SECTION 19

ULTRASONOGRAPHY

CHAPTER
84

Prem Kumar

ROLE OF ULTRASOUND IN CRITICAL CARE

INTRODUCTION

Ultrasound is a recently introduced technology in the field of anesthesiology, critical care and emergency room. The growing concern for procedures to be performed in real time, reducing complications, aiding diagnosis and interventions has made ultrasound to be one of the best modality in critical care. Ultrasound has become the gold standard for bedside diagnosis, hemodynamic assessment and for guidance in performing interventions in real time in critically ill patients (Fig. 84.1).

Fig. 84.1 Portable ultrasound machine

PHYSICS OF ULTRASOUND

Ultrasound is high frequency sound waves with frequency >20 KHz (human ears can hear sound frequencies between 20 Hz and 20 KHz). Medical ultrasound has a frequency of 2.5 MHz–15 MHz. It allows noninvasive imaging of tissues in real time based on reflection and scattering. This is based on a phenomenon called piezoelectric effect where there is mechanical deformation in response to an electric field applied to lead zirconate titanate. The term piezoelectric means pressure electric effect. By incorporating piezoelectric elements into transducer, it converts electric energy into mechanical oscillations thereby acting both as transmitter and receiver.

Terminologies to be understood in ultrasound physics:

- Acoustic velocity
- Acoustic impedance
- Axial and lateral resolution
- Attenuation coefficient.

Acoustic velocity is the speed at which sound wave travels through a medium which is equal to frequency times the wavelength. Acoustic impedance is the degree of impedance a sound wave undergoes while it travels through a medium. There are two types of spatial resolution—axial and lateral. The minimal distance of the superior and inferior planes along the axis of the beam is axial resolution. The ultrasound wave undergoes various characteristics as it travels through the tissues—reflection, scattering and absorption.

There are 2 properties in ultrasound which determines the selection of probe—wavelength and frequency. Wavelength is the distance between two areas of maximal rarefaction and penetration of the ultrasound wave is proportional to wavelength. Frequency is the number of wavelengths that pass per unit time. It is measured as cycles per second and the unit is hertz (Hz). Higher the frequency, better the resolution but the lower the penetration and vice versa in case of lower frequency.

Imaging Modes

A-mode

The transducer emits ultrasound wave into medium and a single dimensional image is generated as a series of vertical peaks which corresponds to the depth of the tissues. This mode does not provide information about the spatial relationship of the structures, hence it is a basic mode for imaging the structures.

B-mode

This mode produces a 2 dimensional image due to a linear array of many piezoelectric crystals in the transducer. This mode produces dots of different brightness based on the amplitude of a series of A scans. Intensity of gray scale indicates the strength of echogenicity and the side to side and upward downward distance in the display reflects the real distances in the tissue. Since this mode provides cross-sectional image, this mode is commonly used in regional anesthesia and critical care.

M-mode

This mode produces a single beam with a motion signal where structural movement like heart valve can be visualized in a waveform manner. This mode is used for cardiac valve imaging and fetal cardiac imaging.

Doppler

This is superimposed on a B mode image in which the color depends on whether blood flow direction is towards the transducer or away from it. Red and blue color indicates the direction and velocity of blood flow where red color indicates the flow away from the probe and blue color indicates the flow towards the probe.

Selection of Ultrasound Transducer

Frequency is the main element of transducers and they are also described by their array (e.g. linear) configuration. Based on frequency, transducers are classified into high, mid and low frequency transducers (Table 84.1 and Fig. 84.2).

Table 84.1 Transducers and its indications

High frequency (>10 MHz)	Suited to visualize structures within 3 cm from the skin surface. Good to visualize superficial structures (e.g. internal jugular vein, nerve blocks)
Mid frequency (5–10 MHz)	Suited for structures within 3–6 cm from skin surface. Used for nerve blocks, deeper vascular structures
Low frequency (<5 MHz)	Used for visualizing deeper structures (e.g. IVC collapsibility)

Fig. 84.2 Transducers—linear array and curvilinear

ULTRASOUND IMAGE CHARACTERISTICS

Any image obtained on the screen can be controlled by depth and gain. The intensity of the returned ultrasound waves is depicted by the brightness on the screen (echogenicity). Strong reflection of a structure back to the transducer is portrayed as white color on screen (hyperechoic or echogenic). Less reflection of the structure which shows dark image on the screen is depicted as hypoechoic. Bone, pleura are seen as hyperechoic and nerves, fluids, muscle tissues are seen as hypoechoic (Table 84.2).

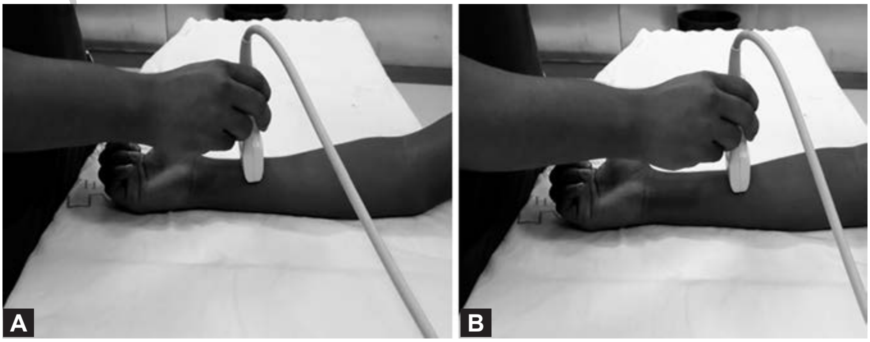
Transducer Movements (Figs 84.3 to 84.7)

- Sliding
- Tilting
- Rotating
- Angling
- Compression.

Before starting to scan, the orientation of the transducer is confirmed in relation to the image on the screen. The U symbol in the top left screen corner represents the palpable prominence on one side of the transducer. Transducer position on the screen is confirmed by placing the finger on one side of the transducer to note a change in the image of the screen. It is better to always orient

Table 84.2 Ultrasound appearance of various structures

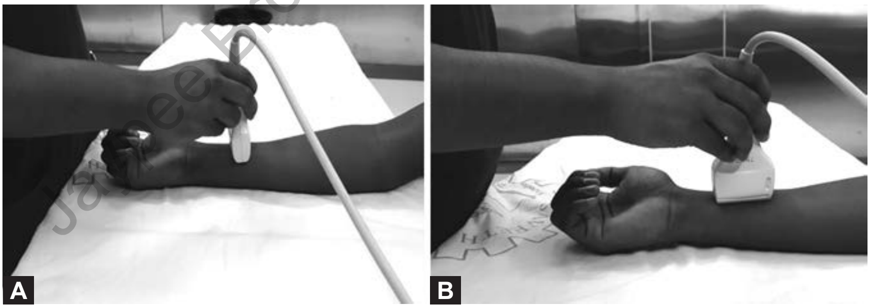
Structure	*Appearance*
Artery	Hypoechoic, pulsatile, noncompressible. Doppler shows pulsatile flow
Vein	Hypoechoic, nonpulsatile, compressible. Valsalva effect, Doppler shows continuous flow
Bone	Hyperechoic
Tendon	Hyperechoic with anisotropy—bright lines longitudinally or bright dots at right angles fibrillary pattern
Nerves	Variable hypo- or hyperechoic with anisotropy fascicular pattern
Muscle	Hypoechoic with multiple hyperechoic lines



Figs 84.3A and B Sliding

Figs 84.4A to C Angling

Fig. 84.5 Compression

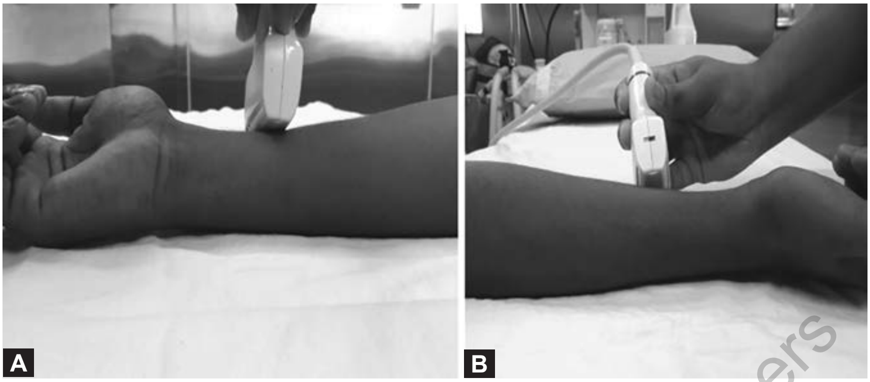


Figs 84.6A and B Rotation

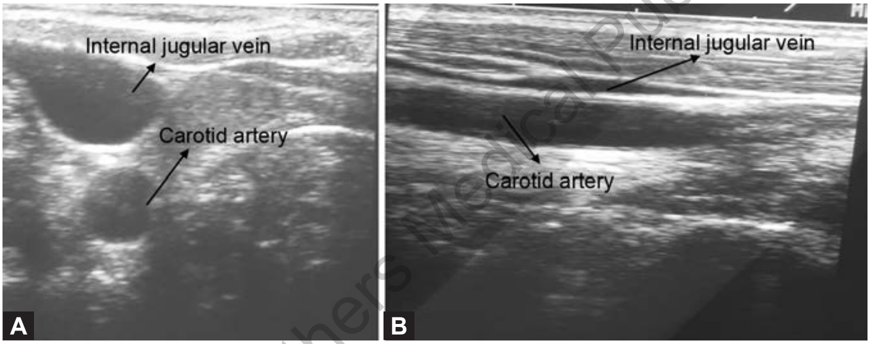
ourselves that the left and right side of the screen image corresponds to the left and right side of the structure of interest in the patient.

Imaging (Figs 84.8A and B)

Short-axis view: Imaging is a cross-sectional view of the structure with the transducer kept at right angle to the direction of the structure of interest.



Figs 84.7A and B Tilting



Figs 84.8A and B Ultrasound image of internal jugular vein—short axis view and long axis view

Long-axis view: Probe and target structure are aligned in a way or kept parallel so that the image of the structure is in longitudinal axis.

NEEDLE ORIENTATION

When needles are introduced into the field, they are depicted as being in plane or out of plane based on whether the needle is in or out of the plane of the ultrasound beam (Figs 84.9 and 84.10).

In plane imaging—needle is introduced to the target structure in the same plane of the ultrasound beam, hence the needle can be seen in its entire length. So the needle tip can be seen and positioned precisely in the area of interest.

Out of plane imaging—needle is introduced to the target structure perpendicular to the ultrasound beam, hence the needle can be seen as a bright spot on the screen. Disadvantage is this method does not indicate the needle tip position.

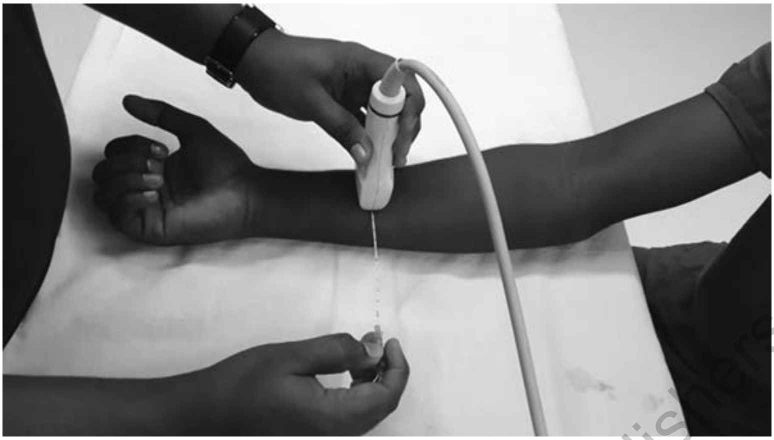


Fig. 84.9 Needle orientation—in plane

Fig. 84.10 Needle orientation—out of plane

Clinical Uses of Ultrasound in ICU (Table 84.3)

- Diagnosis and assessment—thoracic, cerebral, abdominal, vascular, ocular structures. RUSH protocol is done for diagnosing the cause of shock (Tables 84.4 and 84.5, Fig. 84.11). e-FAST (Focused Assessment with Sonography for Trauma) protocol is done for patients coming to emergency room with trauma (Figs 84.12A to F). Aortic view can be seen in Figures 84.13A to D.
- Echocardiography—diagnosis and assessment of volumes
- Procedural—central venous catheterization, regional nerve blocks, etc.

PULMONARY EMBOLISM

The echocardiographic findings suggestive of pulmonary embolism are RV dilation, impairment of the RV free wall contraction, paradoxical septal wall motion, or dilation of the right pulmonary artery, in a patient with hemodynamic instability/collapse.

Table 84.3 Uses of ultrasound in critical care

Site	*Findings*	*Diagnosis*
Abdomen	Free fluid Abdominal aorta >3 cm	Intraperitoneal fluid/blood Abdominal aortic aneurysm
Thorax	Lung sliding sign (absence) (Figs 84.18, 84.20 to 84.22) Comet tail artifacts (absence) Echo-free space between visceral and parietal pleura A, B lines (Fig. 84.19)	Pneumothorax Pleural effusion Pulmonary edema
Vascular (lower limb)	Compressibility of common femoral vein and popliteal vein (Figs 84.14 and 84.15).	Deep venous thrombosis
Echocardiography (TTE)	Assessment of left ventricular (LV) and right ventricular (RV) function/ Regional wall motion abnormalities Assessment of the pericardial space Dilated right ventricle, right atrium Underfilled ventricles, IVC diameter and collapsibility on respiration (Figs 84.16A and B) Ventricular activity	Myocardial ischemia/ infarction Pericardial effusion Pulmonary embolism Hypovolemia Cardiac arrest
Transcranial Doppler	Flow velocity, pulsatile index	Cerebral vasospasm, cerebral artery obstruction
Ocular	Optic sheath diameter >5 mm	Increased intracranial pressure

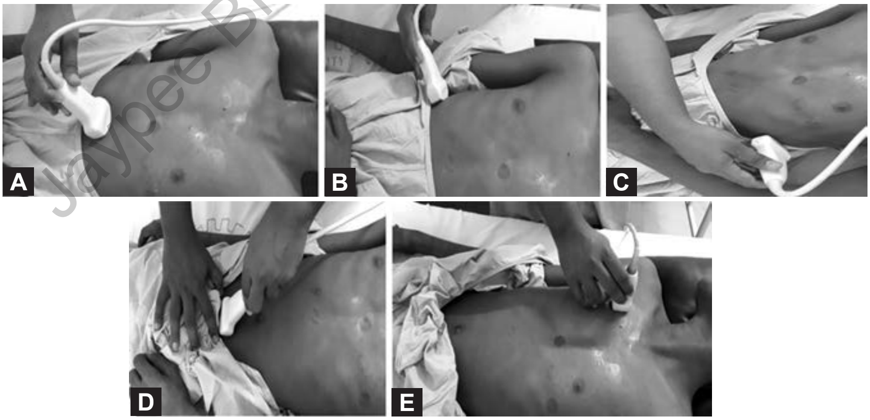
Table 84.4 RUSH protocol

RUSH exam	*Hypovolemic shock*	*Cardiogenic shock*	*Obstructive shock*	*Distributive shock*
Pump	Underfilled ventricles	Dilated ventricles	Pericardial effusion dilated RV Hypercontractile heart	Hypercontractile heart (early sepsis) hypocontractile heart (late sepsis)
Tank	Flat IVC Peritoneal fluid pleural fluid	Distended IVC RWMA	Distended IVC Absent lung Sliding Comet tail artifacts	Normal/small IVC normal/small IJV Pleural fluid (empyema) Peritoneal fluid (peritonitis)
Pipes	Aortic dissection	Normal	DVT	Normal

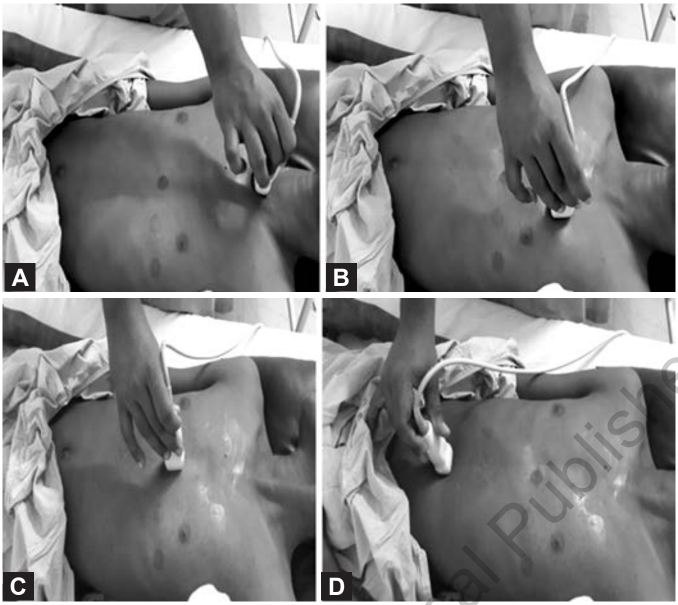
Table 84.5 Stepwise approach in RUSH protocol

	Step no. 1	*Step no. 2*	*Step no. 3*
Pump	Pericardial effusion: • Effusion? • Signs of tamponade? • Diastolic collapse of RV	Left ventricular contractility: Normal or reduced?	Right ventricular strain: • Increased size of RV? • Septal displacement from right to left
Tank	Inferior vena cava: Size, collapsibility based on inspiration.	E-FAST exam: • Free fluid abd/pelvis? • Free fluid thoracic cavity? • Pulm edema: Lung rockets?	Tension pneumothorax: Absent lung sliding? Absent comet tails?
Pipes	Abdominal aorta aneurysm: Abdominal aorta >3 cm		Femoral or popliteal vein DVT? Compressible?

Figs 84.11A to C RUSH protocol: (A) Parasternal view; (B) Subxiphoid view; (C) Apical view



Figs 84.12A to F e-FAST (Focused Assessment with Sonography for Trauma) protocol: (A) Subxiphoid view; (B) Perihepatic and hepatorenal view; (C) Perisplenic view; (D) Pelvic view; (E) Pleural view



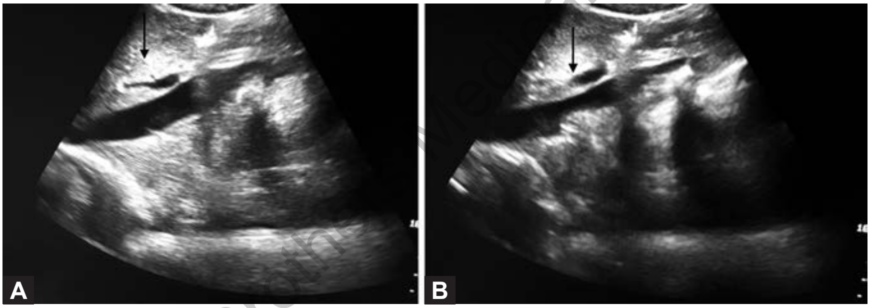
Figs 84.13A to D Probe positions for aortic view. (A) Suprasternal; (B) Parasternal; (C) Epigastric; (D) Supraumbilical

Fig. 84.14 Common femoral vein for DVT

Bedside Lung Ultrasound in Emergency Protocol for Acute Respiratory Failure

Bedside lung ultrasound in emergency (BLUE) protocol is a fast protocol which requires less than minutes for an expert and little longer for a novice. The purpose of BLUE protocol is that it allows diagnosis of acute respiratory failure based on the venous analysis (Flow chart 84.1). Pulmonary edema, pulmonary embolism,

Fig. 84.15 Popliteal vein for DVT



Figs 84.16A and B Ultrasound-guided IVC imaging showing collapsibility in the second image

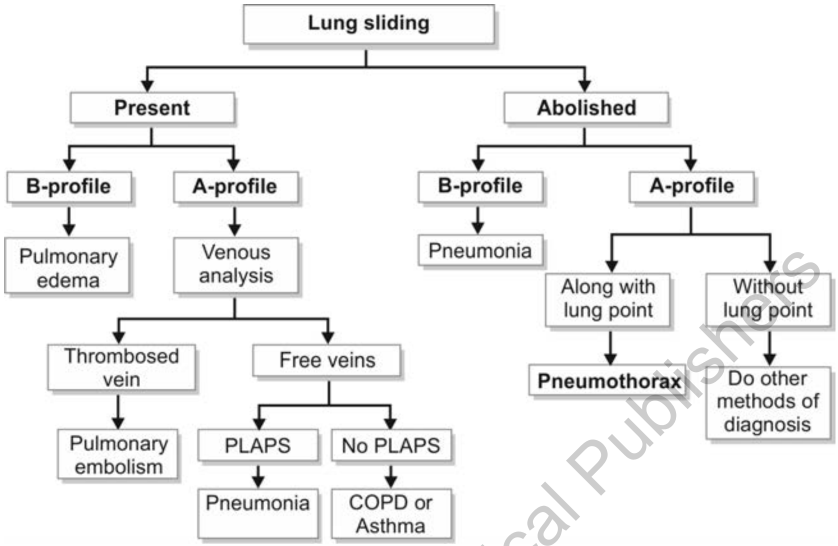
pneumonia, chronic obstructive pulmonary disease, asthma, and pneumothorax yield specific profiles in this protocol.

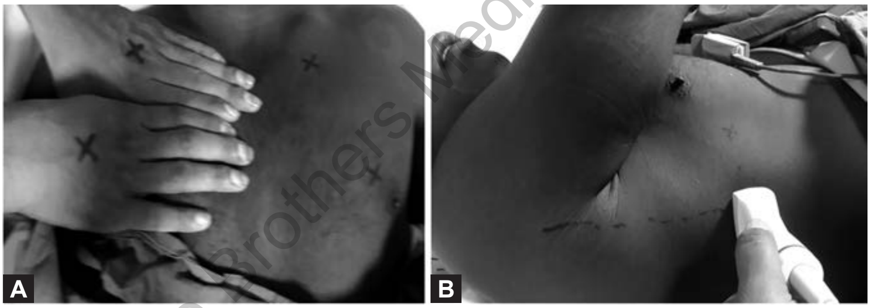
BLUE-points: Two hands are placed on the chest with the upper hand touching the clavicle, thumbs excluded which correspond to the location of the lung. This allows three standardized points to be defined. The upper-BLUE-point is at the middle of the upper hand. The lower-BLUE-point is at the middle of the lower palm. The PLAPS (posterolateral alveolar or pleural syndromes) point is defined by the intersection of a horizontal line at the level of the lower BLUE-point; a vertical line at the posterior axillary line (Figs 84.17A and B).

Cardiac Arrest Ultrasound Exam
Protocol for Cardiac Arrest

Cardiac arrest ultrasound exam (CAUSE). This protocol helps in identifying the cause of pulseless electrical activity or asystole and guides the management (Flow chart 84.2).

Flow chart 84.1 Algorithm showing the bedside lung ultrasound in emergency protocol for lung ultrasound





Figs 84.17A and B BLUE and PLAPS points

Fluid Administration Limited by Lung Sonography Protocol

Fluid administration limited by lung sonography (FALLS). This protocol is mainly used for hemodynamic assessment of circulatory failure using lung ultrasound. This protocol identifies causes based on lung ultrasound for circulatory failure.

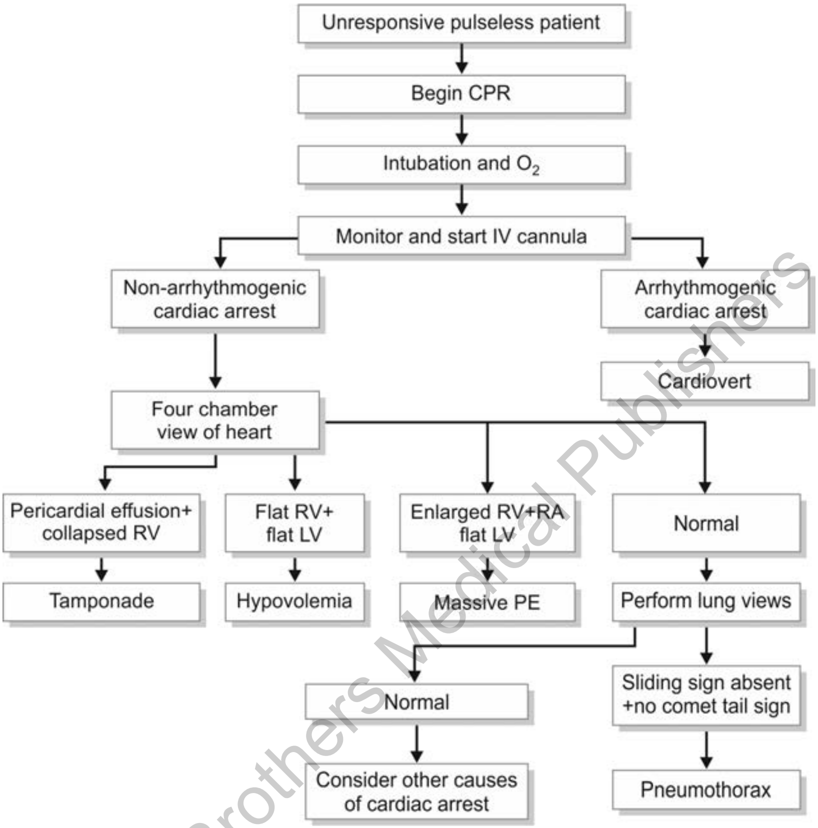
Secure European System for Applications in a Multi-vendor Environment (SESAME) Protocol

This is done for identifying the causes of cardiac arrest.

PROCEDURAL USES OF ULTRASOUND

- *Central vein catheterization:* It is used for both central and peripheral vein catheterization. NICE guidelines recommend the use of ultrasound for catheterization of central veins.

Flow chart 84.2 Algorithm showing the cardiac arrest ultrasound exam protocol for cardiac arrest



Abbreviations: RV, right ventricle; LV, left ventricle; RA, right atrium; PE, pulmonary embolus

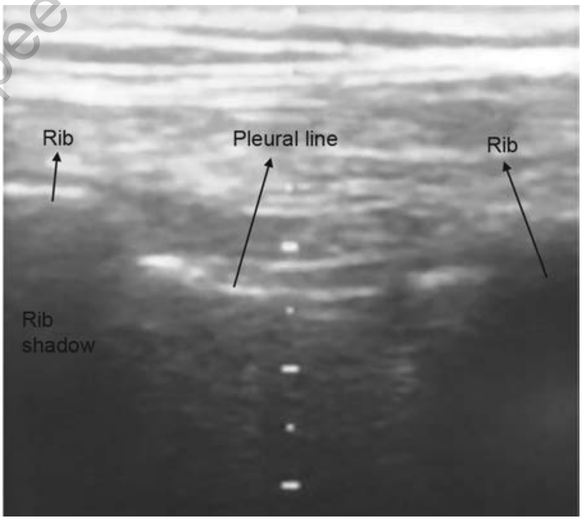


Fig. 84.18 B-mode showing the bat sign and lung sliding sign

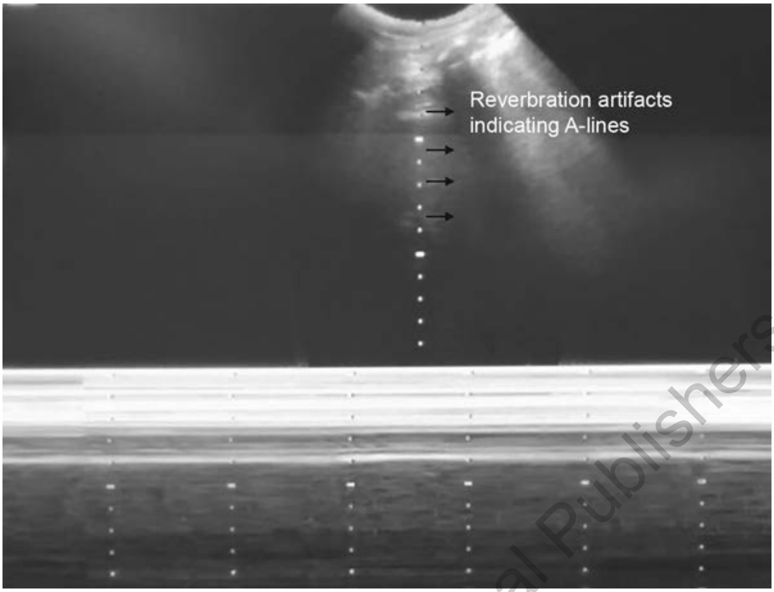


Fig. 84.19 Normal lung image by M-mode showing A-lines which are reverberation artifacts

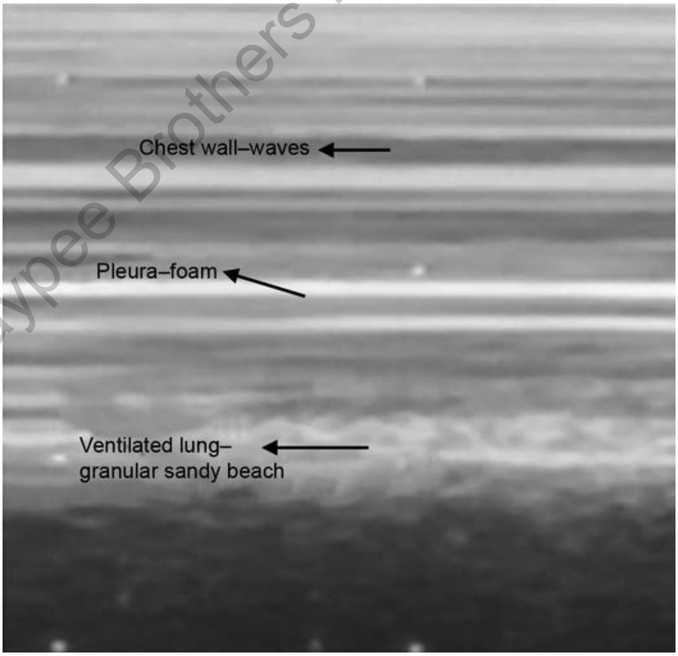


Fig. 84.20 Sea shore sign in M–mode (normal lung sliding with respiration)

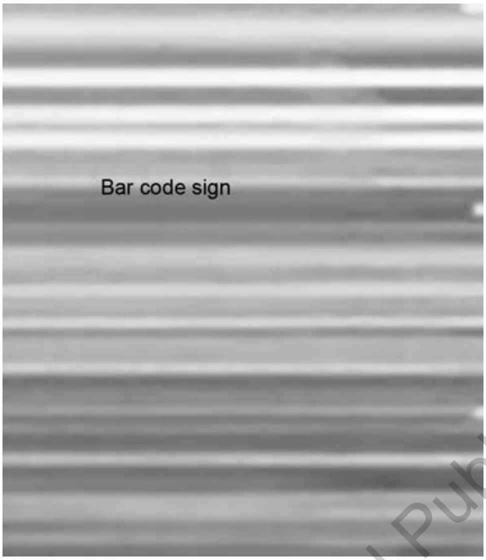


Fig. 84.21 Bar code sign indicating pneumothorax

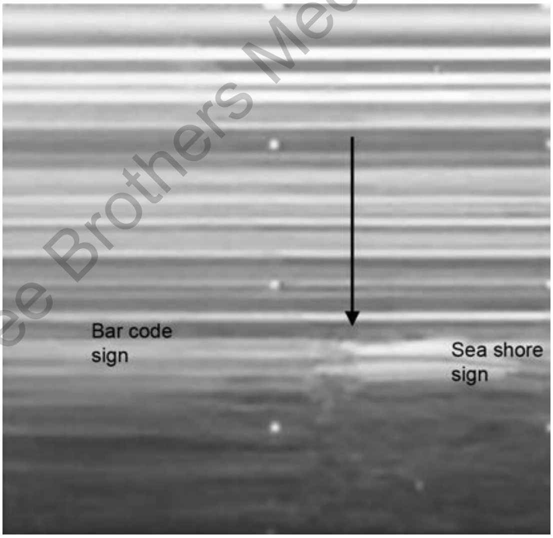


Fig. 84.22 Lung point indicating the transition between normal lung and pneumothorax

- *Percutaneous tracheostomy*: To determine the site of puncture and to identify aberrant vessels (Fig. 84.23).
- *Thoracentesis:* Done with ultrasound guidance for all pleural procedures (e.g. Needle thoracotomy or intercostal drainage for pneumothorax, draining pleural effusion).

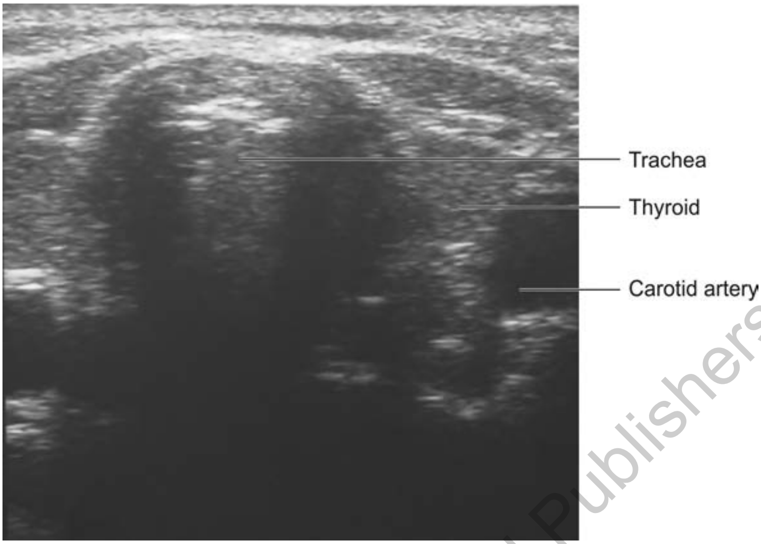


Fig. 84.23 Ultrasound image showing trachea for percutaneous tracheostomy

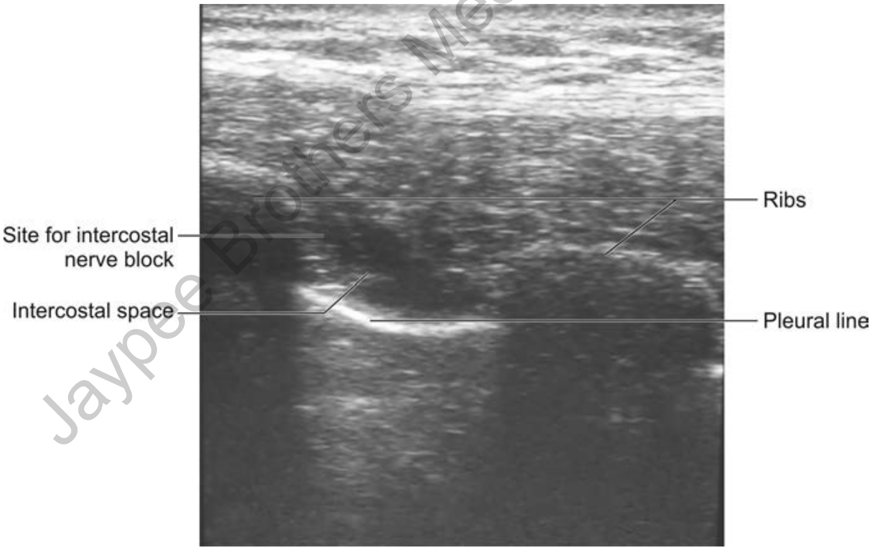


Fig. 84.24 Ultrasound image for intercostal nerve block for analgesia in chest injury

- *Regional nerve blocks*: It is the gold standard for performing peripheral nerve blocks for patients with trauma for pain relief and to reduce the inflammatory process (Fig. 84.24).

BIBLIOGRAPHY

1. Hendrickson RG, Dean AJ, Costantino TG. A novel use of ultrasound in pulseless electrical activity: the diagnosis of an acute abdominal aortic aneurysm rupture. J Emerg Med. 2001;21:141-4.
2. Hernandez C, et al. CAUSE: Cardiac arrest ultra-sound exam—A better approach to managing patients in primary non-arrhythmogenic cardiac arrest. Resuscitation. 2008;76:198-206.
3. Joyner CR, Herman RJ, Reid JM. Reflected ultrasound in the detection and localisation of pleural effusion. JAMA. 1967;200:399-402.
4. Kirkpatrick AW, Sirois M, Laupland KB, Liu D, Rowan K, Ball CG, et al. Hand-held thoracic sonography for detecting post-traumatic pneumothoraces: the Extended Focused Assessment with Sonography for Trauma (EFAST). J Trauma. 2004;57(2):288-95.
5. Legome E, Pancu D. Future applications for emergency ultrasound. Emerg Med Clin North Am. 2004;22:817-27.
6. Lichtenstein D, Menu Y. A bedside ultrasound sign ruling out pneumothorax in the critically ill: lung sliding. Chest. 1995;108:1345-8.
7. Lichtenstein D, Mezière G, Biderman P, Gepner A, Barré O. The comet-tail artifact: an ultrasound sign of alveolar-interstitial syndrome. Am J Respir Crit Care Med. 1997;156:1640-6.
8. Lichtenstein D, Mezière G, Biderman P, Gepner A. The comet-tail artefact an ultrasound sign ruling out pneumothorax. Intensive Care Med. 1999;25:383-8.
9. Lichtenstein D, Mezière G, Lagoueyte JF, Biderman P, Goldstein I, Gepner A. A-lines and B-lines: lung ultrasound as a bedside tool for predicting pulmonary artery occlusion pressure in the critically ill. Chest. 2009;136:1014-20.
10. Lichtenstein D, Mezière G. The BLUE-points: three standardized points used in the BLUE-protocol for ultrasound assessment of the lung in acute respiratory failure. Crit Ultrasound J. 2011;3:109-10.
11. Lichtenstein D. FALLS-protocol. In Whole Body Ultrasonography in the Critically Ill. Edited by. Heidelberg, Berlin, New York: Springer-Verlag; 2010.pp.223-41.
12. Lichtenstein DA. Lung ultrasound in the critically ill. Lichtenstein Annals of Intensive Care. 2014;4:1.
13. Lyon M, Blaivas M, Brannam L. Sonographic measurement of the inferior vena cava as a marker of blood loss. Am J Emerg Med. 2005;23:45-50.
14. Mayo PH, Goltz HR, Tafreshi M, Doelken P. Safety of ultrasound-guided thoracentesis in patients receiving mechanical ventilation. Chest. 2004;125(3):1059-62.
15. Miller RD. Miller's Anesthesia. 7th edition. Elsevier Publications; 2009.
16. Miniati M, Monti S, Pratali L, et al. Value of transthoracic echocardiography in the diagnosis of pulmonary embolism: results of a prospective study in unselected patients. Am J Med. 2001;110(7):528-35.
17. Salen P, Melniker L, Chooljian C, et al. Does the presence or absence of sonographically identified cardiac activity predict resuscitation outcomes of cardiac arrest patients? Am J Emerg Med. 2005;23:459-62.
18. Slasky BS, Auerbach D, Skolnick ML. Value of portable real-time ultrasound in the intensive care unit. Crit Care Med. 1983;11:160-4.
19. Vignon P, Chastagner C, Berkane V, Chardac E, Francois B, Normand S, Bonnivard M, Clavel M, Pichon N, Preux PM, Maubon A, Gastinne H. Quantitative assessment of pleural effusion in critically ill patients by means of ultrasonography. Crit Care Med. 2005;33:1757-63.
20. Volpicelli G, El Barbary M, Blaivas M, Lichtenstein D, Mathis G, Kirkpatrick AW, Melniker L, Gargani L, Noble VE, Via G, Dean A, Tsung JW, Soldati G, Copetti R, Bouhemad B, Reissig A, Agricola E, Rouby JJ, Arbelot C, Liteplo A, Sargsyan A, Silva F, Hoppmann R, Breitkreutz R, Seibel A, Neri L, Storti E, Petrovic T. International evidence-based recommendations for point-of-care lung ultrasound. Intensive Care Med. 2012;38:577-91.