrical signals. While certain naturally occurring substances like quartz exhibit piezoelectric properties, most clinical US transducers utilize a synthetic piezoelectric compound called lead zirconate titanate (PZT) [(17)].

The propagation of US energy occurs via rapid cycles of compression and rarefaction within the medium, thus US cannot traverse a vacuum. Within human biological tissue, sound generally travels at a relatively constant velocity of approximately 1540 meters per second. The spatial distance between two consecutive wave peaks is referred to as the wavelength (λ), and a typical US pulse comprises several such wavelengths. The wavelength is inversely related to the frequency (f) of the wave, with their product equating to the speed of sound (c) in the medium, expressed as: $\mathbf{c = \lambda \times f}$. Attenuation, defined as the loss of wave intensity, within soft tissues is directly proportional to both the frequency and the distance traveled. Hence, doubling the frequency leads to a doubling of attenuation. High-frequency US waves exhibit limited tissue penetration due to increased attenuation, which is why superficial structures like the thyroid or breast are examined using high frequencies, whereas deeper anatomical regions such as the abdomen and pelvis require lower frequencies for adequate visualization [(17)].

❖ **Interaction of sound and tissue**

As US waves traverse a medium, they typically move in straight paths until they encounter boundaries between materials of differing acoustic impedance. At such interfaces, the beam may be reflected, refracted (transmitted), or scattered. In a homogenous medium, sound continues undisturbed. However, at interfaces, a portion of the wave is reflected back while the rest is transmitted at an altered angle. Structures with uniform acoustic impedance do not reflect sound and thus appear anechoic (black) on US images. This principle underlies the core mechanism of most medical US technologies. The extent of reflection at an interface depends on the acoustic mismatch between the media; greater differences yield more substantial reflection. The angle at which the beam meets the interface also influences the proportion of reflected versus transmitted sound; angles closer to 90° enhance reflection [(18)].

When encountering structures with significantly different impedance values, such as bone, almost the entirety of the US beam is reflected, rendering deeper tissue visualization beneath bone difficult. This produces an imaging artifact termed an *acoustic shadow*. Similarly, air has markedly lower impedance compared to soft tissues, resulting in near-total reflection at the air–tissue boundary. For this reason, coupling gel is applied between the transducer and the patient's skin to displace air and facilitate optimal sound transmission during US examination [(19)].

❖ **Pulsed sound and imaging**

US imaging systems generate a short-duration pulse of high-frequency sound and then remain idle to detect the echoes that return from tissues within the scanning field. These pulses typically consist of 2 to 4 acoustic cycles. The duration of this emitted pulse is referred to as the *pulse duration*, which is calculated by multiplying the period of the sound wave by the number of cycles within the pulse. For instance, a 10-megahertz (MHz) wave comprising 3 cycles would yield a pulse duration of 0.1 microseconds (µs) × 3 = 0.3 µs. These brief acoustic bursts are initiated by applying a short electrical stimulus to the piezoelectric crystal, typically lasting around 1 µs. The *spatial pulse length* represents the physical length of the pulse within the medium and is calculated as the product of the wavelength (λ) and the number of cycles. For example, a 10-MHz wave with 3 cycles would produce a spatial pulse length of 0.154 millimeters (mm) × 3 = 0.462 mm [(16)].

The methods of displaying located echo information that are utilized are:

❖ **A-mode**

The earliest diagnostic US modality was amplitude mode (A-mode), in which echo signal strength was displayed relative to tissue depth along a single line of sight. This technique used a stationary transducer, and the echo amplitudes were visualized on a cathode ray oscilloscope. A-mode was notably employed for detecting midline brain shifts. While now rarely used in routine clinical practice, modern US systems may still allow A-mode visualization of echo strength along a selected line as a function of time [(20)].

❖ **B-mode**

Brightness mode (B-mode) forms the basis of standard 2-dimensional (2D) grayscale imaging. This method constructs an image by displaying intensity "spots" generated from sequential lines of sight. Initially, the scanning process required manual manipulation of the transducer, which was mounted on a mechanical apparatus to track its orientation and position during linear movement. These early systems gradually built up an image. Later, mechanical scanning techniques were introduced using electric motors to shift or rotate transducers across the surface. With the advent of real-time imaging, multiple frames per second could be generated. Contemporary US machines achieve this using electronically steered transducer arrays composed of numerous miniature piezoelectric elements, eliminating the need for mechanical movement [20].

- ❖ **3d imaging**

Three-dimensional (3D) US imaging utilizes two primary techniques: Mechanical scanning of linear or phased array transducers to acquire successive 2D slices, which are then digitally reconstructed into a 3D representation; or static 2D arrays that electronically steer the beam in all three spatial dimensions. Due to the expanded volume of tissue surveyed in 3D scanning, this modality operates at a slower rate than conventional 2D imaging [21].

- ❖ **M-mode**

Motion mode (M-mode) echocardiography provides exceptional temporal resolution, making it particularly suited for detecting subtle physiological changes. Compared to 2D or 3D modalities, M-mode facilitates more accurate measurements of cardiac chamber dimensions, assuming that the imaging plane is properly aligned. Additionally, it enables assessment of asynchronous septal movement, prosthetic valve function, valvular regurgitation-induced leaflet fluttering, and abnormal timing in valve motion such as premature closure or opening during the cardiac cycle. Independent movement of intracardiac structures, including vegetations, is also more easily discernible with M-mode [22].

UPPER AIRWAY SONO-ANATOMY (Figure 4)

Air is categorized a poor conductor of US waves, making it ineffective for transmitting sound to deeper anatomical structures. When US beams encounter intraluminal air, characteristic artifacts such as comet tail and reverberation effects are frequently observed. Osseous structures, including the mentum, mandibular rami, hyoid bone, and sternum, are visualized as bright, hyperechoic linear echoes accompanied by a posterior hypoechoic acoustic shadow. In contrast, cartilaginous elements such as the thyroid and cricoid cartilages exhibit a uniform hypoechoic appearance. Muscular and connective tissues typically demonstrate a striated, heterogeneous hypoechoic pattern. Adipose and glandular tissues are generally homogeneous and exhibit mild to marked hyperechogenicity, depending on the fat content within the glandular parenchyma. The interface between air and mucosa (A-M interface) is represented as a sharp, hyperechoic linear boundary [23].

In regions where an air-filled cavity lies beneath the A-M interface, artifacts such as comet tails and reverberations become evident. The presence of intraluminal air obstructs the sonographic visualization of deeper structures, including the posterior pharyngeal wall, the posterior commissure, and the posterior tracheal boundary. For optimal imaging of superficial airway components, within a 2 to 3 cm depth from the skin, a high-frequency linear transducer is most appropriate. Conversely, for capturing sagittal and parasagittal views of deeper structures in the submandibular and supraglottic areas, a low-frequency curved transducer is preferable due to its broader field of view [24].

Bones	Mentum	Linear hyperechoic with acoustic shadow
	Mandible	Linear hyperechoic with acoustic shadow
	Hyoid	Linear hyperechoic with acoustic shadow
	Sternum	Linear hyperechoic with acoustic shadow
Cartilages	Thyroid	Homogenously hypoechoic
	Cricoid	Homogenously hypoechoic
Muscles		Hypoechoic Heterogenous striated
Tissue membranes		Hypoechoic Heterogenous striated
Glands	Sub - mandibular	Homogenous hyperechoic
	Thyroid	Homogenous hyperechoic

Figure (4): Sonographic appearance of upper airway anatomy [23].

Accurate interpretation of airway sonography is influenced by foundational knowledge of US physics, appropriate transducer selection, patient body habitus, and correct probe orientation, alongside a sound understanding of airway anatomy. When viewed in the longitudinal plane, the cricoid cartilage appears as a hypoechoic elevation or "hump", whereas in the transverse plane, it presents as an oval-shaped hypoechoic structure. The tracheal rings manifest in the longitudinal plane as a “string of beads” pattern, while in the transverse plane, they form an inverted "U" shape. A distinct linear hyperechoic line posterior to the trachea, visible in both longitudinal and transverse views, is produced by reverberation artifacts generated at the A-M interface [25].

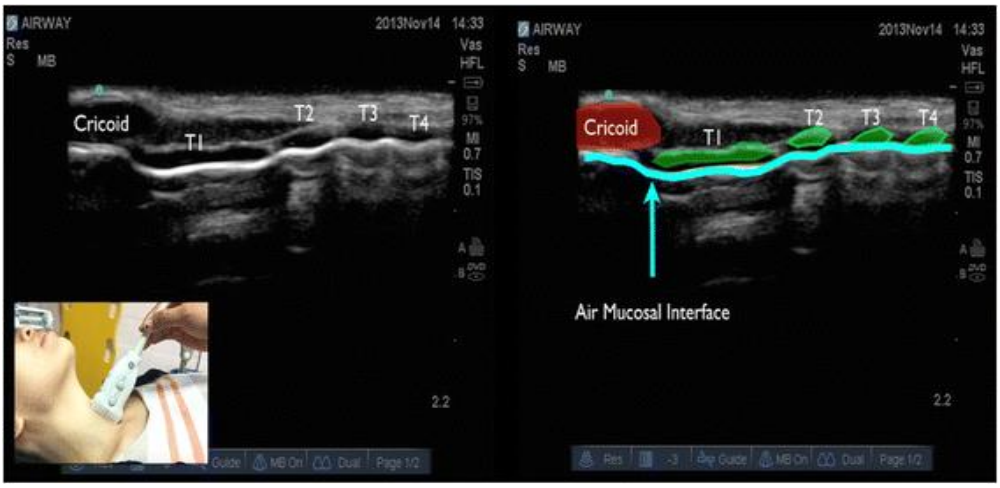

Figure (5): Cricoid and tracheal cartilages in the longitudinal plane present as a “string of beads,” where T1 denotes the first tracheal cartilage, T2 the second, T3 the third, and T4 the fourth [26].

The optimal visualization of the vocal cords via US is achieved in the transverse plane, utilizing the thyroid cartilage as an acoustic window. The vocal ligaments exhibit a hyperechoic pattern, which aids in delineating the vocal cords. The esophagus can be identified in a transverse view at the level of the first and second tracheal cartilages; it lies posterior to the left thyroid lobe. Swallowing activity within the esophageal lumen results in observable peristaltic movement [23].

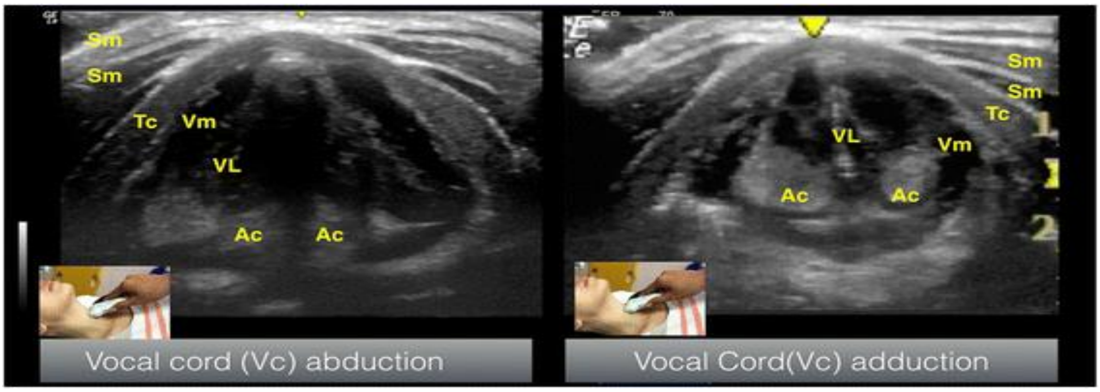

Figure (6): Transverse US view of the vocal cord. Abbreviations: Sm – sternocleidomastoid muscle, Tc – thyroid cartilage, VM – vocalis muscle, VL – vocalis ligament, AC – arytenoid cartilage [26].

US imaging is an essential tool for anesthesiologists and critical care physicians, frequently used in both the operating room and intensive care settings. While airway US is not as routinely performed as other bedside procedures, it holds significant value in perioperative contexts, particularly for pre-intubation airway assessment. In patients who are already intubated, US aids in confirming the correct positioning of the ETT and evaluating the pressure exerted by the tube cuff on the tracheal wall. This is crucial for preventing complications such as tracheal wall ischemia or the formation of a tracheoesophageal fistula. However, in emergency settings, the utility of airway US is limited due to its operator dependence and variability in image acquisition, as well as reduced reproducibility across users and anatomical targets [23].

- **Perioperative ultrasound airway evaluation utility**

Despite advancements in clinical assessment tools, the prediction of a difficult airway continues to involve considerable subjectivity and variability. Although the most critical scenario where the patient cannot be ventilated or intubated is infrequent, the consequences of such a situation can be catastrophic. A thorough preoperative evaluation conducted by the anesthesiologist may reveal suggestive indicators of potential intubation challenges including limited oral opening, reduced thyromental distance, inability to protrude the lower jaw over the upper lip, or a high Mallampati classification. However, these conventional markers often suffer from a lack of objectivity and may fail to accurately predict the actual airway difficulty encountered during DL (as assessed by the Cormack–Lehane scale) or post-induction, when effective ventilation proves unsuccessful. In such instances, US becomes a valuable adjunct, offering real-time anatomical visualization that may detect structural anomalies potentially hindering effective ventilation or tracheal intubation [4].

- **Ultrasound approaches, which are practical for the airway**

A variety of ultrasonographic techniques are available for evaluating airway anatomy, including transcutaneous, endobronchial, and intraoral (Transoral or sublingual) methods. The transcutaneous technique, which is the most widely utilized, includes trans-laryngeal and transtracheal US windows for assessing upper airway structures. This approach can be performed with either high-frequency or low-frequency transducers, depending on the depth and resolution required. Probe orientations used in this method may be sagittal, parasagittal, oblique, or transverse, depending on the anatomical target [27].

The endobronchial method combines external US imaging with bronchoscopy, providing a more detailed and integrated view but requiring more sophisticated instrumentation and expertise. The transoral or sublingual approach, although capable of producing high-resolution images due to superior probe-tissue contact, is the least preferred by both clinicians and patients. This technique involves inserting the US probe beneath the tongue, a procedure that can be uncomfortable for the patient, limiting its routine use despite its superior imaging quality [28].

- **Airway measurements performed by ultrasound**

US imaging facilitates the measurement of various anatomical distances, diameters, and ratios to aid in the prediction of difficult airway scenarios. This modality also allows for the identification of anatomical variations or pathological masses, should they exist. Although the sonographic landmarks for airway evaluation are well-defined, there is ongoing uncertainty regarding which specific measurement, or combination of measurements, serves as the most reliable predictor of a difficult airway [27].

Numerous US-derived parameters have been explored, with some of the most studied outlined below [4]:

- Tongue thickness and anterior cervical soft tissue: Measured at the level of the hyoid bone in the short-axis view, spanning from the skin surface.
- Thyrohyoid membrane distance: Defined as the linear distance between the hyoid bone and the upper margin of the thyroid cartilage.
- Transverse tracheal air shadow diameter: Assessed in the subglottic region from the anterior aspect of the neck at the level of the true vocal cords.
- Soft tissue thickness at key landmarks: Measured from the skin to the anterior tracheal wall at three anatomical levels; vocal cords, thyroid isthmus, and suprasternal notch. Each measurement is averaged from three locations: along the midline and approximately 1.5 mm lateral to both the right and left of midline.
- Hyomental distance ratio: Evaluated using submandibular US, this measurement compares the hyomental distance with the neck in neutral versus hyperextended positions.
- Tongue volume: Estimated by multiplying the cross-sectional mid-sagittal area of the tongue by its width as observed in a transverse US image.
- Anterior commissure depth: The shortest vertical distance from the skin surface to the anterior commissure of the larynx.
- Tongue thickness-to-thyromental distance ratio: Assessed in the mid-sagittal plane with the patient instructed to place the tip of their tongue against the lower incisors, accounting

for the dynamic nature of the tongue as a muscular structure.

All measurements were performed with patients in the supine position, except for the hyomental distance ratio, which was obtained with the patient in a resting and conscious state [4].

- **Prediction of a difficult airway and identification of some airway pathologies, with the aid of ultrasound**

A significant portion of the existing literature supports the utility of US in airway assessment as a promising adjunctive tool for identifying difficult airways. However, consensus is lacking regarding specific anatomical measurements that should be routinely obtained pre-intubation. Only a select few of the distances and diameters evaluated through US have demonstrated statistically significant associations with clinical predictors of airway difficulty. These findings have primarily been correlated with conventional grading systems such as the Mallampati classification, the Cormack–Lehane scale, and observations from DL [29].

Among the more notable results is the association between increased tongue thickness and difficult intubation, with values exceeding 6.1 mm serving as a potential indicator of complexity. This is of particular relevance, as the tongue is frequently manipulated during airway instrumentation. Additionally, the ratio between tongue thickness and thyromental distance has emerged as a strong independent predictor of airway difficulty. Similarly, the skin-to-epiglottis distance has demonstrated clinical value, with a proposed threshold of 2.54 cm yielding a sensitivity of 82% and specificity of 91%. Another promising index, the pre-epiglottic area, was reported with a cut-off value of 5.04 cm, showing 85% sensitivity and 88% specificity in predicting a difficult airway [3].

Despite the skin-to-epiglottis distance being one of the most frequently studied US parameters in this context, there is considerable variability in the reported cut-off values. This inconsistency is attributed to demographic variables such as ethnicity and gender, which can introduce up to a 1 cm deviation in measurement outcomes. For instance, studies have found that the average skin-to-epiglottis distance is approximately 1.6 cm in Indian populations and 2.5 cm in Italian cohorts. These discrepancies are largely explained by interethnic anthropometric differences, particularly in the pattern of adipose tissue distribution, Asians, for example, tend to accumulate fat primarily on the torso. Additionally, US measurements have identified relevant airway predictors at other levels. A cut-off value of 2.7 mm for anterior soft tissue at the level of the vocal cords, and 4.3 mm at the suprasternal notch, have shown statistical significance in the context of difficult airway prediction. These measurements are feasible to obtain at the bedside and can enhance early identification and preparedness in cases where intubation may prove challenging [30].

- **Determination of the trachea size or the tracheal potential abnormalities**

US can be effectively utilized to assess tracheal wall thickness and to detect deviations from normative values, typically 1.5 ± 0.2 mm in males and 1.2 ± 0.2 mm in females. An increase in tracheal wall thickness may be indicative of pathological conditions such as airway inflammation, infections, neoplastic infiltration, congenital disorders including Wegener's granulomatosis, smoke inhalation injuries, or thermal airway trauma. Furthermore, evaluating both the internal and external tracheal diameters is essential for selecting the appropriate size of airway cannula. Due to its non-invasive nature and bedside applicability, US serves as a superior alternative to traditional imaging modalities such as radiography, computed tomography, or magnetic resonance imaging in this context [28].

A subglottic US view is particularly valuable for determining the correct cannula dimensions, whether for a single-lumen or a double-lumen tube, thereby minimizing the risk of excessive airway instrumentation. On US imaging, the trachea appears as a hyperechoic curvilinear structure accompanied by common artifacts like comet tails and acoustic shadowing. The most clinically relevant dimension for single-lumen cannula selection is the subglottic airway diameter, whereas for double-lumen tube placement, the tracheal width should be measured at the suprasternal notch. To overcome the challenge posed by the air-filled cuff, which is invisible on US, a novel technique involves inflating the cuff with saline instead of air. This modification enables visualization of the cuff on US and is referred to as the *Tracheal Rapid* US *Saline Test* (T.R.U.S.T.) [27].

- **Cuff pressure and the trachea wall pressure determination**

Inflation of the cuff on a tracheal cannula is essential to ensure airway sealing for both effective ventilation and aspiration prevention. This is particularly relevant in critically ill patients who often require prolonged intubation in intensive care settings. Research demonstrated that inflation of the cuff alters the tracheal diameter, an effect that can be detected sonographically at the suprasternal notch window [3].

In the study conducted by **Ye and colleagues** [31], significant correlations were found between cuff inflation pressure and both the inner and outer diameters of the trachea. Their experimental work, using an animal model, showed that injecting 10 mL of air into the cuff resulted in an average increase of 7.55% (range 5.39–9.12%) in the outer tracheal diameter and 11.20% (range 8.16–14.90%) in the inner diameter. These findings emphasize the clinical utility of US, particularly because it enables real-time, non-invasive assessment at the bedside or immediately prior to anesthesia induction. While cuff inflation is necessary to maintain airway patency and prevent leakage. It simultaneously imposes pressure on the tracheal wall, which may result in ischemic damage or, in severe cases, the development of tracheoesophageal fistulas [31].

It is important to distinguish between cuff inflation pressure and the actual pressure exerted on the tracheal wall. To date, no definitive method exists for directly measuring tracheal wall pressure. Several techniques have been proposed, including the *pressure difference method*, the *wall pressure membrane technique*, which is invasive and applicable only in vitro, and the *microchip sensor probe method*, which has been criticized for producing falsely elevated values. The pressure difference approach offers a theoretical estimation of tracheal wall pressure, derived from comparative analysis of inner and outer tracheal diameters before and after cuff inflation. Although preliminary studies have reported promising correlations using this method, further validation and refinement are needed before definitive clinical adoption can occur [4].

❖ **Epiglottitis diagnosis**

The epiglottis can be visualized sonographically through the thyrohyoid membrane in the transverse plane, where it appears as a curved, hypoechoic structure. The posterior margin of the epiglottis is defined by a bright linear air–mucosa (A–M) interface, while the anterior margin is bordered by the hyperechoic pre-epiglottic space (PES). Any boundary between the mucosal lining of the upper airway and the air within it consistently generates a distinct hyperechoic linear echo. The epiglottis can typically be identified in nearly all individuals when scanning in the transverse plane, with slight cephalad or caudad adjustments of the linear transducer to optimize visualization. However, due to acoustic shadowing from the hyoid bone, identifying the epiglottis in the parasagittal view is more challenging [32].

Inflammation of the epiglottis, epiglottitis, can result in compromised ventilation and difficulty with endotracheal intubation. US imaging provides a non-invasive method for detecting such changes. The most effective sonographic approach for evaluating suspected epiglottitis is a mid-sagittal transverse scan of the neck using a low-frequency probe. The diagnostic hallmark is an increase in the anterior–posterior diameter of the epiglottis. This assessment is particularly useful in patients who have undergone neck radiotherapy, where epiglottitis may arise as a common treatment-related complication [2].

❖ **Determination of thyroid cancer or the Goiter Influence upon the Airway**

Endotracheal intubation in patients undergoing thyroid surgery is often associated with increased airway management difficulty due to potential compression or deviation of the airway by thyroid tumors or large goiters. Preoperative US evaluation of the upper airway in such patients can reveal anatomical abnormalities that may not be evident upon external examination, thereby minimizing the risk of encountering an unanticipated "cannot intubate, cannot ventilate" scenario. In these cases, the optimal imaging windows are the suprasternal and supraclavicular regions, and imaging should be conducted using a low-frequency transducer for deeper tissue penetration [33].

❖ **Vocal cord functionality** (Figure 7)

Assessment of vocal cord mobility can be effectively performed by placing the US transducer at the level of the thyroid cartilage. For enhanced visualization, the probe may be tilted cranially or caudally. This examination is particularly useful in evaluating vocal cord function post-thyroid surgery, after prolonged intubation in intensive care settings, or as part of preoperative screening prior to general anesthesia. The procedure is non-invasive, well tolerated by patients, highly reproducible, and requires minimal training to execute reliably [34].

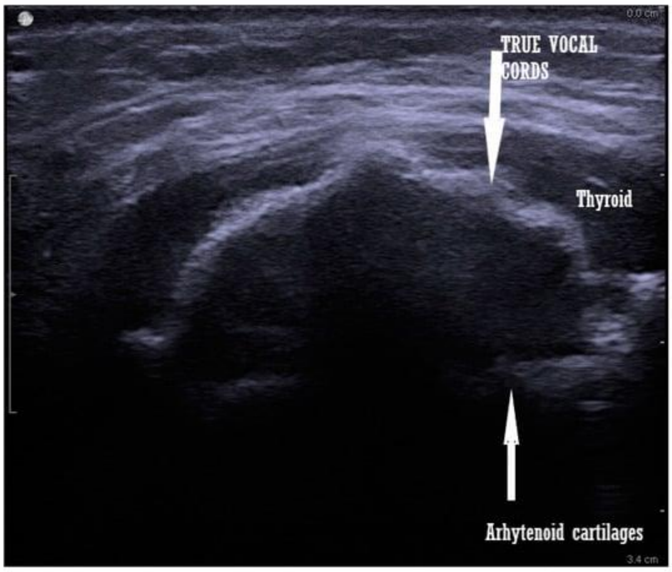

Figure (7): Sonographic view of the vocal cords in an intubated patient [34].

CONCLUSION

US assessment of the airway represents a valuable advancement in clinical practice, significantly enhancing patient safety in both pre-intubation and post-intubation scenarios. With ongoing technological progress, US serves as a vital tool for not only evaluating airway anatomy but also monitoring potential complications related to intubation, such as tracheal wall injury or tracheoesophageal fistula formation. To maximize its clinical utility, there is a clear need for standardized protocols and evidence-based guidelines that facilitate broader adoption of airway US by anesthesiologists and critical care physicians. Once such protocols are unified and widely implemented, the accuracy, reliability, and safety of airway evaluation will be substantially improved.

No funding.
No conflict of interest.

REFERENCES

1. **Wiles M, Iliff H, Brooks K *et al.* (2024):** Airway management in patients with suspected or confirmed cervical spine injury: Guidelines from the Difficult Airway Society (DAS): Association of Anaesthetists (AoA): British Society of Orthopaedic Anaesthetists (BSOA): Intensive Care Society (ICS): Neuro Anaesthesia and Critical Care Society (NACCS): Faculty of Prehospital Care and Royal College of Emergency Medicine (RCEM). Anaesthesia, 79 (8): 856–868.
2. **Miller K, Goldman M, Nagler J (2023):** Management of the Difficult Airway. Pediatric Emergency Care, 39 (3): 192–200.
3. **Chang M, Berra L, Bittner E (2024):** Bedside Ultrasound: The Silent Guardian for Upper Airway Assessment and Management. https://www.clinicalkey.com.au/#!/content/journal/1-s2.0-S0887217123001038
4. **Dhir A, Bhasin D, Bhasin-Chhabra B *et al.* (2024):** Point-of-Care Ultrasound: A Vital Tool for Anesthesiologists in the Perioperative and Critical Care Settings. Cureus, 16 (8): e66908. https://doi.org/10.7759/cureus.66908
5. **Shetty S, Archana S (2023):** Anatomy and Physiology of the Airway Applied Aspects, Pp: 21–43. https://doi.org/10.1007/978-981-19-4747-6_2
6. **Wilton N, Hack H (2021):** Developmental anatomy of the airway. Anaesthesia & Intensive Care Medicine, 22 (11): 693–698.
7. **Mehran R (2018):** Fundamental and Practical Aspects of Airway Anatomy: From Glottis to Segmental Bronchus. Thoracic Surgery Clinics, 28 (2): 117–125.
8. **Ball M, Hossain M, Padalia D (2025):** Anatomy, Airway. In StatPearls. StatPearls Publishing. http://www.ncbi.nlm.nih.gov/books/NBK459258/
9. **Hagberg C. (2012):** Benumof and Hagberg's Airway Management: Third Edition. Elsevier Inc. https://doi.org/10.1016/B978-1-4377-2764-7.00057-9
10. **Kollmeier B, Boyette L, Beecham G *et al.* (2025):** Difficult Airway. In StatPearls. StatPearls Publishing. http://www.ncbi.nlm.nih.gov/books/NBK470224/
11. **Mouri M, Krishnan S, Hendrix J *et al.* (2025):** Airway Assessment. In StatPearls. StatPearls Publishing. http://www.ncbi.nlm.nih.gov/books/NBK470477/
12. **Apfelbaum J, Hagberg C, Connis R *et al.* (2022):** 2022 American Society of Anesthesiologists Practice Guidelines for Management of the Difficult Airway. Anesthesiology, 136 (1): 31–81.
13. **Roth D, Pace N, Lee A *et al.* (2018):** Airway physical examination tests for detection of difficult airway management in apparently normal adult patients. The Cochrane Database of Systematic Reviews, 5 (5): CD008874. https://doi.org/10.1002/14651858.
14. **Sotoodehnia M, Abbasi N, Bahri R *et al.* (2023):** Accuracy of airway ultrasound parameters to predict difficult airway using the LEMON criteria as a reference: A cross-sectional diagnostic accuracy study. Turkish Journal of Emergency Medicine, 23 (1): 38–43. https://doi.org/10.4103/2452-2473.366484
15. **Onal O, Onal M (2023):** Cormack-Lehane scoring system does not predict difficult intubation. Journal of Voice, 37 (4): e1. https://doi.org/10.1016/j.jvoice.2022.02.022
16. **Rumack C, Levine D (2023):** Diagnostic Ultrasound E-Book. Elsevier Health Sciences. https://shop.elsevier.com/books/diagnostic-ultrasound-2-volume-set/rumack/978-0-323-87795-4.
17. **Bhargava S (2020):** Principles and Practice of Ultrasonography. Jaypee Brothers Medical Publishers, Pp: 471. Doi.10.5005/jp/books/18452
18. **Patey S, Corcoran J (2020):** Physics of ultrasound. Anaesthesia & Intensive Care Medicine, 22: 58. https://doi.org/10.1016/j.mpaic.2020.11.012
19. **Sehmbi H (2015):** Basics of Ultrasound Imaging. In book: Regional Nerve Blocks in Anesthesia and Pain Therapy, Pp: 27-56. https://doi.org/10.1007/978-3-319-05131-4_3
20. **Zhang Z, Liu R, Li G *et al.* (2021):** A Dual-Mode 2D Matrix Array for Ultrasound Image-Guided Noninvasive Therapy. IEEE Transactions on Bio-Medical Engineering, 68 (12): 3482–3490.
21. **Bendjador H, Foiret J, Wodnicki R *et al.* (2022):** A theranostic 3D ultrasound imaging system for high resolution image-guided therapy. Theranostics, 12 (11): 4949–4964.
22. **Cerbu M, Cerbu C, Papuc I (2023):** M-Mode Echocardiography in Canine Veterinary Practice: A Comprehensive Review of Left Ventricular Measurements in 44 Different Dog Breeds. Animals, 13 (18): 2986. https://doi.org/10.3390/ani13182986
23. **Jain K, Yadav M, Gupta N *et al.* (2020):** Ultrasonographic assessment of airway. Journal of Anaesthesiology, Clinical Pharmacology, 36 (1): 5–12.
24. **Salama A, Baky H, Amin M *et al.* (2022):** Assessment And Visualizing Of Airway Using Ultrasonography: An Overview. Journal of Pharmaceutical Negative Results, 22: 3377–3387.
25. **Luo H, Ma L, Wu X *et al.* (2022):** Deep learning-based ultrasonic dynamic video detection and segmentation of thyroid gland and its surrounding cervical soft tissues. Medical Physics, 49 (1): 382–392.
26. **Osman A, Sum K (2016):** Role of upper airway ultrasound in airway management. Journal of Intensive Care, 4: 52. https://doi.org/10.1186/s40560-016-0174-z
27. **Gottlieb M, Holladay D, Burns K *et al.* (2020):** Ultrasound for airway management: An evidence-based review for the emergency clinician. The American Journal of Emergency Medicine, 38 (5): 1007–1013.
28. **Austin D, Chang M, Bittner E (2021):** Use of Handheld Point-of-Care Ultrasound in Emergency Airway Management. Chest, 159 (3): 1155–1165.
29. **Giordano G, Alessandri F, Zulian A *et al.* (2023):** Pre-operative ultrasound prediction of difficult airway management in adult patients: A systematic review of clinical evidence. European Journal of Anaesthesiology, 40 (5): 313–325.
30. **Zetlaoui P (2021):** Ultrasonography for airway management. Anaesthesia, Critical Care & Pain Medicine, 40 (2): 100821. https://doi.org/10.1016/j.accpm.2021.100821
31. **Ye R, Cai F, Guo C *et al.* (2021):** Assessing the accuracy of ultrasound measurements of tracheal diameter: An in vitro experimental study. BMC Anesthesiology, 21 (1): 177. https://doi.org/10.1186/s12871-021-01398-3
32. **Pineau P, Gautier J, Pineau A *et al.* (2021):** Intubation decision criteria in adult epiglottitis. European Annals of Otorhinolaryngology, Head and Neck Diseases, 138 (5): 329–332.
33. **Boñar-Álvarez P, Padin-Iruegas E, Chamorro-Petronacci C *et al.* (2021):** Assessment of saliva and oral candidiasis levels 12, 24 and 36 months after radiotherapy in patients with head and neck cancer. Journal of Stomatology, Oral and Maxillofacial Surgery, 122 (6): 566–572.
34. **Lazar A, Gherghinescu M (2022):** Airway Ultrasound for Anesthesia and in Intensive Care Patients-A Narrative Review of the Literature. Journal of Clinical Medicine, 11 (21): 6327. https://doi.org/10.3390/jcm11216327.