Sonography Assessment of The Airway and Difficult Intubation and Ventilation

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Abstract

Background: 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. Difficult ventilation is defined as the inability of a trained anesthesiologist to maintain oxygen saturation >90% using a face mask, with a goal of oxygen fraction of 100 %. Difficult intubation is defined as the need for more than three attempts for intubation of the trachea or more than 10 min to achieve it, a situation that occurs in between 1.5 and 8% of general anesthesia procedures. Because inadequate airway management continues to be an important contributor to serious complication, ultrasound is an emerging tool that has many obvious advantages (safe, fast, repeatable, portable, widely available, and gives dynamic images in real time) that we can use for patient safety. Accurate interpretation of US images requires a basic understanding of the physical principles involved in US image generation. In addition, transducer selection, orientation and anatomy of airway relevant to US imaging is important to evaluate anatomy of the airway. US is the acoustic frequency above the threshold for human hearing (20 kHz). In medical practice, high-frequency pulses of sound waves are used (2.5–10 MHz). The probe that generates this wave contains material that produces piezoelectric effect. Lower the frequency, higher is the penetrance of tissues but lower is the potential image resolution. Depending on the shape and configuration of the probe, different shaped fields of view are generated. Two types of probes commonly used are linear and curved. Standard 7.5 MHz linear probe and 5 MHz curved array probe are commonly used for visualization of superficial and deeper structures of the airway, respectively. Reflection, refraction, scatter, absorption and transmission of sound occur as it passes through soft tissue structures, allowing characterization of the shape and internal architecture of that structure in addition to those behind it. Reflection of sound is marked at interfaces between tissues of different acoustic impedance. The image is built from the reflected sound signals.

Keywords: Sonography Assessment, Airway, Difficult Intubation

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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).**

Difficult ventilation is defined as the inability of a trained anesthesiologist to maintain oxygen saturation >90% using a face mask, with a goal of oxygen fraction of 100 % **(2)**.

Difficult intubation is defined as the need for more than three attempts for intubation of the trachea or more than 10 min to achieve it, a situation that occurs in between 1.5 and 8% of general anesthesia procedures **(3)**.

1. **Difficult facemask ventilation:**

It is not possible for the anesthesiologist to provide adequate face mask ventilation due to one or more of the following problems: inadequate mask seal, excessive gas leak, or excessive resistance to the ingress or egress of gas **(4)**.

Signs of inadequate face mask ventilation include (but are not limited to) absent or inadequate chest movement, absent or inadequate breath sounds, auscultatory signs of severe obstruction, cyanosis, gastric air entry or dilatation, decreasing or inadequate oxygen saturation (SpO2), absent or inadequate exhaled carbon dioxide,

absent or inadequate spirometric measures of exhaled gas flow and hemodynamic changes associated with hypoxemia or hypercarbia (e.g. hypertension, tachycardia and arrhythmia) **(5)**.

2. **Difficult laryngoscopy:**

It is not possible to visualize any portion of the vocal cords after multiple attempts at conventional laryngoscopy.

3. **Difficult tracheal intubation:**

Tracheal intubation requires multiple attempts, in the presence or absence of tracheal pathology.

4. **Failed intubation:**

Placement of the endotracheal tube fails after multiple intubation attempts **(2)**.

Conventional methods of airway assessment:

A complete airway assessment for every patient requiring airway management is mandatory in all guidelines, to predict the difficult airway, The proper prediction directs the proper preparation and planning to reduce the risk of difficult airway **(5)**.

Airway evaluation includes; history, previous airway records, physical examination, imaging studies, in addition to evaluation of patient cooperation, clinician skills and equipment **(6)**.

I. History:

Medical, surgical or anaesthetic factors may be indicative of a Difficult Airway.

II. General, regional and physical examination:

A global assessment should include the:

- **Patency of nares**: Masses inside nasal cavity (e.g., polyps) or deviated nasal septum should be looked for.
- **Mouth opening:** Mouth opening of a three finger breadths between upper and lower incisors in adults is desirable **(7)**.
- **Teeth:** Prominent upper incisors, or canines with or without overbite, can impose a limitation on alignment of oral or pharyngeal axes during laryngoscopy.
- **Palate**: A high arched palate or a long, narrow mouth may present difficulty.
- Patient‟s **ability to protrude the lower jaw** beyond the upper incisors (Prognathism) must be assessed.
- **Temporo-mandibular joint movement:** It can be restricted in ankylosis, fibrosis, tumors, and rheumatoid arthritis.
- **Measurement of submental space:** Thyromental length should ideally be > 6 cm **(8)**.
- **Observation of patient's neck:** 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.

- Presence of **hoarse voice/stridor** or previous tracheostomy may suggest stenosis.
- Any **systemic or congenital disease** requiring special attention during airway management must be recognized, (e.g., respiratory failure, significant coronary artery disease, acromegaly, etc.
- Presence of **infections** of airway (e.g., epiglottitis, abscess, croup).
- Presence of **some physiologic conditions** such as pregnancy.
- Prescence of **specific diseases** such as obesity **(9)**.

III- Specific tests for assessment:

A) Anatomical criteria:

1. Relative to tongue/pharyngeal size:

Modified Mallampati Classification:

The Modified Mallampati Classification 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 **(9)**:

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

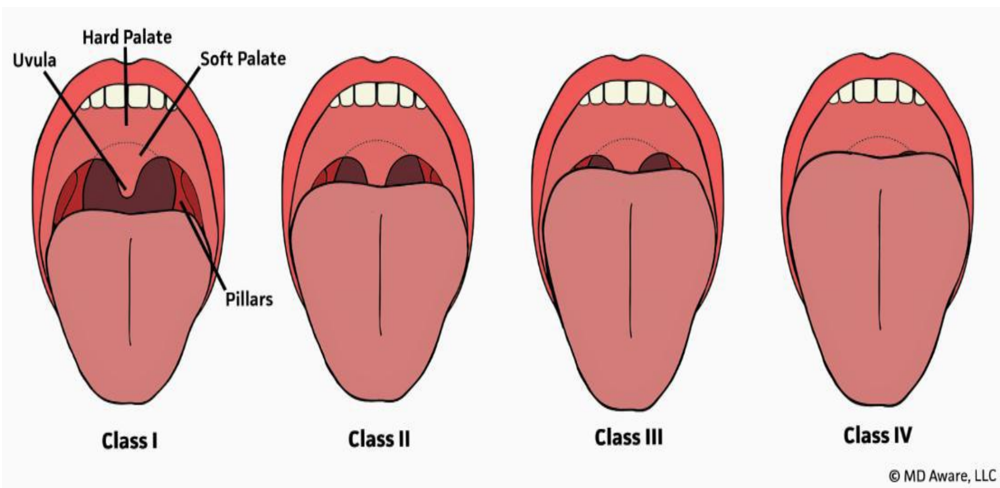

Figure (1): Modified Mallampati Classification **(10)**.

2. Atlanto-occipital joint (AO) extension:

It assesses feasibility to make sniffing or Magill position for intubation i.e. alignment of oral, pharyngeal and laryngeal axes into an arbitrary straight line. The patient is asked to hold head erect, facing directly to the front, then he is asked to extend the head maximally and the examiner estimates the angle traversed by the occlusal surface of upper teeth. Measurement can be by simple visual estimate or more accurately with a goniometer. Any reduction in extension is expressed in
grades **(11).**

- **Grade I**: >35°.
- **Grade II**: 22°-34°.
- **Grade III**: 12°-21°.

Normal angle of extension is 35° or more **(12).**

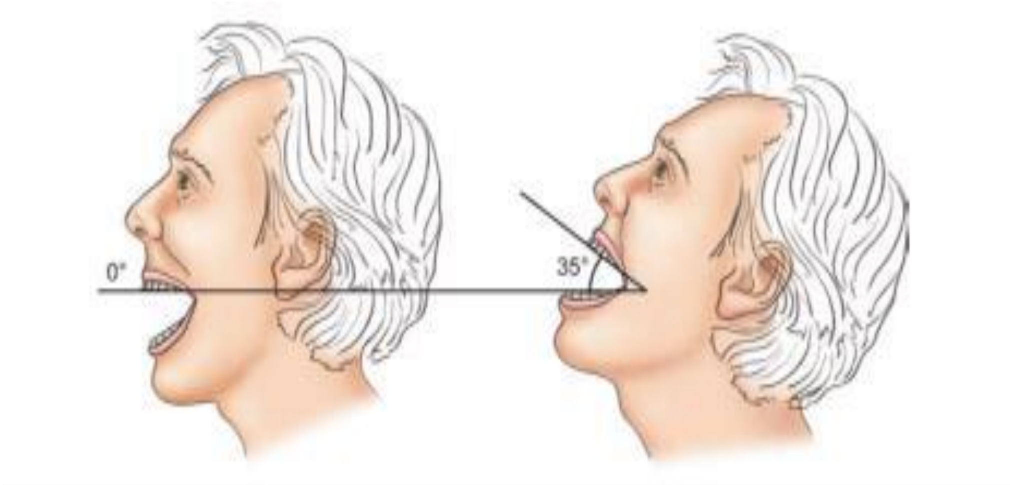

Figure (2): An assessment of atlanto-occipital extension can be made by estimating the angle traversed by the maxillary teeth when the neck is extended **(13)**.

3. Mandibular space:

Thyromental (T-M) distance (Patil’s test):

It is 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 **(14)**.

Inter-incisor distance:

Measured from the upper central incisors to the lower central incisors while 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 **(14).**

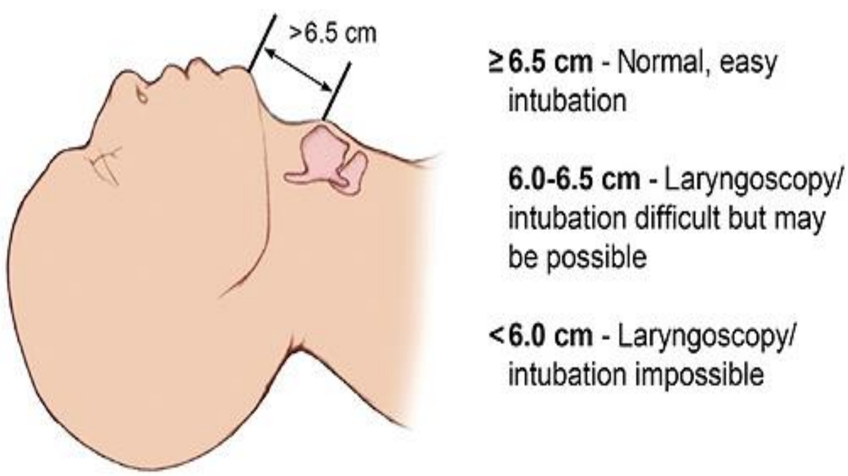

Figure (3): Thyromental distance **(11, 15)**.

B) Scores for airway assessment

1. 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).
N = Neck mobility (limited neck mobility)

Patients in the difficult intubation group have higher LEMON scores **(10)**.

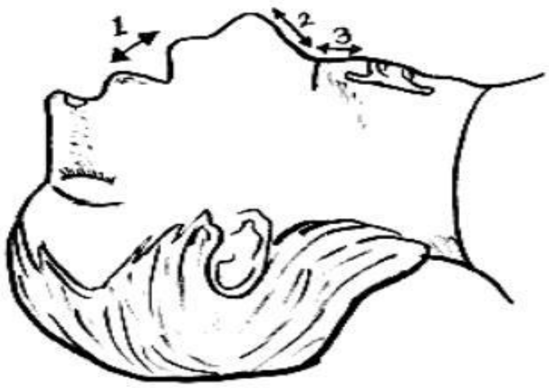

Figure (4): LEMON airway assessment method. 1 = Inter-incisor distance in fingers, 2 = Hyoid-mental distance in fingers, 3 = Thyroid-to-floor of mouth in fingers **(16).**

2. **Cormack –Lehane scoring system:**

Difficulty in intubation can be classified according to the view obtained during direct laryngoscopy into 4 grades. These 4 grades of laryngoscopic views were defined by Cormack and Lehane in 1984.

- **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.

- Grades III and IV predict difficult intubation **(17)**.

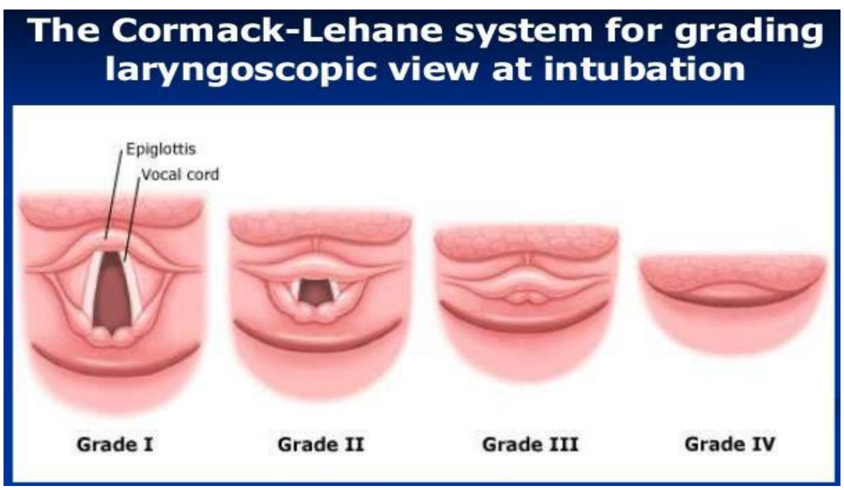

Figure (5): Grades of laryngoscopic views **(18)**.

3. El-Ganzouri score:

Table (1): Risk index of El-Ganzouri for difficult tracheal intubation **(10)**

Points	Finding	Variable
0 1	≥ 4 cm < 4 cm	Mouth opening
0	> 6.5 cm	Thyromental distance
1	6.0−6.5 cm	
2	< 6.0 cm	
0	I	Mallampati score
1	II	
2	III	
0	> 90°	Neck movement
1	80−90°	
2	< 80°	
0	Yes	Ability to prognathy
1	No	
0	< 90 kilograms	Body weight
1	90−110 kilograms	
2	>110 kilograms	
0 1 2	None Questionable Definite	History of difficult intubation

The minimum score is 0 and the maximum score is 12:

Tracheal Intubation	**Index Score**
unlikely to be difficult	< 4
likely to be difficult	≥ 4

Sonography of Airway

Because inadequate airway management continues to be an important contributor to serious complication, ultrasound is an emerging tool that has many obvious advantages (safe, fast, repeatable, portable, widely available, and gives dynamic images in real time) that we can use for patient safety **(19)**.

Accurate interpretation of US images requires a basic understanding of the physical principles involved in US image generation. In addition, transducer selection, orientation and anatomy of airway relevant to US imaging is important to evaluate anatomy of the airway. US is the acoustic frequency above the threshold for human hearing (20 kHz). In medical practice, high-frequency pulses of sound waves are used (2.5–10 MHz). The probe that generates this wave contains material that produces piezoelectric effect. Lower the frequency, higher is the penetrance of tissues but lower is the potential image resolution. Depending on the shape and configuration of the probe, different shaped fields of view are generated. Two types of probes commonly used are linear and curved. Standard 7.5 MHz linear probe and 5 MHz curved array probe are commonly used for visualization of superficial and deeper structures of the airway, respectively. Reflection, refraction, scatter, absorption and transmission of sound occur as it passes through soft tissue structures, allowing characterisation of the shape and internal architecture of that structure in addition to those behind it. Reflection of sound is marked at interfaces between tissues of different acoustic impedance. The image is built from the reflected sound signals **(20)**.

Position of the patient:

Patients should be placed in supine sniffing position with a pillow under the occiput to achieve optimum head extension and neck flexion.

Orientation of transducer in neck:

- Sagittal view (longitudinally in the midline).
- Parasagittal view (longitudinally lateral to the midline).
- Transverse view (transversely across the anterior surface of the neck).

Appearances of different medium of the airway:

Air is a poor US medium and does not allow visualization of deeper structures. Intraluminal air produces both comet tail and reverberation artefacts. Bony structures like mentum, rami of the mandible, hyoid bone, and sternum appear as bright hyperechoic linear structures with a hypoechoic acoustic shadow underneath. Cartilaginous structures (thyroid and cricoid cartilages) are homogeneous hypoechoic. Muscle and connective tissue have hypoechoic, heterogeneous striated appearance. Fat and glandular structures are homogeneous and mildly to strongly hyperechoic in comparison with adjacent soft tissues, depending on the fat content in the glandular parenchyma. Air–mucosa (A–M) interface has a bright hyperechoic linear appearance.

Sonoanatomy of the upper airway:

Oral and nasal cavities, pharynx, larynx, and trachea are nearly completely filled with air. However, various other structures can be visualized in relation to their anatomic location.

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 **(21).**

A longitudinal scan of the floor of the mouth and the tongue 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 **(22).**

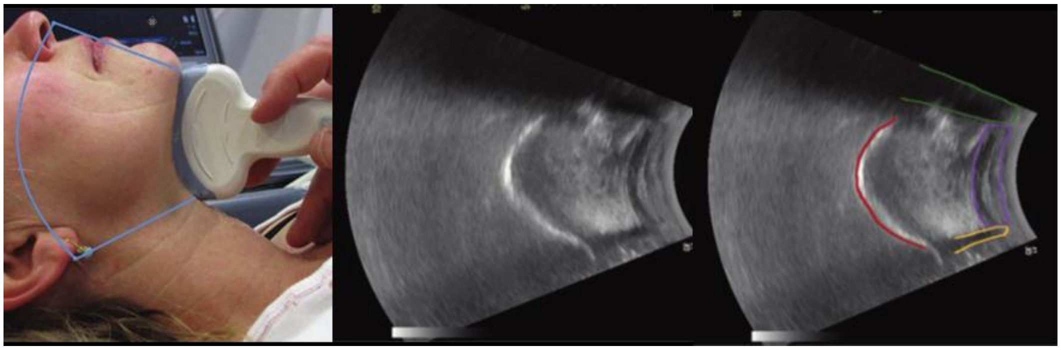

Figure (6): Longitudinal scan of the floor of the mouth and the tongue. **Left**, Placement of the curved low-frequency transducer. The area covered by the scan is outlined in light blue. **Middle**, The resulting ultrasound image. **Right**, The shadow from the mentum of the mandible is outlined in 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 **(23).**

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 **(24).**

Hyoid Bone:

Hyoid bone can be visualized by both transverse and sagittal views. On the transverse view. it is visulized as a superficial hyperechoic inverted U-shaped linear structure with posterior acoustic shadowing . On the sagittal, parasagittal and extended submandibular views, it has a narrow hyperechoic curved structure that casts an acoustic shadow **(25).**

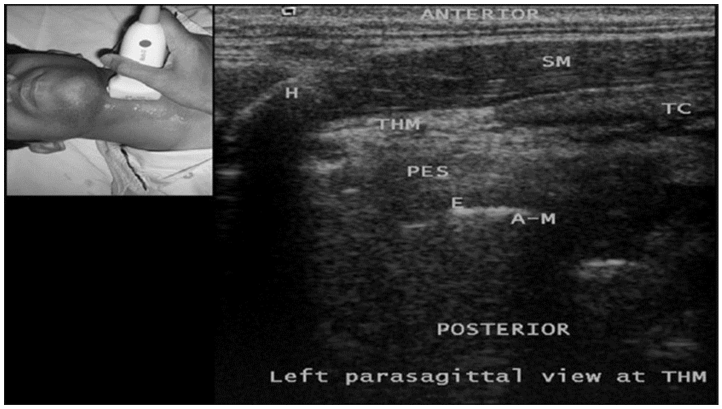

Figure (7): Left parasagittal view at thyrohyoid membrane (THM). H = Hyoid bone, SM = Strap muscles, THM = Thyrohyoid membrane, TC = Thyroid cartilage, PES = Pre-epiglottic space, E = Epiglottis, A–M = Air mucosal interface **(25).**

The anterior neck soft tissue thickness at the level of the hyoid bone (ANS-Hyoid) is one of the methods of airway assessment by ultrasound. If it is 1.69 cm (1.19 to 2.19 cm), this suspects difficult laryngeoscopy. If it is 1.37 cm (1.27 to 1.46 cm), this suspects easy laryngeoscopy **(26)**.

Figure (8): 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 **(27)**.

The hyomental distance of the patient in neutral position of the neck and in fully extened neck calculating the ratio between both of them is one of methods pf airway assessment by ultrasound. If the mean hyomental distance ratio is (1.02 ± 0.01), this suspects difficult intubation. If it is (1.14 ± 0.02), this suspects easy intubation **(23)**.

Epiglottis:

Epiglottis in the transverse and parasagittal views through the thyrohyoid membrane (THM) is visible as a hypoechoic curvilinear structure. Its anterior border is demarcated by the hyperechoic pre-epiglottic space (PES) and its posterior border by a bright linear A–M interface. Epiglottis can be easily identified in almost all individuals in the transverse plane with a varying cephalad or caudad angulation of the linear transducer. Extended submandibular sagittal view (between the hyoid bone and mentum) using a curved transducer can also identify epiglottis .Identification of the epiglottis can be facilitated by tongue protrusion and swallowing, when it becomes visible as a discrete mobile structure inferior to the base of the tongue **(28)**.

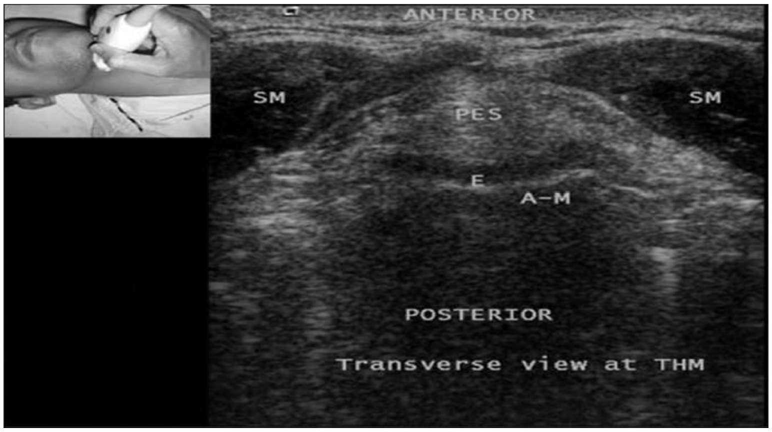

Figure (9): Transverse view at thyrohyoid membrane (THM). E = Epiglottis, A–M = Air–mucosal interface, PES = Pre-epiglottic space, SM = Strap muscles **(26).**

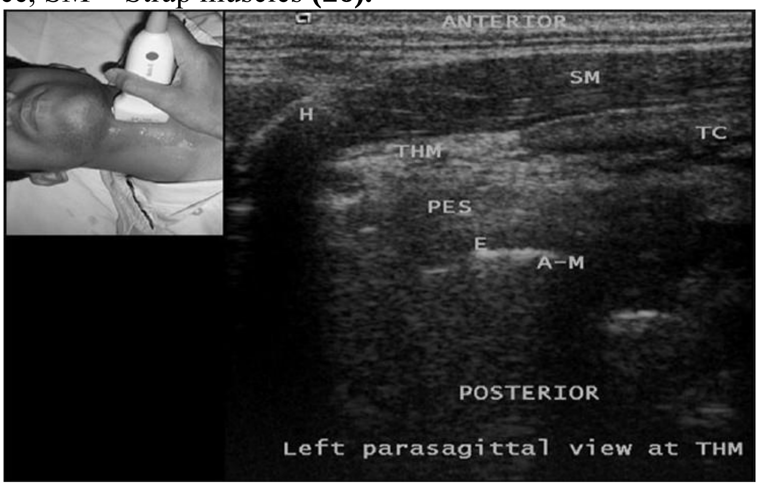

Figure (10): Left parasagittal view at thyrohyoid membrane (THM). H = Hyoid bone, SM = Strap muscles, THM = Thyrohyoid membrane, TC = Thyroid cartilage, PES = Pre-epiglottic space, E = Epiglottis, A–M = Air mucosal interface **(28).**

The ratio of the depth of the pre-epiglottic space (Pre-E) to the distance from the epiglottis to the mid-point of the distance between the vocal cords (E-VC) is one of the methods of airway assessment by Ultrasonography. **(23).**

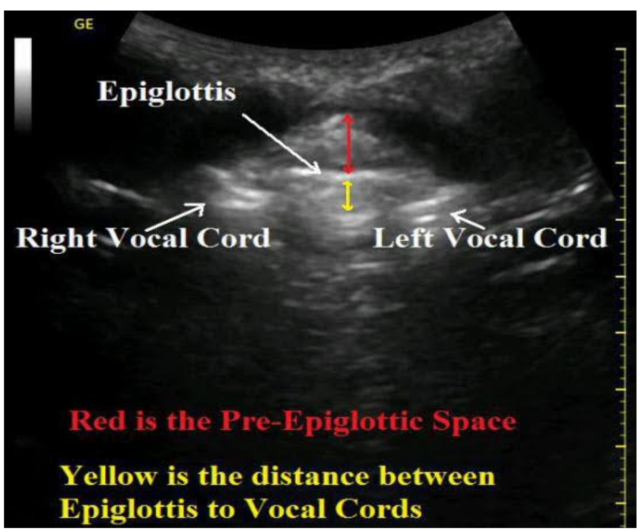

Figure (11) : shows the preepiglottic space . Red arrow – Depth of the pre-epiglottic space; Yellow arrow – Distance from the epiglottis to the mid-point of the distance between the vocal cords **(29).**

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.

Vocal cords:

In individuals with noncalcified thyroid cartilages, the false and the true vocal cords can be visualized through the thyroid cartilage. 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 **(29).**

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 **(29).**

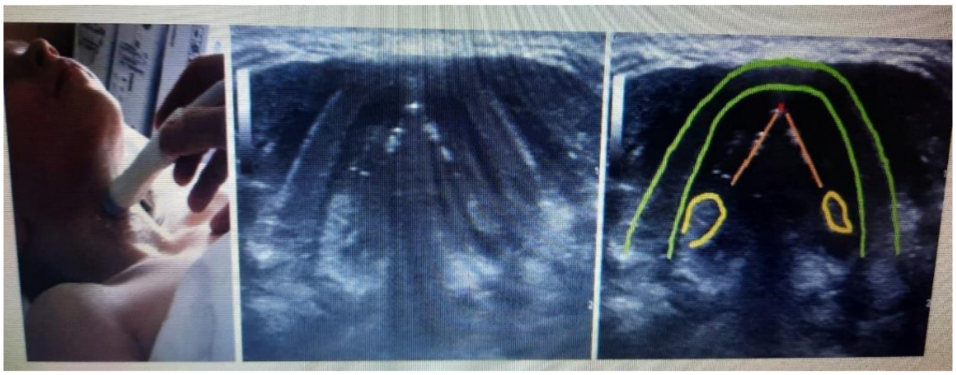

Figure (12): shows transverse midline scan over the thyroid cartilage in an 8-year-old boy. Left, Placement of the transducer. Middle, The scanning image. Right, The thyroid cartilage is marked in green, the vocal cords in orange, the anterior commissure in red, and the arytenoid cartilages in yellow **(29).**

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-Lehane Grade 3 or 4 **(30)**.

Cricoid cartilage and cricothyroid membrane:

The cricoid cartilage has an oval hypoechoic appearance in the parasagittal view and can be seen as a hump in the transverse view. The posterior surface of its anterior wall is delineated by a bright A–M interface as well as reverberation artefacts from intraluminal air. The cricothyroid membrane (CTM) is seen on sagittal and parasagittal views as a hyperechoic band linking the hypoechoic thyroid and cricoid cartilages **(29).**

The tracheal rings (T1, T2, T3) have a hyperechoic appearance. On the parasagittal and sagittal views, they resemble a "string of beads" and on the transverse view they form an inverted U highlighted by a linear hyperechoic A–M interface and reverberation artefact posteriorly **(31)**.

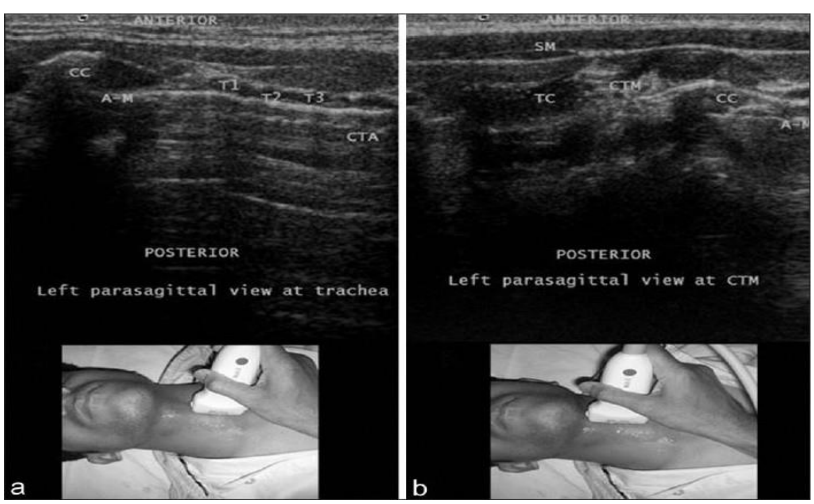

Figure (13): (a) Left parasagittal view at trachea. (b) Left parasagittal view at cricothyroid membrane. CC = Cricoid cartilage, T1–T3 = Tracheal cartilages, A–M = Air–mucosal interface, CTA = Comet tail artifact **(29).**

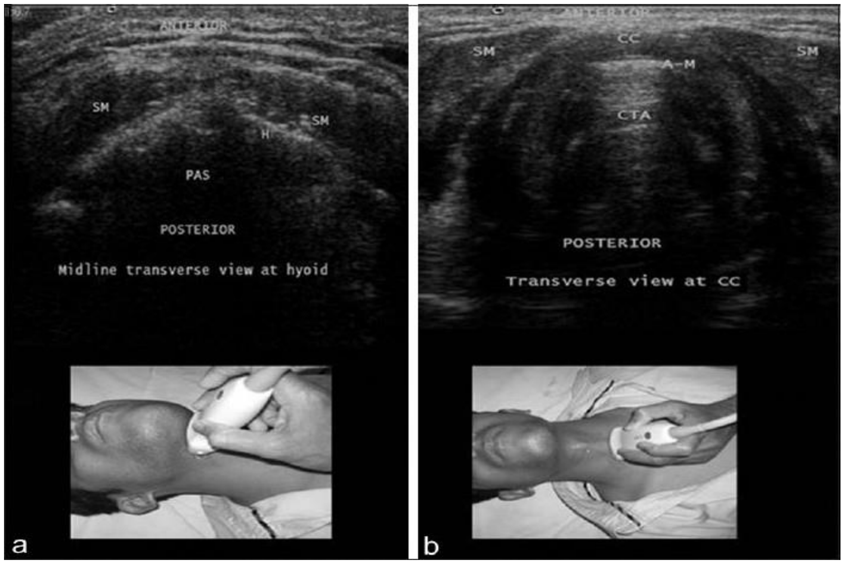

Figure (14): Transverse view at thyroid cartilage. AC = Arytenoid cartilage, TC = Thyroid cartilage, SM = Strap muscles, VL = Vocal ligaments, V = Vocalis muscle, FC = False cord **(29).**

Thyroid gland:

At the level of the suprasternal notch in the transverse view, the two lobes and isthmus of the thyroid gland can be visualized anterolateral to the trachea. The normal thyroid parenchyma has a characteristically homogeneous US appearance which is more echogenic (hyperechoic) than the adjacent strap muscle. In the oblique transverse view other relevant neck structures like oesophagus, vertebral bodies and internal carotid can be easily identified lying lateral to the thyroid gland.

Oesophagus:

Oesophagus is seen in the oblique transverse view at the level of the suprasternal notch posterolateral to the trachea. The identification of the oesophagus can be made easy by asking the patient to swallow, which results in visible peristaltic movement of the oesophageal lumen **(29).**

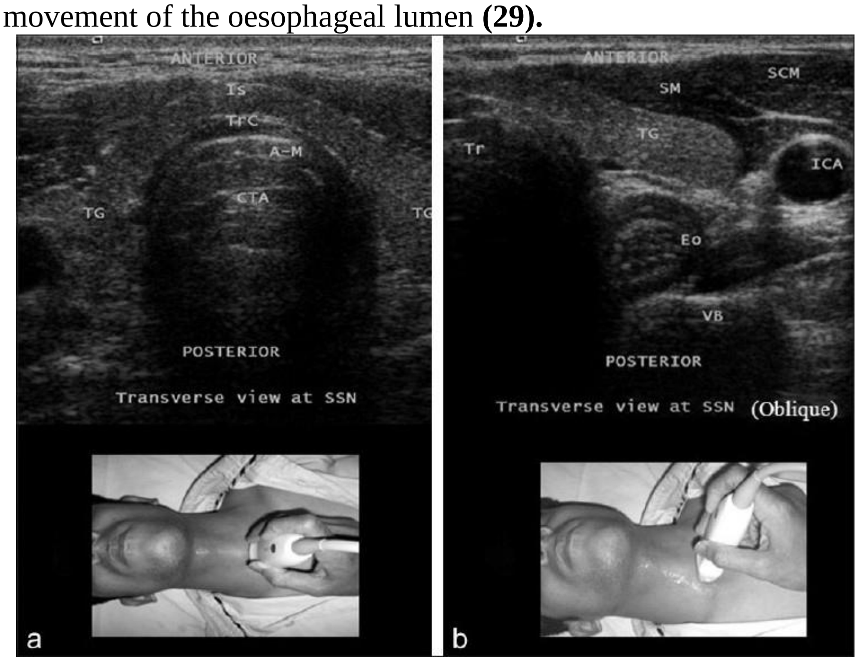

Figure (15): Transverse (a) and oblique transverse view (b) at the level of the suprasternal notch (SSN) showing trachea, thyroid gland, and oesophagus. TG = Thyroid gland, Tr = Trachea, Trc = Tracheal cartilage, A–M = Air–mucosal interface, CTA = Comet tail artefact, ICA = Internal carotid artery, Eo = Oesophagus, SCM = Sternocleidomastoid muscle, SM = Strap muscle, VB = Vertebral body **(29).**

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