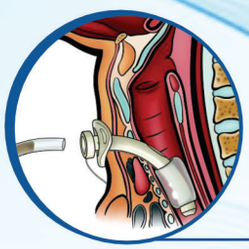

CHAPTER 3

Airway Ultrasound Relevant to Airway Procedures: Cricothyroidotomy and Tracheostomy

Bikash Ranjan Ray, Anil Kumar, Debyani Dey

Sonography for assessment and management of the upper airway has become a useful adjunct to existing clinical methods. Increased availability of ultrasound units in the intensive care unit, operating rooms and emergency department has made it more assessable. This has led to effective use of ultrasound in different aspects of airway management. By combining the knowledge of regional anatomy with the skills of ultrasound technology, one can gather a lot of information regarding different aspects of airway assessment in various scenarios, which helps the intensivist in proper decision making and further management. With advancement in technology and development of better probes with high-resolution imaging, ultrasound has emerged as a vital non-invasive tool for airway management in intensive care practice. In this chapter we emphasize on the application of airway ultrasound relevant to cricothyrotomy and percutaneous dilatational tracheostomy.

ULTRASOUND IMAGING OF AIRWAY

Position of the Patient

Upper airway scanning with ultrasound is performed in supine position with a pillow under the occiput to achieve optimum head extension and neck flexion mimicking the sniffing position for laryngoscopy and intubation.

Ultrasound Transducer

The transducer frequency used for airway ultrasound varies from 2 MHz to 10 MHz the curvilinear probe (2–5 MHz) is preferred for scanning of the submandibular region as it allows visualization of deeper structures and wider field of view. The linear probe (7.5–10 MHz) is useful for imaging of superficial structures from the skin. Normally, B mode imaging is used for airway imaging. Both M mode and Doppler has limited application in airway imaging, however, Doppler may be useful to detect blood vessels within the needle tract, during front of neck procedures. Sagittal, parasagittal and transverse views are used for scanning depending upon the structure of interest.

Airway Anatomy: What Does Ultrasound Reveal?

Air has been described as the enemy for ultrasonography as the ultrasound beams cannot penetrate air. Hence, whenever air is encountered in the path of ultrasound beams; all of it is reflected back, producing a strong echo, which appears as a bright white line. Thus, during airway scanning the air-mucosa (A-M) interface appears as a bright hyperechoic linear line (Fig. 3.1).

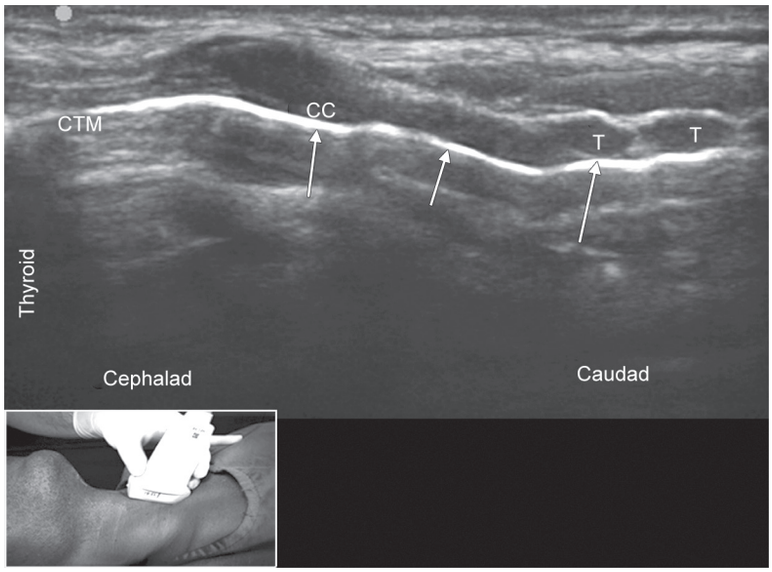

Fig. 3.1: Sagittal view of the upper airway. CTM, CC, T in a "string of pearls" appearance. Arrows indicate air mucosal interface-White line. Anything beyond this white line is considered as artifact. Hence, only the tissue from the skin to the anterior part of the airway can be visualized distinctly as the intraluminal air prevents visualization of structures beyond the A-M interface. (CTM: Cricothyroid membrane; CC: Cricoid cartilage; T: Tracheal rings)

Sonoanatomy, Image Acquisition and Interpretation of Upper Airway Ultrasound

Imaging of upper airway with ultrasound has been described using transcutaneous and sublingual approaches, however, the transcutaneous approach is preferred as it is easy and efficient (Table 3.1).

Sublingual Approach

The sublingual approach is mainly useful for preoperative airway assessment. It has a significant role in assessment of the possible difficult laryngoscopy and/or intubation in patients that would otherwise be identified by laryngoscopy.

Transcutaneous Approach

The transcutaneous approach involves a systematic scanning of the airway from the mentum to the suprasternal notch (Fig. 3.2), along the course of the floor of the mouth.

Airway assessment with ultrasound can be classified into: Scanning of the suprahyoid and infrahyoid regions.

Table 3.1: Structures visualized in ultrasound of airway

Tongue	*Epiglottis*	*Thyroid gland*
Muscles of floor of tongue	Vocal cords	Esophagus
Hypopharynx	Cricoid cartilage tracheal rings	Pleura
Hyoid bone	Cricothyroid membrane	Carotid and internal jugular vessels
Thyroid cartilage		

For suprahyoid measurements, the patient is placed in a supine sniffing position and the low frequency curved probe is gently placed in the suprahyoid region both in sagittal and transverse orientation to visualize the tongue, muscles of the floor of the mouth and hyoid bone.

For infrahyoid measurements, the high-frequency linear probe should be used (both in sagittal and transverse plane) to visualize the structures, which includes thyroid cartilage, the epiglottis, vocal cords, cricoid cartilage, cricothyroid membrane, strap muscles, thyroid gland, tracheal ring cartilages, and esophagus.

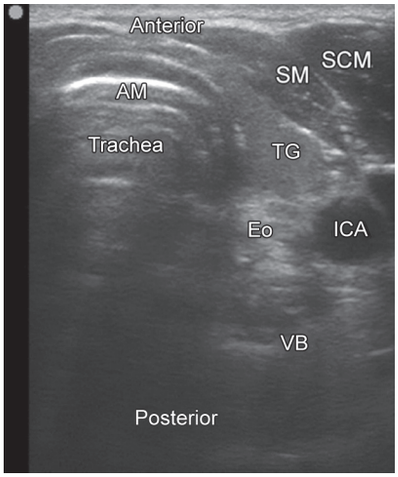

Fig. 3.2: Oblique transverse view at suprasternal notch. (AM: Air mucosal interface; SM: Strap muscles; SCM: Sternocleidomastoid; TG: Thyroid gland; ICA: Internal carotid artery; VB: Vertebral body; Eo: Esophagus)

CLINICAL APPLICATION

There are multiple clinical applications of airway ultrasound, some of them are summarised below.

Localization of Trachea and Cricothyroid Membrane

Ultrasound is helpful in locating trachea in challenging conditions like obesity, short thick neck, neck mass, previous surgery, radiotherapy, etc. It can be used as a prelocation technique for localization of trachea in emergency airway management and tracheostomy in awake person.

Identification of cricothyroid membrane is crucial in airway management. In all airway management guidelines, the final solution for failed intubation and ventilation, is always oxygenation through the cricothyroid membrane. It can be achieved either with a small-bore jet-insufflation catheter, or with the larger-bore needle technique, or as a surgical emergency cricothyroidotomy. Yet accuracy of cricothyroid membrane identification through conventional palpatory and surface landmark techniques is only 30%.

Ultrasonography allows reliable and rapid identification of the cricothyroid membrane. Both, transverse and sagittal views can be used for localization of the membrane. Mean time for cricothyroid membrane localization with ultrasound has been found to be 24.3 seconds.

Use of Upper Airway Ultrasound for Cricothyroidotomy

Cricothyroidotomy is a lifesaving procedure in the "cannot intubate cannot ventilate situation", but sometimes identification of cricothyroid membrane may be difficult by digital palpation guided by landmark techniques. Conventional palpation-based method for identification of cricothyroid membrane is prone to inaccuracies and frequently results in failures to perform the life-saving procedure.

To enhance the success rate of emergency cricothyroidotomy, it has been recommended to routinely identify the cricothyroid membrane in cases of suspected difficult intubation. In such situation, use of ultrasound (US) guidance offers significant advantages. It does not only precisely identify the location of the cricothyroid membrane but also provides information about the thickness of the tissue that has to be transversed to access the airway.

Two techniques have been described for the systematic and precise identification of the cricothyroid membrane:

1. The Longitudinal "String of Pearls" (SOP) Technique
2. The Transverse "Thyroid-Airline-Cricoid-Airline" (TACA) Technique

The SOP technique, which identifies the optimal space between the tracheal rings for tracheostomy, can also be used for identification of cricothyroid membrane.

TACA technique is applied in situations where patients have a very short neck or neck deformities that make it challenging to position the ultrasound transducer longitudinally. It involves positioning the transducer transversely to identify key landmarks, such as thyroid cartilage, cricoid cartilage, and confirms the location of cricothyroid membrane.

STRINGS OF PEARLS (SOP) TECHNIQUE

1. **Initial tracheal identification:** Begin by positioning the ultrasound transducer transversely on the patient's neck, just above the suprasternal notch. This positioning allows visualization of a horseshoe-shaped dark structure with a white posterior line, which represents the trachea (Fig. 3.3).

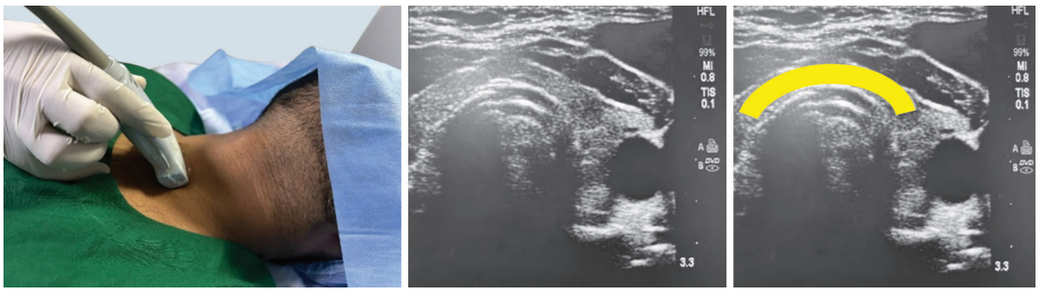

Fig. 3.3: Utrasound-guided localization in transverse view

2. **Transducer adjustment:** Slide the transducer slightly to the patient's right side (towards the operator), aligning the right edge of the transducer with the midline of the trachea. (Fig. 3.4).

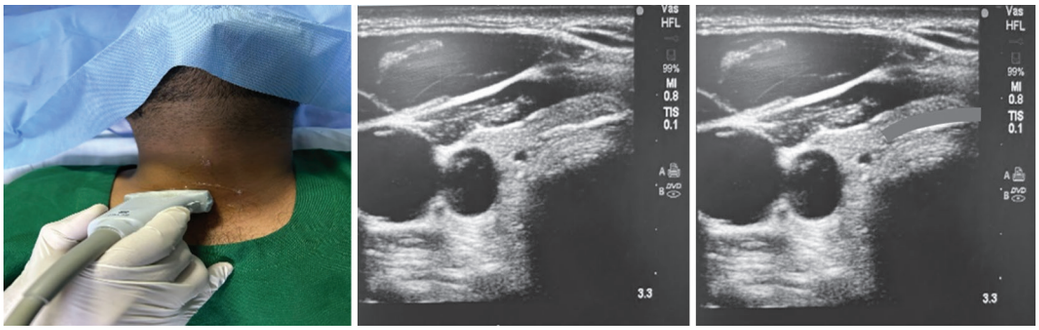

Fig. 3.4: Further movement of the probe for better visualization

3. **Transducer rotation:** Rotate the left end of the transducer by 90° while keeping the right end of the transducer over the midline of the trachea. This maneuver transitions the scan into a longitudinal view of the midline of the trachea. In this view, you will observe several dark (hypoechoic) rings located anterior to the white hyperechoic line, resembling a "string

of pearls." These hypoechoic "pearls" correspond to the anterior portion of the tracheal rings (Fig. 3.5).

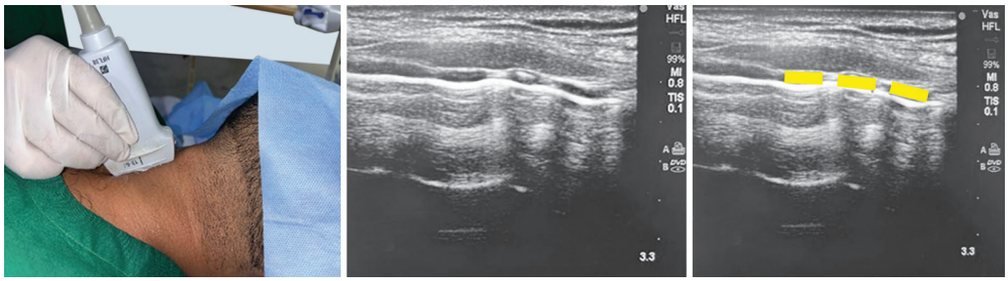

Fig. 3.5: Transducer rotation, string of pearls appearance

4. **Cephalad movement:** Maintaining the transducer longitudinally along the midline, move it cephalad (towards the head) until we visualize the cricoid cartilage (larger, elongated, and anteriorly positioned dark "pearl" in comparison to the other tracheal rings) and distal part of the thyroid cartilage (Fig. 3.6).

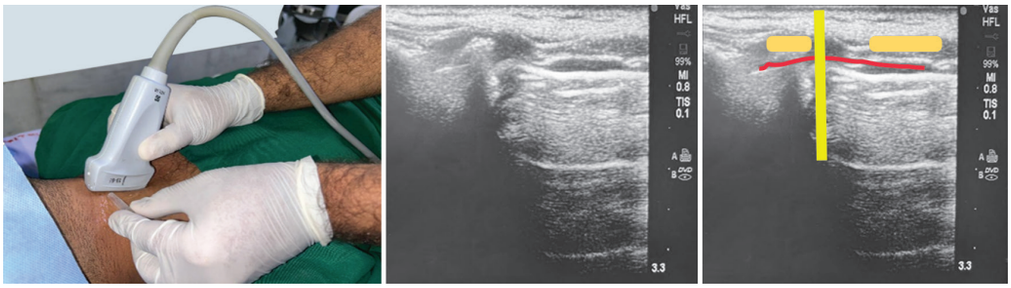

Fig. 3.6: Cricoid cartilage

At this point, a needle can be introduced as a marker, casting a shadow in the ultrasound image. Slide the needle between the transducer and the patient's skin until its shadow is visualized midway between the lower border of the thyroid cartilage and the upper border of the cricoid cartilage. This area is marked on the skin with marker and cricothyrotomy can be performed with the marker point being the point of puncture.

Transverse "Thyroid-Airline-Cricoid-Airline" (TACA) Technique

1. **Locating the thyroid cartilage:** Place the ultrasound transducer transversely at the level of the thyroid cartilage. The thyroid cartilage appears as a triangular and hyperechoic structure on the ultrasound image (Fig. 3.7).

Fig. 3.7: Thyroid cartilage

2. **Identification of the cricothyroid membrane:** Gradually move the transducer downward (caudally) until you identify the cricothyroid membrane, visualised as a hyperechoic white line, which results from the reflection of ultrasound waves at the air-tissue border of the mucosal lining within the cricothyroid membrane. Often seen with parallel white lines, known as reverberation artifacts, located below (Fig. 3.8).

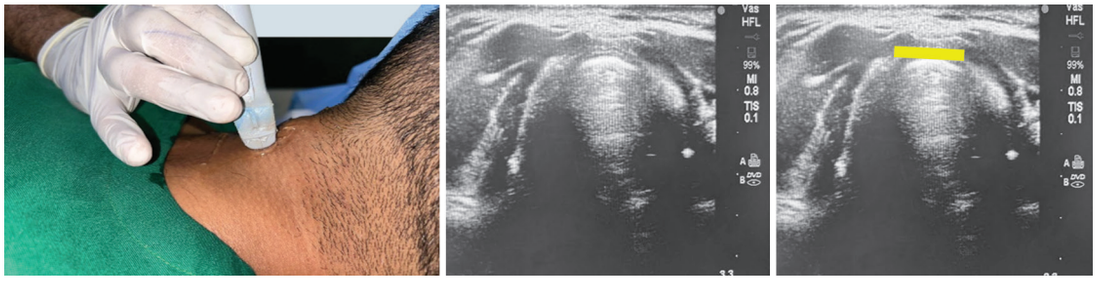

Fig. 3.8: Cricothyroid membrane

3. **Locating the cricoid cartilage:** Further move the transducer caudally to identify the cricoid cartilage. It is visualized as a "lying C" shape with a white lining, surrounded by a darker background (Fig. 3.9).

Fig. 3.9: Cricoid cartilage

4. At the end, slide the ultrasound transducer slightly upward (cephalad) until the precise center of the cricothyroid membrane is visualized (Fig. 3.10).
5. The centre of the cricothyroid membrane can be marked on the skin using a marker pen, see in both transverse and sagittal reference section.

Fig. 3.10: Cricothyroid membrane

In summary, the use of ultrasound guidance for locating the cricothyroid membrane addresses the limitations associated with less accurate identification through visual inspection or palpation. This technique is easily acquired and should be considered, if not as a routine practice, at least before undertaking the management of cases involving anticipated difficult airway scenarios. This approach significantly enhances the safety and accuracy of airway-related procedures.

Upper Airway Ultrasound for Percutaneous Dilatational Tracheostomy

Percutaneous dilatational tracheostomy (PDT) is a routinely used procedure in modern intensive care units. Bronchoscopic guidance is recommended for the procedure and is often used. Even though bronchoscopic guidance provides excellent visualization, it has certain disadvantages. It may hamper ventilation leading to hypercarbia and increased intracranial pressure, which may not be tolerated by patients with head and spine injuries. Also, bronchoscopy may itself induce pulmonary hyperventilation and pneumothorax.

Ultrasonography guidance is an alternative technique which overcomes the limitations of bronchoscopy and provides several advantages for PDT. It helps in real-time localization and visualization of the anterior tracheal wall, identification of tracheal rings and detection of blood vessels in the pretracheal tissue. It also allows the clinician to select proper site for the tracheostomy and helps in estimating appropriate size of tracheostomy tube. One of the studies found that preprocedural ultrasound assessment leads to change in PDT puncture site in about one in four patients. USG-guided PDT has been found to be successful in cases when bronchoscope-guided PDT has failed.

Many clinical studies have advocated the pre-procedural airway ultrasound as it improves safety during PDT by facilitating successful tracheal puncture and wire insertion, and avoiding posterior wall injury.

The traditional landmark versus ultrasound-guided evaluation trial (TARGET) study showed that real-time ultrasound guidance improves success rate of the first PDT attempt and puncture accuracy compared to traditional landmark technique. Similarly, the TRACHUS trial looked at the failure and complication rate of ultrasound-guided PDT in critically ill-patients and suggest it to be as effective as bronchoscopy-guided PDT. Also, when compared with conventional landmark methods, ultrasound-guided PDT has higher success rates and shorter time to successful cannulation.

PERCUTANEOUS DILATATIONAL TRACHEOSTOMY

In the case of real-time ultrasound-guided percutaneous dilatational tracheostomy (PDT), all steps, starting from initial screening, puncturing the site, to confirming the guidewire, are done under ultrasound guidance.

Procedure Steps

1. Initiate a routine pre-emptive neck ultrasound examination to assess neck anatomy, including blood vessels. This examination also helps determine whether percutaneous dilatational or surgical tracheostomy is safer for the patient.
2. Identify the position of the tracheal rings in both transverse and longitudinal views.
3. Techniques for ideal inter-tracheal space identification:
   a. *Longitudinal "String of Pearls" Approach:*
      - Position the transducer longitudinally just above the suprasternal notch in the midline (Fig. 3.11a).

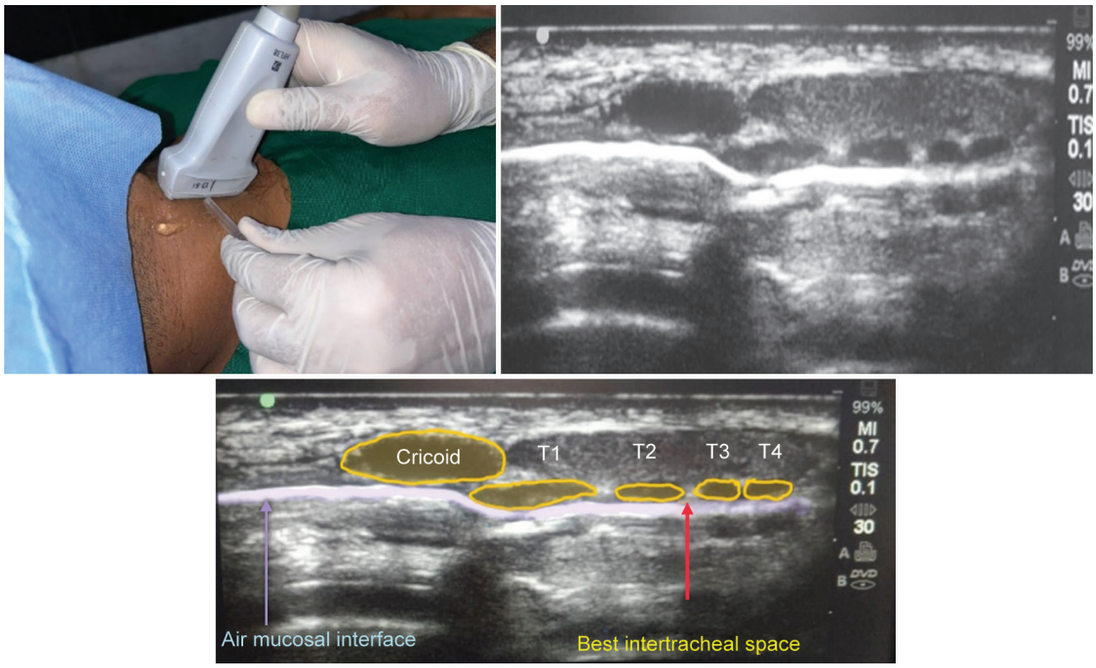

Fig. 3.11a: Longitudinal view

- Slide cephalad until the cricoid cartilage (appearing as a larger, more elongated, and anteriorly placed dark "pearl" compared to the other tracheal rings) and thyroid cartilage are visible.
- Identify the best inter-tracheal space and mark with a pen.

b. *Transverse approach:* Figure 3.11b

- Place the transducer just cephalad to the suprasternal notch to identify the tracheal cartilage (yellow) and thyroid gland (orange) (Fig. 3.12).
- Rule out any midline abnormal structures (blood vessels/swelling, etc.)
- After identifying the safest tracheal interspace in conjunction with the longitudinal view, mark the area with a pen.

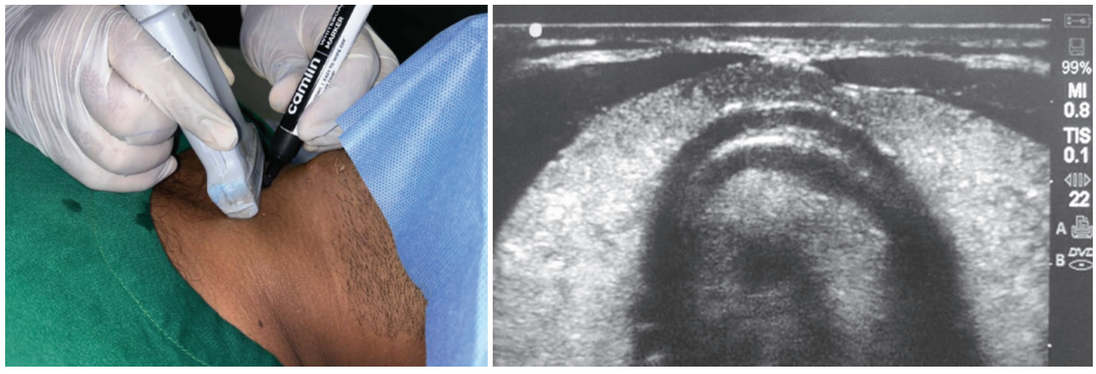

Fig. 3.11b: Transverse view approach

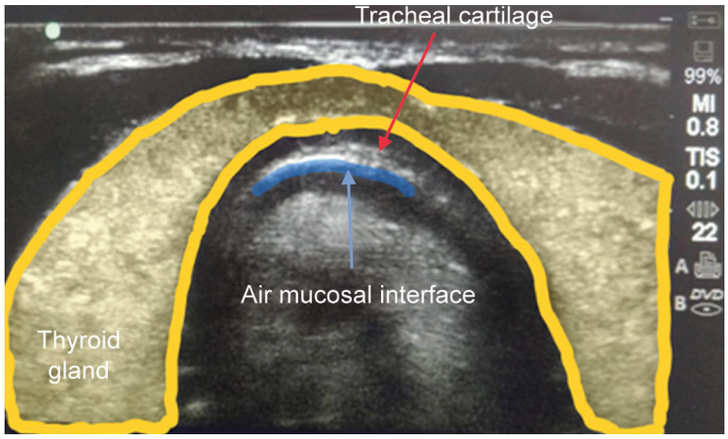

Fig. 3.12: Transverse view. Tracheal cartilage, thyroid gland and air mucosal interface

4. After identifying the safest tracheal interspace, proceed to puncture the trachea with a needle in real-time using the transverse view (Fig. 3.13).
5. Once the guidewire is passed, confirm its placement using the longitudinal view.

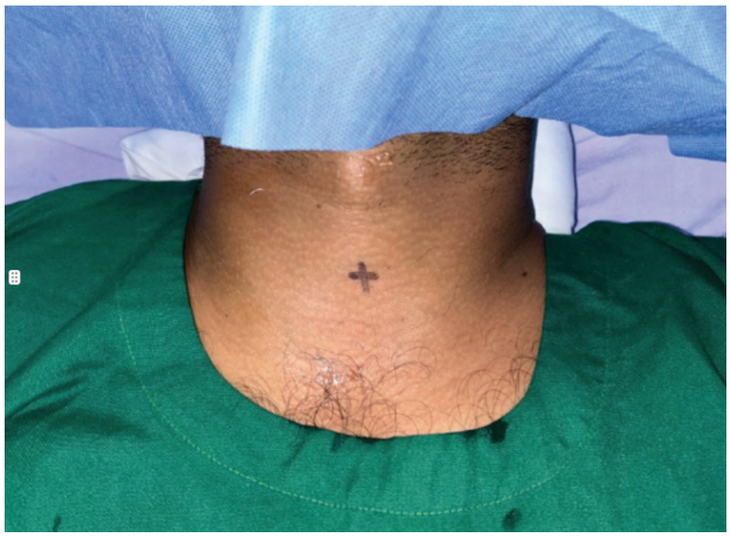

Fig. 3.13: Point-of-puncture for PCT

CONCLUSION

Airway management is a fundamental aspect of critical care, and the adoption of upper airway ultrasound (US) has represented a significant advancement in this field. This is attributed to the identification of airway structures and the ability to perform procedures in real-time contribute to reducing complication rates in both planned and emergency airway interventions. With further researches and growing evidences, these airway ultrasound techniques are highly likely to become routine practice in future of airway management. So the optimal benefit of airway ultrasound can be achieved by using it dynamically in direct conjunction with clinical methods for airway assessment and procedures.

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