Original Article

Assessment And Visualizing Of Airway Using Ultrasonography: An Overview

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Abstract

Airway management is of paramount importance to an anesthesiologist. Airway management is a common procedure performed in the Emergency Department with significant potential for complications. Many of the traditional physical examination maneuvers have limitations in the assessment and management of difficult airways. Ultrasound is gaining increasing popularity among anesthesiologists as it is readily available and provides real-time imaging for various procedures. It is considered as a "visual stethoscope" of the anesthesiologist. Diagnostic ultrasound uses a device known as a transducer, which can both emit and detect ultrasound waves. Ultrasound transducers are available in different shapes and sizes. This is to adapt to different body areas. Frequencies of transducers also vary to suit all tissue depths. Transducers are made from a material known as a piezoelectric crystal, which vibrates millions of times per second when a short burst of electric current is applied to it. These crystals also have the property of detecting ultrasound by converting vibrations back into electrical energy. Ultrasound shows promise for enhancing provider knowledge preoperatively, by allowing for visualization of many airway structures.The aim of the present study was to review the assessment and visualizing of airway using ultrasonography.

Keywords: Airway Assessment; Ultrasonography; Airway Visualizition

INTRODUCTION

Preoperative airway assessment should be performed routinely to identify factors that lead to anticipate difficulty with face-mask ventilation, a supraglottic airway device insertion and tracheal intubation. Difficult airway can be divided into difficult Supraglottic Airway (SGA) placement, difficult mask or SGA ventilation, difficult laryngoscopy, difficult or failed endotracheal intubation **(1).**

A global assessment should include patency of nares, mouth opening, teeth, palate and patient's ability to protrude the lower jaw beyond the upper incisors (Prognathism) must be assessed. Temporo-mandibular joint movement can be restricted in ankylosis, fibrosis, tumors, and rheumatoid arthritis. Thyromental length should ideally be > 6 cm. A short, thick neck is often associated with difficult intubation. Any masses in neck, extension of neck, neck mobility and ability to assume 'sniffing' position should be observed. Any systemic or congenital disease requiring special attention during airway management must be recognized, (e.g., respiratory failure, significant coronary artery disease, acromegaly, etc.) and presence of infections of airway (e.g., epiglottitis, abscess, croup) were assessed **(2).**

I. Methods of airway assessment

Assessment of difficult airway in patients begins with a comprehensive history and physical examination.Medical, surgical or anesthetic factors may be indicative of a difficult airway (DA) **(Table 1) (3)**.

Table (1): Airway-compromising conditions (4).

Congenital : Pierre-Robin syndrome, Treacher-Collins syndrome, Goldenhar's syndrome, Down's syndrome, Kippel-Feil syndrome.
Acquired Infections: Croup, Abscess (intraoral, retropharygeal), Ludwig's angina.
Arthritis: Rheumatoid arthritis, Ankylosing spondylitis.
Benign tumors: Cystic hygroma, lipoma, adenoma, goiter.
Malignant tumor
Trauma: Edema of the airway, facial injury, hematoma, unstable fracture(s) of the cervical spine, maxillae, or mandible, and laryngeal/tracheal trauma.
Obesity: Short thick neck, redundant tissue in the oropharynx, obstructive sleep apnea.
Acromegaly: Macroglossia, prognathism.
Acute burns: Oedema of airway.

- **Modified Mallampatti Classification:**It correlates the tongue size to the pharyngeal size. Classification is assigned according to the extent the base of tongue is able to mask the visibility of pharyngeal structures into four classes **(2):**

Class I: Visualization of soft palate, fauces; uvula, anterior and the posterior pillars.
Class II: Visualization of soft palate, fauces and uvula.
Class III: Visualization of soft palate and base of uvula.
Class IV: Only hard palate is visible. Soft palate is not visible at all.

- **Atlanto-occipital joint (AO) extension:** It assesses feasibility to make sniffing position for intubation. the angle traversed by the occlusal surface of upper teeth is estimated**.**Normal angle of extension is 35° or more. Any reduction in extension is expressed in grades:Grade I: >35° ;Grade II: 22°-34°; Grade III: 12°-21° ; and Grade IV: < 12° **(2).**
- **Thyromental (T-M) distance (Patil's test):** It defined as the distance from the mentum to the thyroid notch while the patient's neck is fully extended.This measurement helps in determining how readily the laryngeal axis will fall in line with the pharyngeal axis when the atlanto-occipital joint is extended. Alignment of these two axes is difficult if the T-M distance is < 3 finger **(5).**
- **Inter-incisor distance:** Measured from the upper central incisors to the lower central incisors while the patient's mouth was fully opened. If it is less than 5 cm (approximately three finger breadths) with limited forward protrusion of the mandible, this is associated with increased risk of difficult laryngoscopy **(5).**

- **Scores for airway assessment**

1. **Wilson score system**: Combination of 5 variables: body weight, head and neck mobility, and jaw movements, mandibular recession (retrognathia) and presence or absence of buck teeth. A risk score was developed between 0 to 10**.** Scores ≥ 2 and ≤4 = a possibly difficult intubation; >4= often difficult intubation **(6)**.

Table (2): The Wilson score system (6).

Risk Factors	Score Points
Weight	
<90 kg	0
90 - 110 kg	1
>110 kg	2
Mobility of the head and neck (Angle formed between the positions of greatest extension and greatest flexion of the neck)	

>90° ~90° <90°	0 1 2
Jaw movement IO: maximum interincisal opening SLux: Jaw subluxation and maximum forward protrusion of the lower incisors beyond the upper incisors. IO > 5 cm or SLux > 0 IO < 5 cm or SLux = 0 IO < 5 cm or SLux < 0	0 1 2
Retrognathia Absent Moderate Severe	0 1 2
Buck teeth Absent Moderate Severe	0 1 2

2. **LEMON airway assessment method:** A score with a maximum of 10 points is calculated by assigning 1 point for each of the following LEMON criteria: **L:** Look externally (facial trauma, large incisors, beard or moustache, large tongue); **E:** Evaluate the 3-3-2 rule (inter-incisor distance-3 finger breadths, hyoid-mental distance-3 finger breadths, thyroid to floor of the mouth distance-2 finger breadths) ; **M:** Mallampati (Mallampati score ≥ 3); **O:** Obstruction (presence of any condition like epiglottitis, peritonsillar abscess, trauma) ; and **N:** Neck mobility (limited neck mobility) **(Figure 1) (4)**.

3. **Cormack –lehane scoring system:**

Difficulty in intubation can be classified according to the view obtained during direct laryngoscopy into 4 grades **(3):**

Grade I: visualization of the entire laryngeal aperture.
Grade II: Visualization of only the posterior commissure of laryngeal aperture.
Grade III: Visualization of only the epiglottis.
Grade IV: Visualization of just the soft palate.

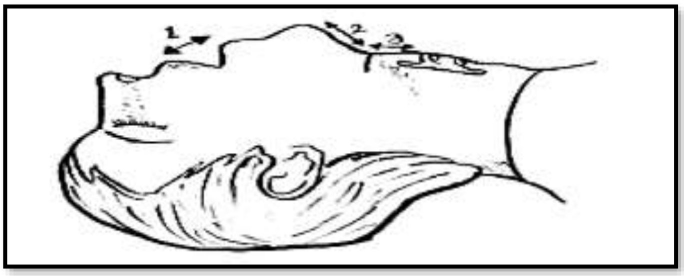

Figure (1): LEMON airway assessment method. (1) Inter-incisor distance in fingers, (2) Hyoid-mental distance in fingers, (3) Thyroid-to-floor of mouth in fingers **(4).**

- **Radiographic assessment:**

1- Plain X-Ray

Lateral cervical x-ray film of the patients with head in neutral position is required for mandibulo-hyoid distance and posterior depth of the mandible **(Figure 2) (7).** AADI is the space between the posterior surface of the anterior arch of C1 and the anterior surface of the dens **(Figure 3)**. In adults, it is generally accepted that the AADI is 3 mm or less **(8).** A-O Distance is the major factor which limits extension of the head on the neck. Although the majority of head extension occurs at the atlanto-occipital joint, some extension can also occur at C1-C2 **(3).**

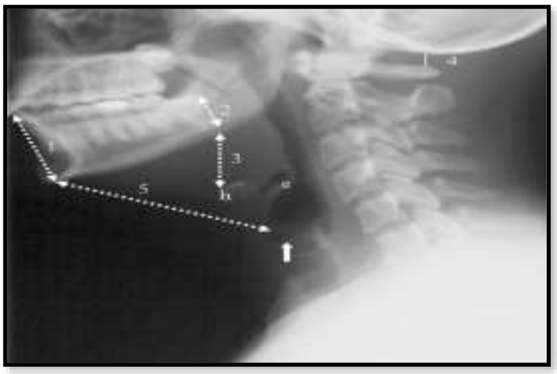

Figure (2): Mandibular and hyoid measurements proposed as predictors of difficult laryngoscopy: (1) Anterior depth of mandible; (2) Posterior depth of mandible; (3) Mandibulo-hyoid distance; (4) Atlantooccipital distance; and (5) Thyromental distance. Laryngeal ventricle (solid arrow) demarcates the level of the larynx. The true vocal cords are just below the level of the laryngeal ventricle. e Epiglottis. h,Hyoid bone **(9)**.

Figure (3): Lateral radiograph of the cervical spine in an adult patient shows AADI. The AADI or predental space (arrows) is normally less than 3 mm (**4)**

2-Soft Tissue Neck Radiography Films:

The lateral cervical spine study with bone and soft tissue technique allows an incidental view of the aerodigestive tract and a gross assessment of the overall patency of the airway. Useful ossified cartilage or bony landmarks of the pharynx and larynx that can be seen on the lateral neck radiograph are the hard palate, hyoid bone, thyroid and cricoid cartilages **(Figure 4) (3).**

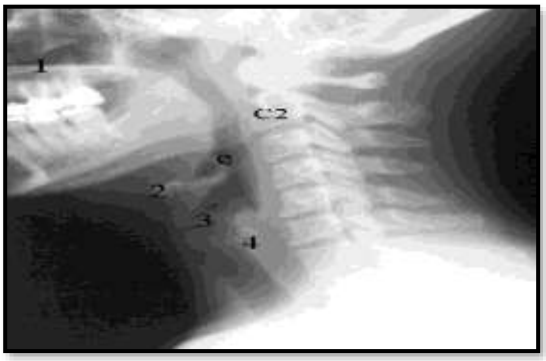

Figure (4): Normal bony landmarks on a lateral cervical spine radiograph: 1, Hard palate; 2, hyoid bone; 3, calcified thyroid cartilage; 4, calcified cricoid cartilage; e, epiglottis **(3).**

II- Diagnostic ultrasound waves:

Ultrasound passes through most biological tissues with a roughly constant speed (c) of 1540 meters per second. The distance between two consecutive peaks in an ultrasound wave is known as the wavelength. The wavelength (**λ**) is inversely proportionate to the frequency (f) as the speed of sound (c) in a given medium is a constant number according to the following equation: ($c = \lambda f$) **(10).** Attenuation in soft tissue is proportional to the frequency of the ultrasound beam and path length. High-frequency sound penetrates much less than low frequency sounds due to attenuation. This explains why superficial structures, such as the breast and thyroid, can be scanned at high frequencies but deep organs in the abdomen or pelvis must be scanned at lower frequencies **(11).**

- **Time-gain compensation:**

The attenuation of ultrasound as it passes through tissues means that echoes obtained from deep structures are much weaker than those obtained from more superficial tissues. To compensate for this effect, the amplitudes of returning echoes are therefore multiplied by a number that increases exponentially with time. This is known as ''time-gain compensation'' (TGC). The degree of compensation required (known as the ''gain'') depends on the attenuation coefficient of the tissue **(12).**

- **Interaction of sound and tissue:**

As sound travels through a medium, it essentially travels in a straight line. When the beam reaches an interface between two media with different acoustic impedances, it undergoes reflection, refraction or scattering. The amount of sound that is reflected depends on the degree of difference between the two media; the greater the acoustic mismatch, the greater the amount of sound reflected**.** The amount of ultrasound reflected or refracted depends on the angle at which the ultrasound beam hits the interface between the different media. As the angle of incidence approaches 90°, a higher percentage of the ultrasound is reflected **(13).**

- **Acoustic impedance of different materials:**

Tissues exhibit differing acoustic impedance values, and sound reflection occurs at the interfaces between different types of tissues. The impedance difference is greatest at interfaces of soft tissue with bone or air. Some tissues give a strong echo (e.g., fat, bone); these are called hyperechoic structures, and they appear white. Other tissues let the ultrasound beam pass easily (e.g., fluid collections, blood in vessels) and therefore create only a weak echo; these are hypoechoic structures and appear black on the screen **(14).**

The acoustic impedance is measured in Rayls and is the product of the density of the tissue and the velocity with which it propagates sound. Air and bone have different impedance compared to other tissues; therefore, at such interfaces the majority of sound waves are reflected **(15).**

- **Pulsed sound and imaging:**

An ultrasound machine produces a short pulse of high frequency sound and waits for part of that sound to be reflected back from tissues in the scan field. The pulse is typically 2 to 4 cycles long. The time that the pulse lasts is called pulse duration, it equals the period of the sound wave times the number of cycles in the pulse.The length that the pulse occupies in space is called the spatial pulse length, it is equal to l times the number of cycles in the pulse **(14).**

- **Resolution:**

Spatial resolution is defined as the ability of an imaging system to distinguish between two closely spaced objects. For ultrasound imaging, this is characterized in terms of two independent measures: the axial resolution and the lateral resolution **(16).**

1. **Axial resolution:** refers to the ability of a system to distinguish between two objects that are separated by a small distance along the axis of the beam. In an ideal system, the minimum resolving distance is equal to half the pulse length. Therefore, to achieve better axial resolution, it requires shorter

pulses, which in turn require smaller ultrasound wavelengths; therefore it requires higher frequency transducers **(12).**

2. **Lateral resolution:** is a measure of the ability to distinguish between two objects at the same depth. The narrowest region of the beam nearest the transducer where lateral resolution is good is termed the Fresnel zone, while the region further from the transducer where the beam broadens significantly is known as the Fraunhofer zone. To achieve good lateral resolution it is essential to have a long Fresnel zone, which in turn needs higher frequencies **(15).**

3. **Contrast resolution:** is the ability of an ultrasound system to display different shades of grey corresponding to subtle changes in tissue reflectivity. This is largely determined by the energy of each pulse emitted into the tissue and by the amount of electronic noise contaminating the signals **(16).**

4. **Temporal resolution:** is defined as the ability of a system to distinguish between the times of occurrence of two separate events. It depends on the frame rate **(14).**

- ## Choice of ultrasound frequency:

The amount of attenuation of ultrasound is directly proportional to its frequency. Low-frequency waves do not attenuate until arriving at a deeper level than those of high frequency ultrasound. This low frequency comes at a cost as there is a reduction in resolution. In contrast, high-frequency sound waves produce greater resolution **(12).** Ultrasound waves in the range of 2.5 to 7.5 MHz provide tissue penetration of 10 to 25 cm and resolve objects 1 mm or less in size. Waves of frequency more than 7.5 MHZ penetrate for a lesser extent and higher quality image **(16).**

- ## Methods of displaying located echo information:

A-mode: The earliest form of diagnostic ultrasound involved displaying echo strength as a function of depth along a single ‘‘line of sight’’ through the tissue. A single fixed transducer was employed, and the echo amplitudes were displayed on the screen of a cathode ray oscilloscope. This was known as ‘‘amplitude mode’’ or ‘‘A-mode’’ **(15).**

B-mode: To produce a two-dimensional (2D) ultrasound image it is necessary to acquire signals along multiple lines of sight through the tissue. For each line, the detected echoes are converted into bright spots on a screen, whose brightness depends on the echo amplitude and whose position depends on the echo arrival time and the direction of the beam **(14).**

Linear arrays use a row of up to 300 transducers, which are pulsed in small groups to emit a beam that travels perpendicular to the array. By selecting different groups, the beam is translated back and forth, sampling a rectangular slice across the tissue. The number of pulses generated per second (equal to the number of lines of sight sampled per second) is known as the pulse repetition frequency (PRF). The PRF limits the maximum depth from which echoes can be detected **(16).** The maximum number of frames displayed per second is always more than 20 frames per second. Higher values of frames provide better images of rapidly moving objects such as heart valves. However, increasing frames means increasing PRF or decreasing the number of sampled lines per frame, both of which mean reducing the size of the scanned area **(12).**

There are two basic 3D scanning mechanisms. One involves mechanical scanning of a linear or phased array to acquire consecutive 2D slice images (which are then combined into a 3D image), while the other utilizes a static 2D transducer array that produces a beam which is steered electronically in three dimensions **(14).**

Ultrasonography transducers

All modern ultrasound transducers used in airway management have a range of frequencies that can be adjusted during scanning to optimize the image. The linear high-frequency transducer is the most suitable for imaging superficial airway structures (within 2 to 3 cm from the skin). The curved low-frequency transducer is most suitable for obtaining sagittal and parasagittal views of structures in the submandibular and supraglottic regions, mainly because of its wider field of view. The micro convex transducer gives a wide view of the pleura between two ribs **(15)**.

Visualizing the Airway with Ultrasonography

A. Mouth and Tongue:

The floor of the mouth and the tongue are easily visualized by placing the transducer submentally. If the transducer is placed in the coronal plane just posterior to the mentum and from there moved posteriorly until the hyoid bone is reached, one can perform a thorough evaluation of all the layers of the floor of the mouth, the muscles of the tongue, and any possible pathologic processes **(17).**

A longitudinal scan of the floor of the mouth and the tongue **(Figure 5)** is obtained if the transducer is placed submentally in the sagittal plane. The acoustic shadows from the symphysis of the mandible and from the hyoid bone form the anterior and posterior limits of this image (**18).**

Transverse scans obtained in the midsection of the tongue (at the glossal end of the genioglossus muscle) provided a measure of the tongue width, which was measured between the most distant points on its upper surface.The midsagittal scans were also used to measure the cross-sectional area of the tongue.The tongue volume was derived from multiplication of the midsagittal cross-sectional area by the tongue width **(19).**

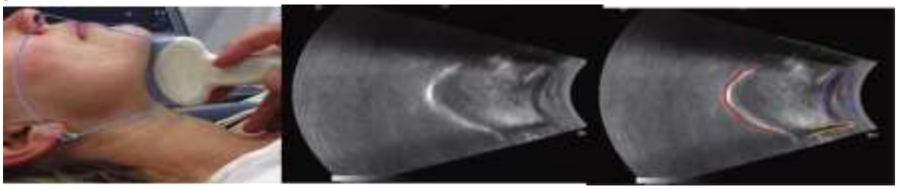

Figure (5): Longitudinal scan of the floor of the mouth and the tongue. **Left**, Placement of the curved low-frequency transducer. The area covered by the scan is outlined in light blue. **Middle**, The resulting ultrasound image. **Right**, The shadow from the mentum of the mandible is outlined in green, the muscles in the floor of the mouth in purple, the shadow from the hyoid bone in light orange, and the dorsal surface of the tongue in red **(20).**

B. Hyoid Bone

The hyoid bone is visible on the transverse view as a superficial, hyperechoic, inverted U shaped, linear structure with posterior acoustic shadowing. On the sagittal and parasagittal views, the hyoid bone is visible in cross section as a narrow, hyperechoic, curved structure that casts an acoustic shadow **(21).**

The anterior neck soft tissue thickness at the level of the hyoid bone (ANS-Hyoid) **(Figure 6)** is one of the methods of airway assessment by ultrasonography. If it is 1.69 cm [1.19 cm to 2.19 cm],this suspects difficult laryngoscopy.If it is 1.37cm [1.27 cm to 1.46 cm], this suspects easy laryngoscopy **(22).** The hyomental distance of the patient in neutral position of the neck and in fully extended neck calculating the ratio between both of them is one of methods of airway assessment by ultrasonography. If The mean hyomental distance ratios is (1.02± 0.01), this suspects difficult intubation. If it is (1.14±0.02),this suspects easy intubation **(20).**

Figure (6): shows the anterior neck soft tissue thickness at the level of the hyoid bone , (A)hyoid bone level,(B)yellow arrows denote hyoid bone, yellow dotted line denotes the distance from skin to hyoid bone **(17).**

C. Larynx

The different parts of the laryngeal skeleton have different sonographic characteristics. The hyoid bone is calcified early in life, and its bony shadow is an important landmark. The thyroid and cricoid cartilages show variable but progressive calcification throughout life, whereas the epiglottis stays hypoechoic. The true vocal cords overlie muscle that is hypoechoic, whereas the false cords contain echoic fat. The thyrohyoid membrane runs between the caudal border of the hyoid bone and the cephalad border of the thyroid cartilage and provides a sonographic window through which the epiglottis can be visualized in all subjects when the linear transducer is oriented in the transverse plane (with varying degrees of cephalad or caudad angulation) (**23).**

The midline sagittal scan through the upper larynx **(Figure 7)** from the hyoid bone cranially to the thyroid cartilage distally reveals the thyrohyoid ligament, the pre-epiglottic space containing echogenic fat, and, posterior to that, a white line representing the laryngeal surface of the epiglottis **(24).** The ratio of the depth of the pre-epiglottic space to the distance from the epiglottis to the mid-point of the distance between the vocal cords is one of the methods of airway assessment by Ultrasonography**.** If It is [0–1], this suspects Cormack-Lehane Grade 1.If it is [1–2],this suspects Cormack-Lehane Grade 2.If it is [2–3],this suspects Cormack-Lehane Grade 3 **(20).**

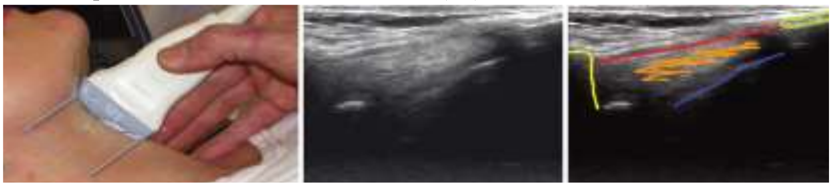

Figure (7): shows midline sagittal scan from the hyoid bone to the proximal part of the thyroid cartilage. Left, The light blue outline shows the area covered by the scan. Middle, The scanning image. Right, The shadow from the hyoid bone is marked in yellow, the thyrohyoid membrane in red, the posterior surface of part of the epiglottis in blue, the pre-epiglottic fat in orange, and the thyroid cartilage in green (**24).**

D. Vocal Cords

In individuals with noncalcified thyroid cartilages, the false and the true vocal cords can be visualized through the thyroid cartilage **(Figure 8)**. In individuals with calcified thyroid cartilage, the vocal cords and the arytenoid cartilages can still be seen by combining the scan obtained by placing the transducer just cranially to the superior extension (**23).**

The true vocal cords appear as two triangular, hypoechoic structures (the vocalis muscles) outlined medially by the hyperechoic vocal ligaments. They are observed to oscillate and move toward the midline during phonation. The false vocal cords lie parallel and cephalad to the true cords, are more hyperechoic in appearance, and remain relatively immobile during phonation **(24).** The anterior neck soft tissue thickness at the level of the vocal cords (ANS-VC) is one of the methods of airway assessment by ultrasonography. ANS-VC >0.23 cm had a sensitivity of 85.7% in predicting a Cormack-Lehan Grade 3 or 4 (**23).**

Figure (8): shows transverse midline scan over the thyroid cartilage in an 8-year-old boy. Left, Placement of the transducer. Middle, The scanning image. Right, The thyroid cartilage is marked in green, the vocal cords in orange, the anterior commissure in red, and the arytenoid cartilages in yellow (**Gupta et al., 2018).**

E. Cricothyroid Membrane and Cricoid Cartilage

The cricothyroid membrane runs between the caudal border of the thyroid cartilage and the cephalad border of the cricoid cartilage. It is clearly seen on sagittal and parasagittal views as a hyperechoic band linking the hypoechoic thyroid and cricoid cartilages **(Figure 9)**. The cricoid cartilage has a round, hypoechoic appearance on the parasagittal view and an arch-like appearance on the transverse view (**20).**

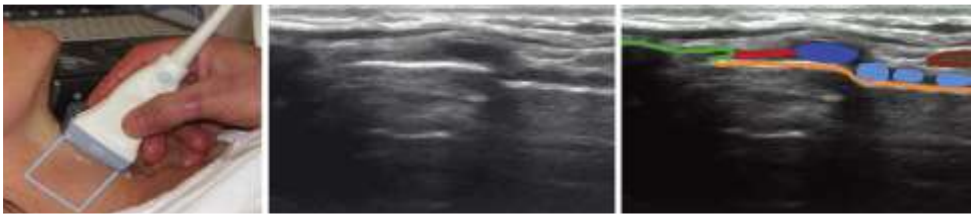

Figure (9): shows cricothyroid membrane.Left, The linear high-frequency transducer is placed in the midsagittal plane. The scanning area is marked with light blue. Middle, The scanning image. Right, The thyroid cartilage is marked in green, the cricoid cartilage in dark blue, the tracheal rings in light blue, the CTM in red, the tissue-air border in orange, and the isthmus of the thyroid **(24).**

F. Trachea

The location of the trachea in the midline of the neck makes it a useful reference point for transverse ultrasound imaging. The cricoid cartilage marks the superior limit of the trachea; it is thicker than the tracheal rings below and is seen as a hypoechoic, rounded structure. It serves as a reference point during performance of the sagittal midline scan **(Figure 10) (23).**

Figure (10): shows Trachea and esophagus. Left, A transverse scan is performed just cranial to the suprasternal notch and to the patient's left side of the trachea. Middle, The scanning image. Right, The anterior part of the tracheal cartilage is outlined in light blue, the esophagus in purple, and the carotid artery in red (**Gupta et al., 2018).**

G. Diaphragm

The diaphragm and its motion can be imaged by placing a convex transducer in the subxiphoid window in the middle upper abdominal region, just beneath the xiphoid process and the lower margin of the liver. The transducer is tilted 45 degrees cephalad, and bilateral diaphragm motion is noticed **(24).**

H. Lower Trachea and Bronchi

Transesophageal ultrasonography displays a part of the lower trachea. The bronchial wall and its layers can be visualized from within the airway by passing a flexible ultrasound probe through the working channel of a flexible bronchoscope (**23).**

I. Peripheral Lung and Pleura

The ribs are identifiable by their acoustic shadow, and between two ribs a hyperechoic line is visible. This line, called the pleural line, represents the interface between the soft tissue of the chest wall and air. In the normal breathing or ventilated subject, one can identify a kind of to-and-fro movement synchronous with ventilation; this is called "pleural sliding" or "lung sliding" **(20).**

Therefore, when teaching endotracheal intubation (ETT) to novice anesthesia residents using conventional direct laryngoscopy, ultrasonography can be used as a reliable method to confirm correct placement of ETT, when compared to capnography and chest auscultation it is the fastest method. Ultrasonography can also promptly detect esophageal intubations by the appearance of double trachea sign and the resident can be guided to redirect the ETT towards the trachea **(25)**.

CONCLUSION:

Ultrasonography is a safe, portable, relatively inexpensive, and easily accessible imaging modality that has been used for airway assessment and visualization.

Point-of-care ultrasound of the airway is an important noninvasive adjunct assessment tool in airway management that should be incorporated.

With conventional transcutaneous ultrasonography, the airway can be visualized from the tip of the chin to the midtrachea, along with the pleural aspect of the most peripheral alveoli and the diaphragm.

Ultrasonography may augment determination of proper endotracheal tube position in combination with other verification modalities such as radiography.

Ultrasound can help identify vocal cord dysfunction and pathology, assess airway size, predict the appropriate diameter of endotracheal and tracheostomy tubes, differentiate tracheal from esophageal intubation, localize the cricothyroid membrane for emergency airway access, and identify tracheal rings for US-guided tracheostomy.

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Author contribution: Authors contributed equally in the study.

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