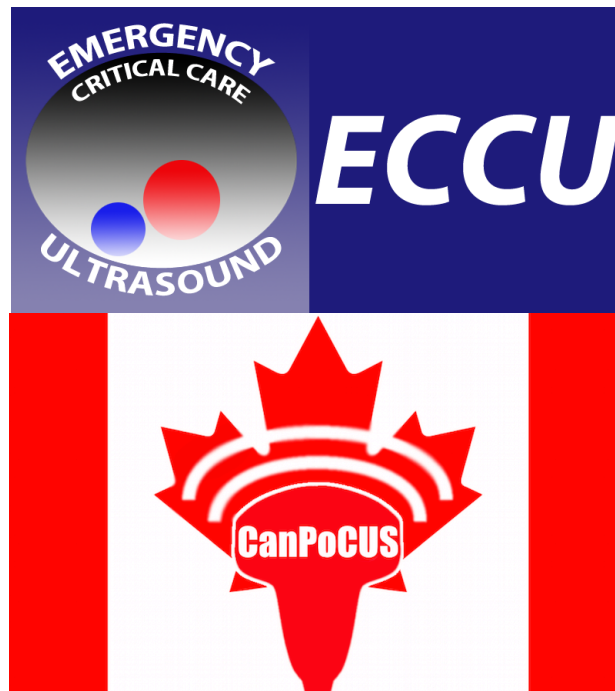




Introduction to Point-of-Care Ultrasound



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Introduction to Point-of-Care Ultrasound

Introduction

This one-day course will introduce you to the use of ultrasound at the bedside to answer focused clinical questions. Ultrasound is safe, rapid and non-invasive, and can be performed by clinicians from a wide range of clinical specialties and is ideal in the setting of patients with acute illness or instability. It does not replace accurate diagnostic reporting provided by formal radiological modalities such as CT scanning and radiology departmental ultrasound, but rather as an extension of the physical examination to assist with limited and specific diagnostic and treatment dilemmas.

CanPoCUS Core and the Clinical Utility of Bedside Ultrasound

The CanPoCUS Core course is designed to introduce clinicians with no prior experience to a focused approach for the use of ultrasound to answer important binary questions relevant to acute care. The course uses guided, practical, hands-on experience along with focused interactive lectures to reinforce key learning points. The objective is for the learner to gain confidence in image generation and interpretation, as well as integrate findings into clinical assessment and reasoning.

Examples of the clinical questions to be answered include:

- Does this hypotensive patient have an abdominal aortic aneurysm?
- In this trauma patient, is there free intra-peritoneal fluid?
- In a patient in cardiac arrest is there pericardial tamponade?

Emergency bedside ultrasound can also be used to facilitate invasive procedures, including:

- Placement of central venous catheters
- The draining of pleural effusions and ascites
- Localization of subcutaneous foreign bodies.

The key question to ask is: *Will a bedside ultrasound scan change or assist the immediate management of the patient?*

Bedside ultrasound can also be used to assess the hemodynamic status of a patient with symptoms and signs of shock; simple measures such as the amount by which the inferior vena cava collapses on inspiration (IVC collapse index), or an ultrasound estimation of the JVP in the patient who is able to sit at 45°, can provide an estimate of venous filling.



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Image Optimization

Ultrasound technology allows the production of images by processing high frequency sound waves transmitted and received by a probe. The frequencies used for medical ultrasound range from 2 – 15 MHz, with lower frequencies capable of deeper tissue penetration useful for abdominal and cardiac scanning, and higher frequencies for superficial and detailed ultrasound.

The modes of ultrasound used in emergency scanning include, B mode (or 2D ultrasound), M Mode (e.g., in cardiac ultrasound), and Doppler imaging when assessing flow. Some simple principles that help interpretation of ultrasound images are:

1. Different tissue types reflect or transmit ultrasonic waves in a variable manner leading to different appearances in the ultrasound picture. Bone or calcified structures, such as gallstones, are highly reflective and appear white with a black acoustic shadow behind them. Fluid transmits ultrasonic waves and appears black. Soft tissue structures and organs reflect some sound and transmit the remainder, therefore, appearing grey.
2. Air is the enemy! To prevent air distorting the picture, gel must be applied between the probe and the skin. Gentle pressure will also help to dislodge any air in the field.
3. Probe selection: A curved low frequency probe is used for abdominal scanning and often thoracic scanning. A high frequency linear probe is used for soft tissue scanning and vascular scanning. A phased array probe is used for cardiac scanning.
4. High frequency settings provide a detailed picture but with less penetration, low frequency settings provide better penetration but with less detail.
5. Structures should be viewed in at least two planes, traditionally longitudinal and transverse.



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Clinical Relevance

Focused Assessment with Sonography in Trauma (FAST)

The objective of the FAST scan is the detection of free intra-peritoneal fluid or pericardial fluid in the trauma patient. The scan involves four views: the right upper quadrant (hepatorenal angle / Morrison's Pouch); the left upper quadrant (spleno renal angle); the pelvic view; and the subxiphoid/pericardial view. The limitations of this study need to be understood, yet when used appropriately, it plays an invaluable role in the assessment of the multiply injured patient.

Focused Aortic Scanning

Emergency ultrasound of the aorta again asks a binary question: Is there an abdominal aortic aneurysm (AAA)? The scan does not determine whether this aneurysm is leaking, rather just that there is an aneurysm present. In the hands of trained Emergency Physicians or Surgeons, ultrasound identification of AAA is both highly specific and sensitive. The overwhelming benefit of this test is the detection of unsuspected AAA in the shocked patient or patient with abdominal pain.

Focused Cardiac Scanning / Echo in Life Support

Bedside cardiac ultrasound evaluation is limited to a global assessment of contractility and to the detection of pericardial effusions and tamponade. This is applied to patients who are in an arrest or in hemodynamic shock. The utility of this scan is to highlight the need for interventions such as pericardiocentesis, and also assist with decisions such as the appropriateness of ongoing resuscitation attempts.

Pelvic Ultrasound

Emergency ultrasound in the first trimester of pregnancy allows the emergency physician to rapidly and accurately evaluate the patient at risk of ectopic pregnancy. Detection of a live intra-uterine pregnancy makes ectopic pregnancy unlikely in the absence of fertility treatment. Detection of intra-peritoneal free fluid, and empty uterus and a positive beta-HCG allows confirmation of ruptured ectopic pregnancy in the shocked female patient.



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Detection of Pleural Disease

Bedside ultrasound can be used to differentiate between pleural effusions and consolidation, which may not be apparent on a plain chest radiography. It can also be used to mark a safe point for pleurocentesis or in the detection of pneumothorax.

Procedural Ultrasound

Ultrasound improves the safety and accuracy of interventional procedures such as the placement of central venous catheters and aspiration of fluid collections such as pleural effusions and ascites. It is important to emphasize the need for aseptic precautions using sterile disposable probe covers and ultrasonic gel.

Shock Ultrasound

Abdominal and Cardiac Evaluation by Sonography in Shock (ACES) is a combination of individual applications in the undifferentiated hypotensive patient (Figure 2). The ACES screening exam is useful to draw attention to possible underlying etiologies: it includes focused scans of the aorta, the FAST exam (for free peritoneal and pleural fluid, pericardial tamponade and general cardiac wall motion) and an Inferior Vena Cava (IVC) collapse index (Figure 1). With experience, focused ultrasound can be invaluable in the assessment of hypotensive or breathless patients. Identification of right ventricular dilatation may indicate possible pulmonary embolism, whereas a dilated hypodynamic left ventricle may indicate dilated cardiomyopathy.

Key Points

- Focused emergency ultrasound is an extension of the bedside clinical assessment
- Scans are performed to answer direct questions
- Bedside ultrasound is particularly useful in critically ill patients
- Appropriate training and assessment are essential

Continue reading for a more detailed description of the key areas of Emergency and Critical Care Ultrasound (ECCU) that are covered in the CanPoCUS Core course:



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CanPoCUS Core Course

This document covers FAST, Assessment of the Abdominal Aorta and IVC, Vascular Access and Echocardiography in Life Support, and Pelvic Ultrasound in Early Pregnancy.

Curriculum

Please refer to www.CPoCUS.ca for details on their certification process in Canada.

Equipment - Basics

Most ultrasound machines are fundamentally the same. Even the most apparently complex machine can be reduced to a simple series of functions. It is important that the following are understood and can be applied or manipulated as the scan progresses. Ensure you can always locate these functions on any machine you use.

- Patient Information
- Probe orientation
- Transducer Change
- Depth Button / Focus
- Time Gain Compensation
- Freeze
- Callipers
- Probe Choice
- Scanning Planes
- Label and pictogram
- Image storage



On/Off Button

There is nothing more embarrassing than not being able to find the on/off button. Most machines for near patient scanning are designed to turn on quickly to a predetermined **pre-set** so that image acquisition can commence rapidly. Some have a standby mode. Larger machines may have an on-board power supply which allows the machine to remain turned on for brief periods away from an AC outlet. This,



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combined with the standby mode, enables a large machine to be moved from patient to patient.

Patient Information

It is essential to enter patient details so that images can be stored and reviewed later if needed. This not only ensures quality but is valuable if images have been misinterpreted to correct mistakes. Most machines have a keyboard and mouse type arrangement to facilitate this.



A minimum data set should include surname, first name, patient identifier, date of scan and the identity of the person carrying out the scan. Some machines are linked to PACS enabling patient data to be directly drawn from the PACS system. It should only be in extreme time limited applications that patient detail input is neglected. As you get to know your machine various pre-set labels are often available to make labelling of scans faster.

Gel Couplant

Air is the enemy of ultrasound! The idea of a gel couplant is to reduce air trapped – whenever you are struggling to get a picture the first thing you should do is to try more gel. A gel with enough adherence not to keep slipping off the skin is ideal but in an extreme emergency any gel will suffice. Patients are appreciative of prewarmed gel.



Probe orientation

A standard orientation is used when looking at images and when storing images so that anyone reviewing the images is able to identify the view. Most probes have a notch or light representing the orientation dot on the screen and it is good practice to identify this (lightly touching one side of the probe or applying a spot of gel to one side are easy ways to check).

Standard longitudinal orientation always has the head to the left (orientation dot) so that the screen





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looks at head to foot from left to right. If a transverse image is then needed rotation anticlockwise will maintain correct orientation because then the right side of the patient is towards the left (orientation dot) of the screen.

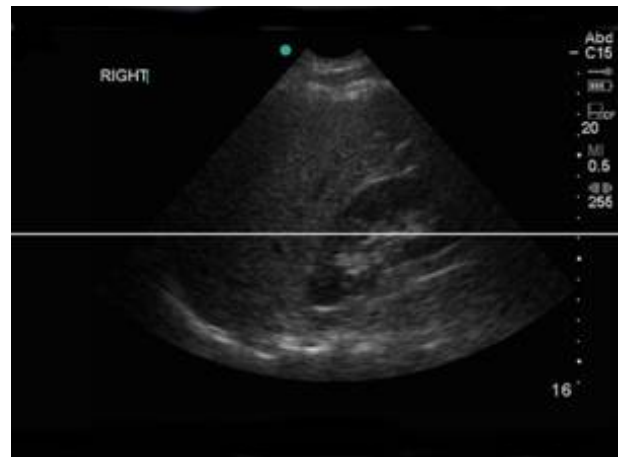
Transducer Change

It is important to become familiar with how the machine changes transducers. Some machines need you to physically change the transducer; others are done from the console. Many machines also allow a change in frequency of individual transducers to enable more penetration (lower frequency) or more resolution (higher frequency).



Depth Button/Focus

Many basic machines will not allow a change in focus and in these machines, it is generally set to the centre of the screen. If it can be altered, however, it should be moved to the area you wish to see and you will concentrate the processing power to that area.



The best area of focus for an image is in the middle of the screen. When one has acquired the desired image it is a good idea to change the depth to place the area of most interest within the middle of the screen. There is often a depth measure on one side of the image for reference.

Callipers

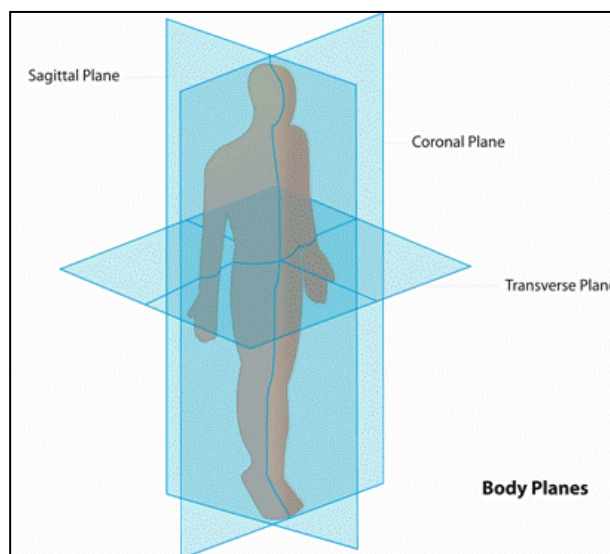
Most machines allow callipers to be placed and then moved, usually with a mouse or roller ball. A measure is given numerically on the screen. In general, anterior-posterior depth measures of circular structures are better (e.g. vessels) since edge artefact can cause loss of definition in the transverse or oblique position.



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Scanning Planes

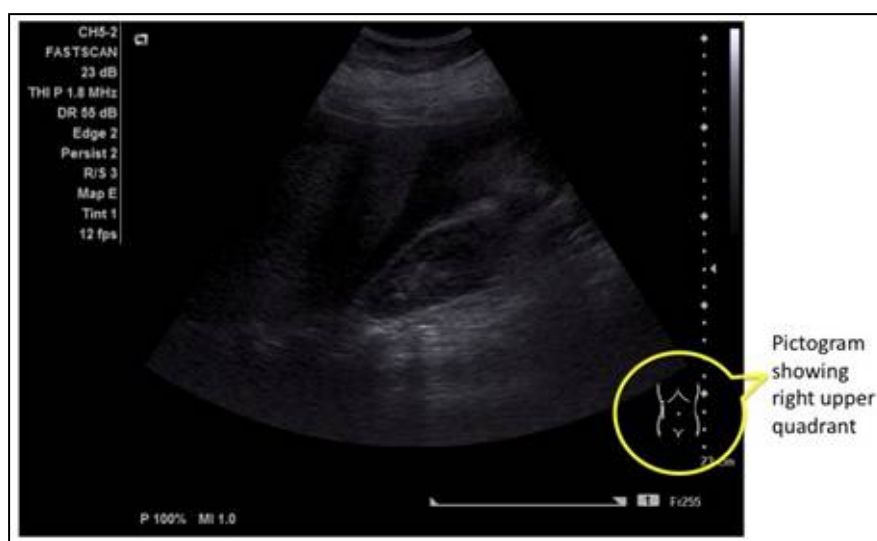
There are 3 standard described scan planes, Coronal, Sagittal and Transverse. The beginner is generally advised to stay in these simple planes so as to be able to reliably obtain recognisable images repeatedly (which is what makes focussed scanning possible). With experience, changes in the inclination of planes helps to obtain improved images.



Label the Image

Label the image with appropriate patient details. These will usually appear at the top of the scan but have not been included in this image for reasons of patient confidentiality.

Always add either a pictogram or a text description of what the image is intended to be. A pictogram is a small body picture (see bottom right of the image). Some operators prefer a simple text insert instead, such as 'RUQ'.



Core knowledge

Physics

In the hands of an expert, the production of an ultrasound image looks easy. However, both image acquisition and interpretation are hugely reliant on a reasonable depth of understanding of how ultrasound works. Where this is lacking, there is considerable scope for confusion and misdiagnosis.





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How Ultrasound works

Sound is simply the transfer of mechanical energy from a vibrating source through a medium. Ultrasound is defined as sound of a frequency above the human audible range, i.e. above 20 kHz. For most emergency medicine applications frequencies in



the region of 1 to 10 MHz are used.

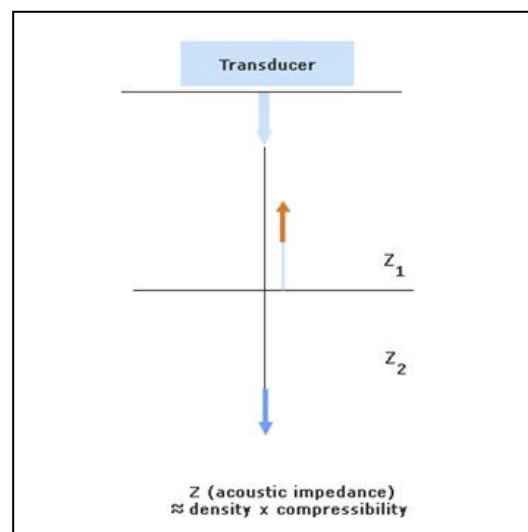
Medical ultrasound utilises the pulse-echo principle to construct a two-dimensional image of anatomical structures within a patient. This is essentially the same principle used by bats to catch insects through echolocation.

An ultrasound transducer converts electrical energy into a mechanical pulse of sound that is transmitted into the patient. Returning echoes are converted into an electrical signal from which the image is formed.



Ultrasound is not emitted continuously from the transducer, as there would be no way of knowing how long a wave had been travelling once it returned to the transducer. Instead, transducers oscillate between emitting a pulse of ultrasound, and then in the pause that follows, the time that elapses for the echoes to be detected is measured. A pulse of sound leaving the transducer will travel into the patient until it encounters a change in acoustic impedance (Z).

At such an interface, a proportion of the sound energy is reflected back to the transducer and this return echo is detected. If the speed of sound is known and the time taken for the echo to return is measured, the depth of the reflecting interface can be calculated.



Distance = speed x time (d=st)



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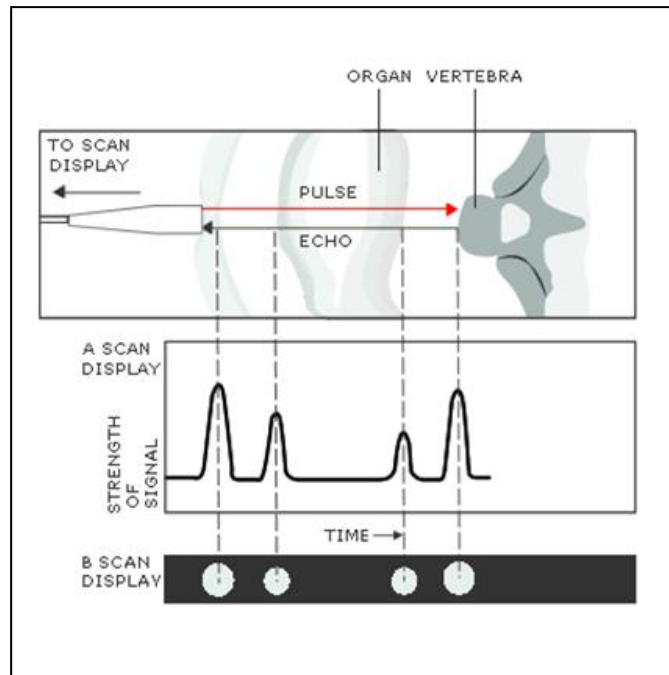
Each pulse of sound transmitted into the patient will generate a stream of returning echoes from multiple reflecting interfaces at various depths within the tissue.

Although all ultrasound is based on reflected sound, the means by which the echoes are analysed and displayed varies. This gives rise to several types, or **modes**, of ultrasound:

- A-Mode
- B-Mode
- M-Mode

A-mode is short for amplitude modulation. It displays as a graph on the screen with the x-axis as time, and the y-axis as amplitude. It is used in scanning the eye. The diagram shows an ultrasound of the abdomen with the A-mode display corresponding to each layer.

B-mode is short for brightness modulation. In its simplest form, it appears as bright spots with varying intensity depending on the amplitude, as in the diagram. The image becomes two-dimensional by virtue of the use of an array of multiple transducer elements, each of which forms a bright spot.



If performed fast enough, rapid update

of frames can create a 'real time' image. Frame rate is limited by the depth to which the image is set. This is an operator control and should be set to display only the area of interest.

It is two-dimensional real time B-mode scanning which forms the basis for emergency medicine scans, such as Focused Assessment with Sonography in Trauma (FAST) and Abdominal Aortic Scanning.

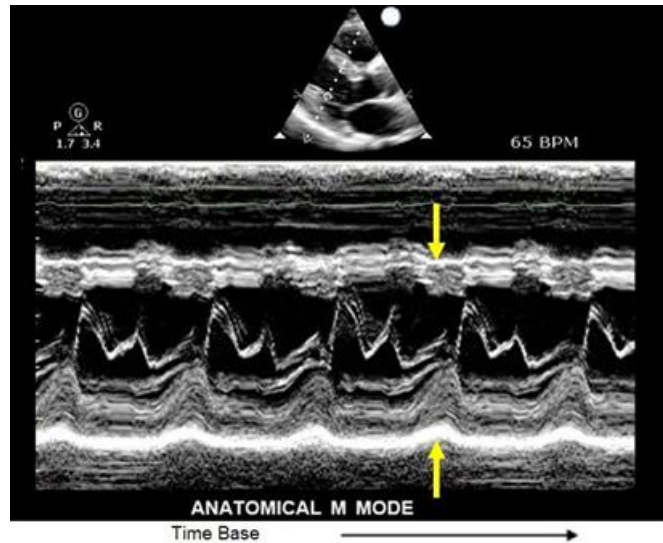
M-mode stands for motion mode and this uses a stationary transducer with a moving recording device. M-mode detects all motion down a line drawn through the tissues. It is a useful modality to measure moving objects, classically the cardiac walls and



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valves. Essentially, M-mode takes a single line of the B-mode image and displays changes within this over time. Movement of reflectors along this line of sight generates a pattern across the monitor or a moving paper strip chart recorder.

The image (right) shows a B-mode view of the heart (top) with the M-mode view (below). B-mode data is



collected from along a single line of sight (indicated by the dotted line) and displayed across a time base. Movement of the mitral valve leaflet and the left ventricular walls is demonstrated.

Most diagnostic conclusions about both normal and abnormal ultrasound appearances are based on four key observations:

- the spatial definition of tissue boundaries
- relative tissue reflectivity (brightness)
- echo-texture
- the effect of tissue on the through transmission of sound

All of these observations are based upon appearances that are the result of how sound waves interact with tissue. A great deal of potentially useful diagnostic information can be inferred from these observations, but some understanding of how sound behaves is required to appreciate why the appearances arise. In many ways, sound and light behave in a similar fashion.

Concepts such as reflection, scattering and



refraction are common to both. Reflection of the ultrasound pulse occurs when there is a change in acoustic impedance across a boundary between tissues. Specular reflection occurs when the sound pulse encounters a large smooth boundary, such



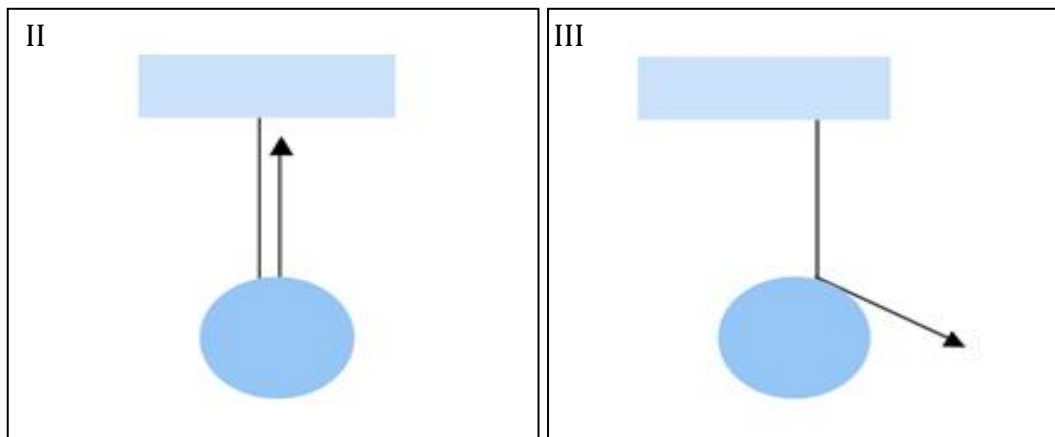
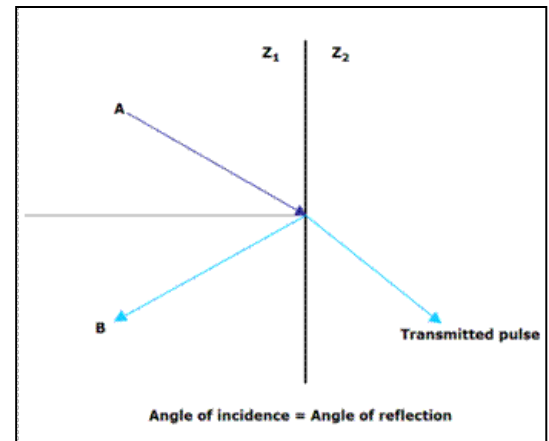
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as the diaphragm (see arrow) or an organ capsule. Sound is reflected from interfaces where there is a change in tissue density and compressibility.

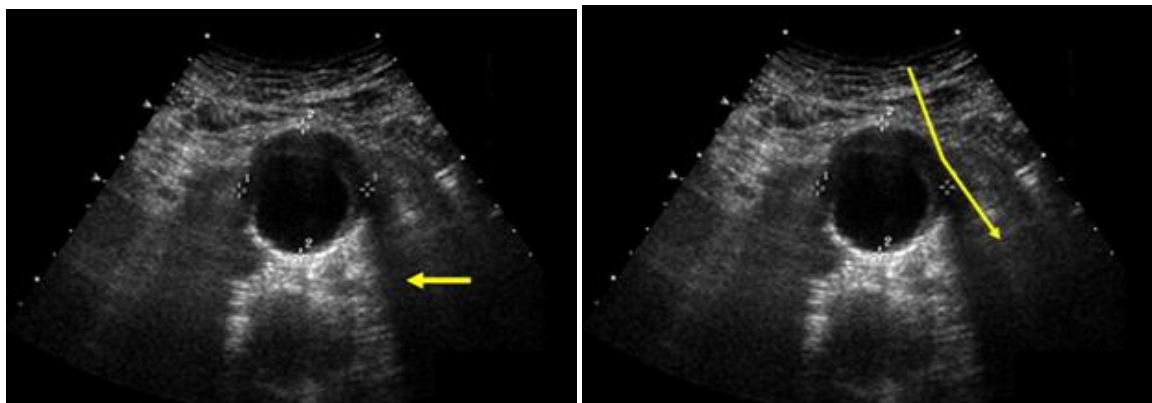
In the graphic (I) adjacent, the incident pulse (A) hits the surface at an angle. The reflected component (B) will be directed at an equal and opposite angle.

Structures insonated (i.e. struck by sound waves) at 90 degrees will generate an echo that is directed back to the transducer. The graphic below (II) shows a structure insonated at 90 degrees.

Reflective interfaces that are curved may not be demonstrated clearly, as the reflected pulse is directed away from the transducer. It may be necessary to scan from a different angle. The graphic below shows a curved reflective interface (III).



In the transverse views of the abdominal aorta below, the lateral borders are ill-defined, and shadowing is seen distal



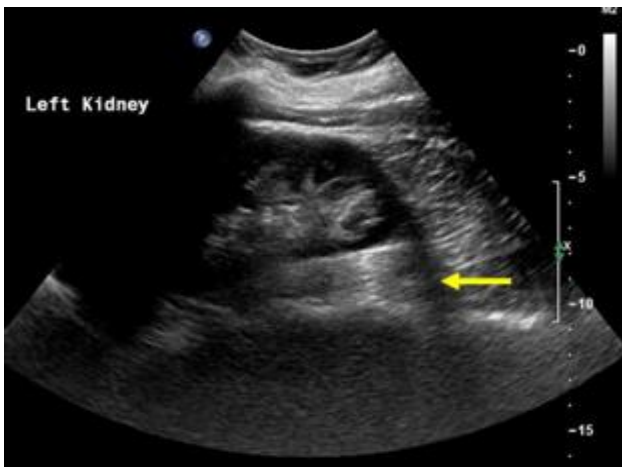
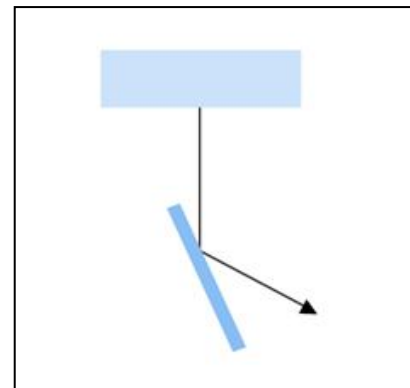


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to the lateral walls of the aorta in the left image (arrow). For this reason, the antero-posterior measurement is used, as calliper placement is more precise and the measurement reproducible. The image on the right shows the reflected pulse being directed deep into the patient. No useful information is gained from this region. Note the anechoic nature of the blood within the aorta.

Reflective interfaces that lie at an angle may not be demonstrated clearly, as the reflected pulse is directed away from the transducer. It may be necessary to scan from a different angle. The graphic (IV) shows an angled reflective interface.

'Critical angle shadowing' is often generated by the edges of structures and is seen in this image distal to the lower pole of the kidney (see arrow left below).



The cellular structure of soft tissue scatters sound energy in all directions.

This is similar to the scattering of light seen when a car's headlights are raised on a foggy evening. Known as Rayleigh Scatter, this produces the characteristic grainy appearance of solid organs on ultrasound (see arrow within renal cortex above right).

The scattering of sound within a soft tissue structure determines the 'brightness' of the organ relative to adjacent tissues. Scattering also produces a characteristic speckle pattern or Echo Texture.

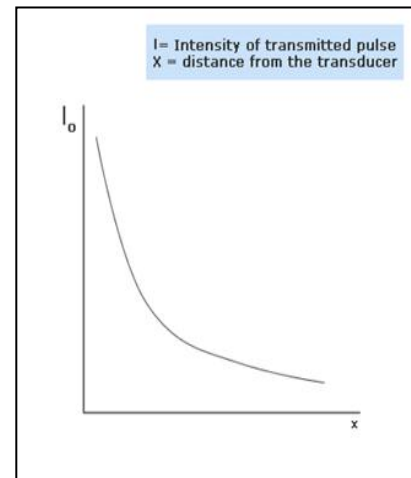


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Absorption and scattering are both highly frequency dependent. High frequency sound produces better image resolution but is attenuated by a smaller depth of tissue. This means that penetration to deeper tissues is limited when using a high frequency transducer.

There is always a compromise between resolution and penetration. In practice, use the highest frequency that allows adequate penetration to the depth of interest.

As sound travels through tissue, it will lose energy. A number of interactions contribute to this process of attenuation including reflection, scattering and absorption. This results in an exponential decrease in the energy of the pulse, therefore producing weaker echo signals, the deeper it travels into the patient.



The acoustic impedance of the tissue being imaged determines attenuation. The variation between diverse tissues can be enormous, as shown in this table.

Material	Speed of sound (m s⁻¹)	Density (kg m⁻³) x 10⁻³	Acoustic Imp Z (kg m⁻² s⁻¹) x 10⁻⁶
Air	330	1.2	0.0004
Water	1480	1000	1.48
Steel	5000	7800	39.0
Blood	1575	1057	1.62
Fat	1459	952	1.38
Muscle	1580	1080	1.70
Bone	4080	1912	7.8



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Basic components of an ultrasound system

Any ultrasound machine is composed of a transducer to transmit and receive ultrasound, a computer for storage and manipulation of the acquired data and a monitor to display the image. Some form of image storage or hard copy device is needed to provide a permanent record of each examination.

The quality of the displayed data is determined by the skill of the operator and the inherent quality of the machine components.

The layout of the control panel will vary considerably between machines and manufacturers. Individual controls will also vary in appearance as well as location. Simple controls such as focus or depth may be a soft key, a dial, a paddle or on-screen. Individual tabs/keys may have multiple functions depending on the mode of operation selected.

It is for this reason that a 'co-pilot', who is familiar with the specific system, is a useful ally when using a machine for the first time. Manufacturers tend to group controls depending on function and to minimise operator movement and reach, such as callipers/measurement.

Freeze allows the operator to produce a static image for archiving and from which measurements can be taken. This is normally a soft key. Typically, it is situated towards the right-hand side of the control panel to be reached easily with the left hand while scanning with the right. The key is normally labelled 'freeze'. (Some of the more imaginative manufacturers use a snowflake.)



On most equipment, the track ball controls the cine-loop facility. The cine-loop feature allows the operator to scroll back through several seconds worth of captured



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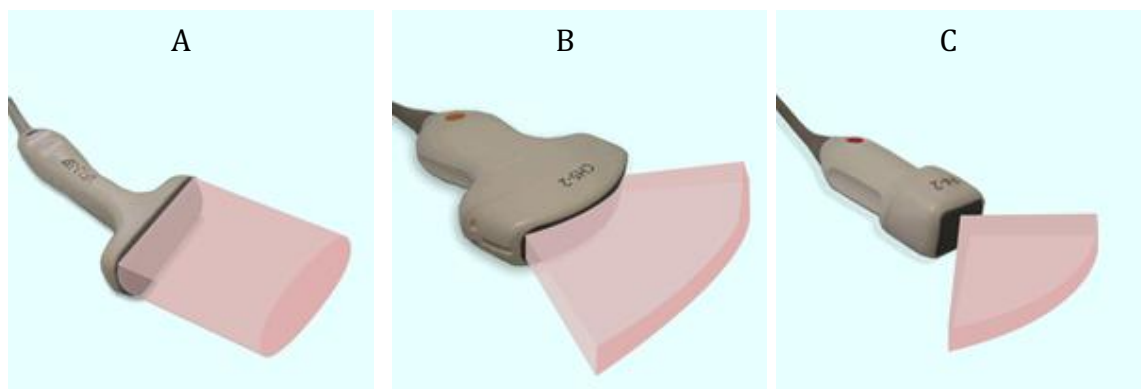
frames once the image has been frozen. This is particularly useful when imaging non-cooperative patients. The tracker ball is probably the only control on an ultrasound keyboard that is common to virtually all manufacturers. This is the equivalent of the computer mouse and is used to move the cursor around the screen when entering patient. The laptop equivalent tracking pad has replaced the tracker ball on handheld systems.

Depending on the scan mode that is operating, the tracker ball is used to move on-screen graphics such as callipers and to position the box location for high resolution zoom. The function of the track ball changes as each application is selected.



Ultrasound Probe

Consider the probe to be like a sword or knife with a very thin blade cutting through the patient. Different probes create different acoustic 'beams', or fields of view, the shape of which varies. A high frequency linear array probe produces a flat beam with parallel sides (A). A low frequency curvilinear probe produces a widening beam (B). The lower frequencies can give considerable depth. A phased array probe produces



ultrasound beams with fractional time differences across the array. A sweeping beam results that gives a wide diverging field of view, but with a small footprint (C). This can be very useful when imaging between ribs, e.g. in cardiac applications.

On a higher specification ultrasound machine, once patient details are entered, an on-screen menu may appear giving options of transducer and application. Up to four transducers may be plugged in at any one time and the operator will need to select



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the correct transducer from the menu to match the area to be examined. Always use the highest transducer frequency that allows adequate penetration to the depth of interest. Some manufacturers offer high resolution or penetration settings for each transducer. This allows the operator to optimise the transmit frequency for slender or obese patients without changing transducers.

Once the correct transducer has been selected, the operator must select a specific body area pre-set. When the relevant body area is selected, the machine will default to a range of settings that are optimised by the manufacturer for that target area. This will include settings affecting penetration, resolution, frame rate etc. It is important to choose the correct transducer/pre-set combination. It is not uncommon

to observe inexperienced operators struggling to image deep into a large patient with these initial settings optimised for superficial structures. Inevitably, image quality will be poor and may be non-diagnostic.





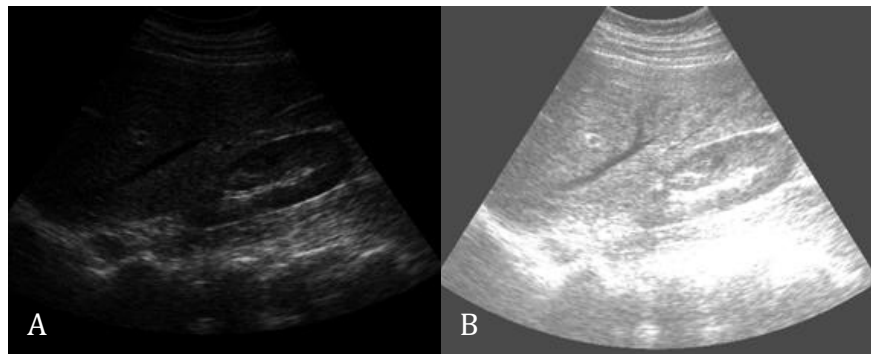
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Time Gain Compensation (TGC) usually consists of a number of sliders/paddles that correspond to specific depths within the patient. TGC is used to compensate for increasing attenuation by increasing amplification of the return signal with depth. On the smaller hand-held



systems, TGC is often replaced by independent near and far gain controls. The operator should aim for an image where similar structures appear at the same brightness level, regardless of depth. Unlike TGC, overall gain alters the amount of amplification applied to signals from any depth. This is used to increase or decrease the overall brightness of the image. Overall gain amplifies the return signal and has no effect on the transmitted pulse. Therefore, gain cannot compensate for inadequate penetration. The only way to do this is to

increase the output power of the equipment or change to a lower transmit frequency. If overall gain is set too high,



the overall gain amplifies noise within the image and reduces both spatial and contrast resolution (A). If overall gain is set too low, the result is too dark and image detail is lost (B). In Image (C), the overall gain is set so that the intra-hepatic veins appear black and the liver parenchyma is within the mid grey range. TGC is adjusted so that the liver is of a uniform brightness regardless of depth. No part of the image is saturated.

Depth is indicated on the monitor by a line of cm markers. The depth control should be set to demonstrate the whole region of interest during an initial survey of the area, as in this image.

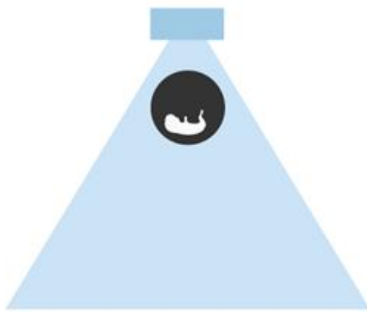
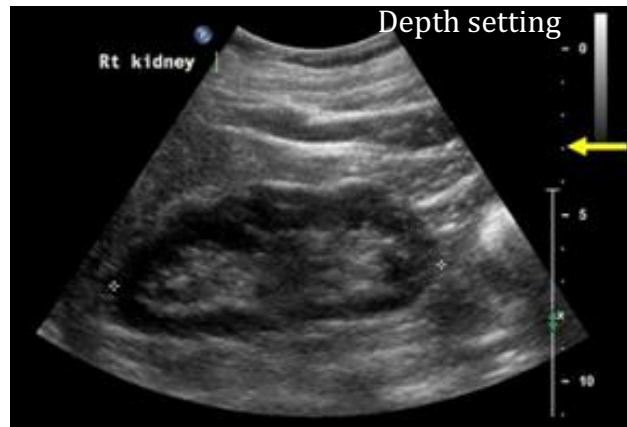




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During interventions that may be guided by ultrasound, such as central line placement, it is often more important that the needle tip misses 'innocent bystanders', rather than the target structure being reached on first pass.

Setting the depth inappropriately deep loses temporal resolution, as in the left hand image. On the right, the correct depth setting enables optimal temporal resolution.



Initial depth settings should be set to demonstrate all of the relevant anatomy, not just the most superficial structures, but no deeper than the area of interest.



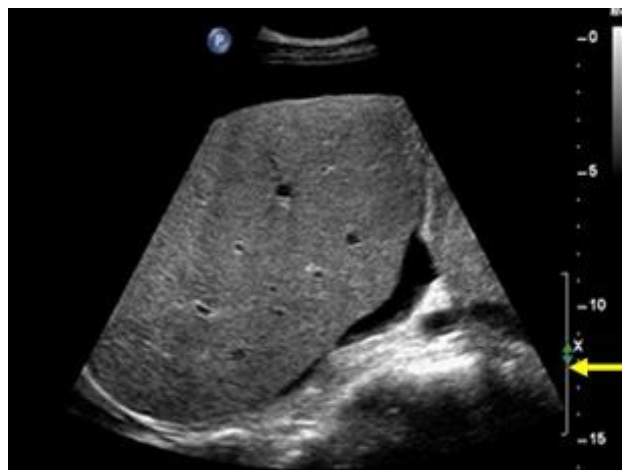
High resolution zoom may be used to provide an expanded view of small structures. A region is selected by placing an on-screen box over the structure of interest, as in the left hand image above. The location of the box is, normally, controlled by the



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tracker ball. Zoom is then activated to provide a high resolution image of this small, defined area, as shown in the right image above.

As the depth of interest changes from one structure to another, the depth to which the ultrasound beam is focused needs to be altered, as shown here. This will improve lateral resolution, making it easier to delineate small structures. This is particularly important when imaging structures such as nerves or foreign bodies that are small, and that may be similar in brightness level to surrounding tissues.



The homogeneous speckle pattern characteristic of many solid organs is, in part, a product of the effective beam width. As beam width is reduced, contrast resolution will improve and structures, such as nerves, will be better visualised. Focus may need to be adjusted throughout the examination.

On some handheld systems, focus is optimised for the entire depth of view and is altered automatically, as the depth setting is changed. On these systems focus cannot be altered independently.

Image quality

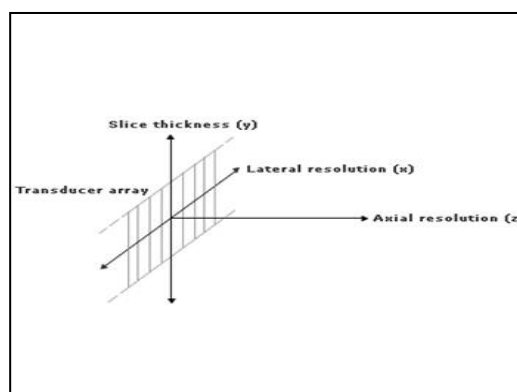
The quality of the image depends on the spatial resolution, which is a function of:

- Axial resolution
- Lateral resolution
- Slice thickness

Limits of both spatial and contrast resolution are important in foreign body localisation.

This table shows spatial resolution limits:

Axial	Wavelength limited	0.2-0.5 mm
Lateral	Array focusing	1-2 mm
Slice thickness	Lens focusing	≈ 5 mm





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Cine-loop feature

Ultrasound machines will have a feature that “memorizes” the real-time image generation. By “freezing” the image at a particular time, the operator may then use the tracker ball to scroll back through several seconds of captured frames. Difficult to obtain views can then be examined or measured, such as with difficult to scan or uncooperative patients, or difficult views.

Is Ultrasound safe?

Ultrasound has been shown to be relatively safe, but no imaging method which deposits additional energy into the body should be considered entirely risk free. When the decision to make a diagnostic image is made, the physician should always make a conscious judgement about whether the potential benefits of the imaging procedure are greater than any potential risk. As kinetic energy is introduced into tissue, there is potential for both thermal and mechanical damage to cells. Fractional increases in tissue temperature occur and varying degrees of cell damage have been observed. While there is no evidence that ultrasound has resulted in actual harm, the fact that these effects may occur should be borne in mind. For this reason, it is considered good practice to avoid extensive periods of scanning in one patient, unnecessary repeats, unwarranted foetal exposure etc. Anyone undertaking diagnostic ultrasound examinations should comply with the British Medical Ultrasound Society or Canadian Emergency Ultrasound Society guidelines for the safe use of ultrasound equipment.

Particular care should be taken when scanning:

- an embryo less than eight weeks after conception
- the head, brain or spine of any foetus or neonate
- an eye (in a subject of any age)

N.B. The use of Doppler imaging is thus contraindicated in each of the above.

A further potential hazard of ultrasound is the risk of cross infection. Transducers should be cleaned after each patient with a non-alcohol based cleaning fluid or wipe. Alcohol based cleaners should be avoided as, over time, these will dissolve the thin protective layer that covers the transducer crystals and will invalidate any warranty.



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Key Points

- two-dimensional, real time B-mode scanning forms the basis for emergency medicine scans, such as FAST and AAA
- use the highest frequency that allows penetration to the depth of interest
- Initial depth settings should be set to demonstrate all of the relevant anatomy, not just the most superficial structures, but should be no deeper than the area of interest
- The cine-loop feature can be used to locate the most useful image, and is particularly useful when imaging non-cooperative patients



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FAST (Focused Assessment with Sonography in Trauma)

Ultrasound has been used in the early assessment of abdominal trauma for the past 30 years. Over the last 15 years, increasing evidence of the utility of the technique in emergency medicine has been published, and it is now widely practiced.¹⁻⁵ It has the advantage of being noninvasive, rapidly performed and readily repeatable.

Chambers et al published a report in 1988 on use of ultrasound⁶; since then growing interest in ultrasound use by non-radiologists has been accompanied by increasing availability of affordable systems and published evaluations of the technique groups of sonographers among trauma staff.^{7,8}

The purpose of ultrasound in the initial assessment of abdominal trauma, is to document the presence of free intraperitoneal fluid. In the context of trauma this fluid is assumed to be blood although it may not actually be the case. There is no attempt to visualise specific organ injuries, as ultrasound is not accurate in the early assessment of solid organ or hollow viscus injury.⁹ The absence of free fluid does not exclude serious intra-abdominal injury.

Further management is dictated by the clinical condition of the patient. Ultrasound is designed to extend the trauma clinician's physical examination capability and complement other investigations particularly when the patient is unstable. While Computed Tomography (CT) remains the gold standard imaging technique for trauma, Ultrasound may rapidly establish the necessity for surgical evaluation or laparotomy especially when there may be reasons for delay in obtaining a CT scan (time, distance, stability of patient to leave the ED),

Key points

Ultrasound complements the physical examination and other investigations, although CT remains the gold standard to detect intra-abdominal injury.

Focused Assessment with Sonography in Trauma (FAST) has largely replaced Diagnostic Peritoneal Lavage (DPL) which, while sensitive, is invasive, time consuming and may compromise other investigations. The advantages of FAST are: it can be repeated as many times as necessary; performed during clinical



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assessment; completed within minutes of the patient arriving and before any other investigation; and done in an unstable patient. As in most aspects of non-radiologist ultrasound it should be operated on a 'rule in', not a rule out principle, i.e. there is no such thing as a normal FAST. This is important when communicating findings to colleagues. It is appropriate to say that free fluid has not been seen, but this should not be taken to mean that bleeding is not occurring.

Training and Accuracy

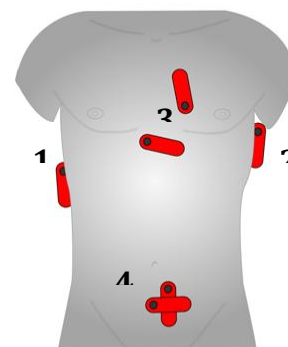
Review of published literature shows that there is no agreed training schedule, with programmes varying widely, from one hour lecture and one hour practical training, to over 500 supervised scans.¹⁰⁻¹² Shackford *et al* suggested that the error rate stabilised after ten scans¹³ but Ultrasound is highly operator dependant. Published data reveals that FAST performed by emergency physicians has a specificity of 95–100% and a sensitivity of 69–98%. Branney *et al*¹⁴ demonstrated that small quantities of fluid (as small as 225 ml) can be detected, but 85% of sonographers will reliably detect only volumes over 850 ml. Therefore, in regard to detecting free fluid, there was no difference between emergency physicians, surgeons or radiologists.

The Standard FAST Views

During the 1990's, six FAST views were described to include two paracolic views, but these paracolic views have generally been dropped. More recently, extended FAST (known as E-FAST) is gaining popularity. This includes an upper thoracic view of the right and left lung fields, to look for signs of pneumothorax. E-FAST is not part of Level 1 training, although the upper thoracic views are readily learned later. Furthermore, ACES (Abdominal and Cardiac Evaluation with Sonography in Shock) combines IVC visualisation and a view of the myocardium together with AAA and FAST, and this is also gaining a place in Critical Care Ultrasound.

The standard FAST views are:

1. The right upper quadrant (RUQ), to include Morison's pouch and the right costo-phrenic pleural recess
2. The left upper quadrant (LUQ), to include the spleno renal recess and the left costo-phrenic pleural recess
3. The pericardial sac, from below or transthoracic
4. The pelvic cavity, in two planes





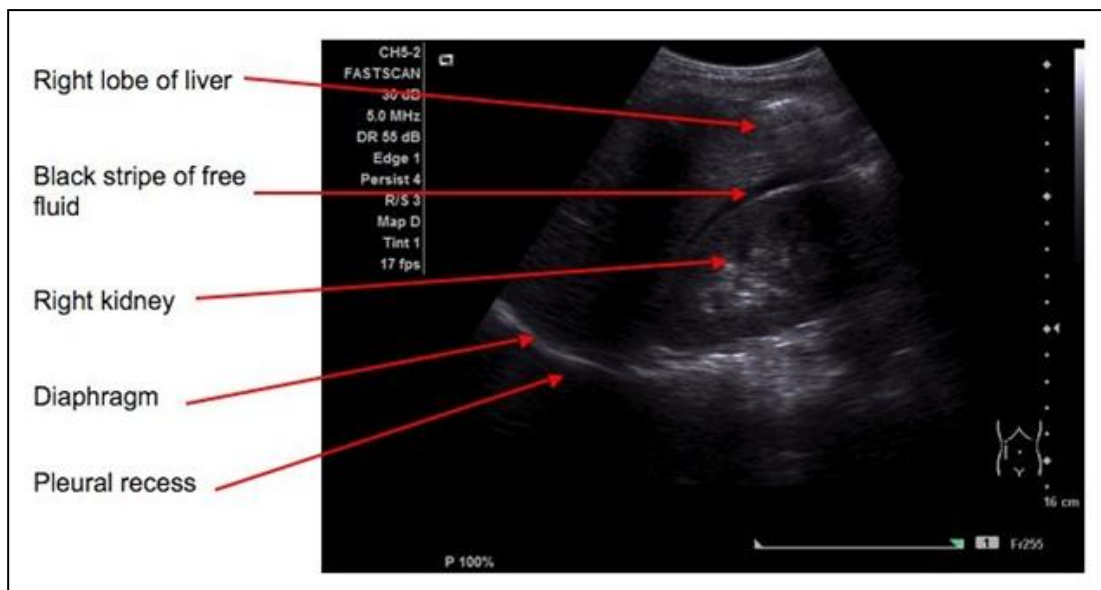
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Positioning the Probe – RUQ and LUQ Views

Imagine the probe is a sword and imagine slicing through the internal area which you want to see; cutting a plane for view. For the RUQ view, start on the right side and site the probe just anterior to the mid-axillary line, angled slightly backward, to look at the anterior aspect of the renal capsule.

The LUQ view is a little more difficult to obtain as the left kidney is higher than the right. A view through an intercostal window may need to be obtained. Site the probe just posterior to the mid-axillary line, angled and slightly backward, to look at the anterior aspect of the renal capsule.

One of the practical considerations in FAST image acquisition is moving the patient's arms, particularly when the stretcher rails are elevated. This can create difficulty in a resuscitation setting.



Key points

- For RUQ and LUQ views, start at the mid-axillary line and angle the probe slightly posterior: the LUQ probe position is always slightly more towards the axilla.
- For the pericardial view, try the sub-xyphoid approach first. Alternatively, the parasternal view may be better. In this instance, the marker should point perpendicular to the heart apex to gain a standard view.
- For the pelvis sagittal view, position the probe as shown. A transverse view should also be obtained.

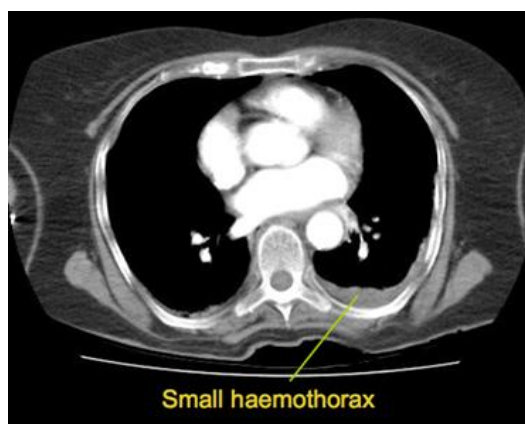


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- The marker on the probe should always be orientated towards the patient's head (cephalad—longitudinal view), or to their right (transverse views), except in the long axis parasternal view.

Image Appearances & Interpretation

Free fluid looks black, both in the peritoneal cavity and pleural recess. Early peritoneal collections are seen just anterior to the renal capsule and appear as a black stripe. Small pleural collections begin to accumulate posteriorly, therefore may not be seen during a FAST scan. In the image shown the FAST appearances were normal but the CT revealed a small left haemothorax.



If no free fluid is seen consider a repeat scan, perhaps 10 minutes later. If at any stage a black line anterior to the renal capsule, or black area in the pleural recess is present, the interpretation should be that there is free fluid present. Be cautious with the assumption that this is blood.

Right Upper Quadrant

The RUQ is the area to scan first, as free fluid will often be seen in this area earlier than in other areas (as shown). In addition, this is probably the easiest area to scan and in which to gain confidence. Ensure the pleural recess is adequately seen.

Key point

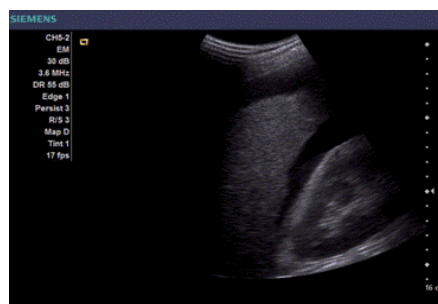
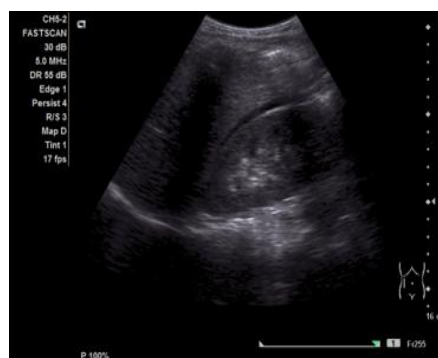
The RUQ is the area where free fluid is likely to be detected first.

Left Upper Quadrant

The LUQ is the area to scan next. Position the probe slightly closer to the axilla than for the RUQ view.

Key point

The LUQ view requires the probe to be slightly more cephalad than in the RUQ view.

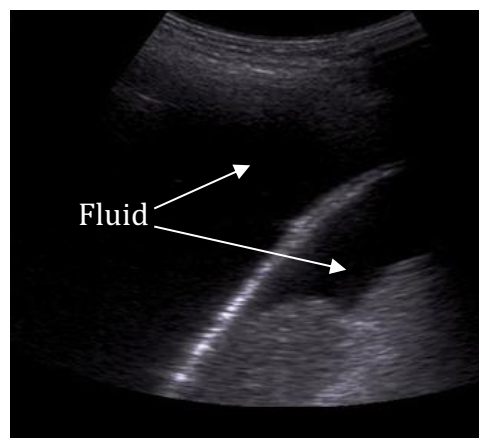




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Pleura

The pleural space can be visualized in the RUQ and LUQ views. Pleural (and peritoneal) fluid is shown here in the RUQ view. Large pleural effusions are easily identified on the FAST exam if the pleural recesses are visualized, and in fact ultrasound is a more sensitive diagnostic test than the supine chest x-ray. The presence of pleural fluid can indicate the presence of intrathoracic hemorrhage, esophageal rupture, cardiac failure or malignancy.



To assess for pneumothorax, a curvilinear or linear transducer placed in sagittal orientation on the anterior chest wall in the mid-clavicular line is used. The pleural line is visualized immediately inferior to the ribs and assessed for horizontal sliding and small vertical B-lines. When no sliding or B-lines are present, a pneumothorax is likely.

Pericardium

The pericardium can be visualised subxiphisternally or parasternally. It is easier to carry this out using a parasternal view in the left parasternal area. The settings need to be changed to limit the view to the area being examined. With more advanced practice, the emergency sonographer will learn to look at the back of the posterior aspects of the pericardial sac and not at the anterior aspects, as in a supine patient this is where fluid will begin to pool earlier. In this apical view there is pericardial fluid present.



Key point

Pericardial fluid will be seen posteriorly at first.



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Pelvic Cavity

The pelvic cavity is a more difficult area to scan and takes experience. The typical appearance of small bowel loops floating in fluid is shown, but much smaller volumes of fluid in the rectovesical pouch in the male, or the pouch of Douglas in the female, can be diagnostic. The technique for selecting these areas needs to be mastered in a practical session. A small amount of fluid in the pouch of Douglas, in the female pelvis, may be normal following ovulation.

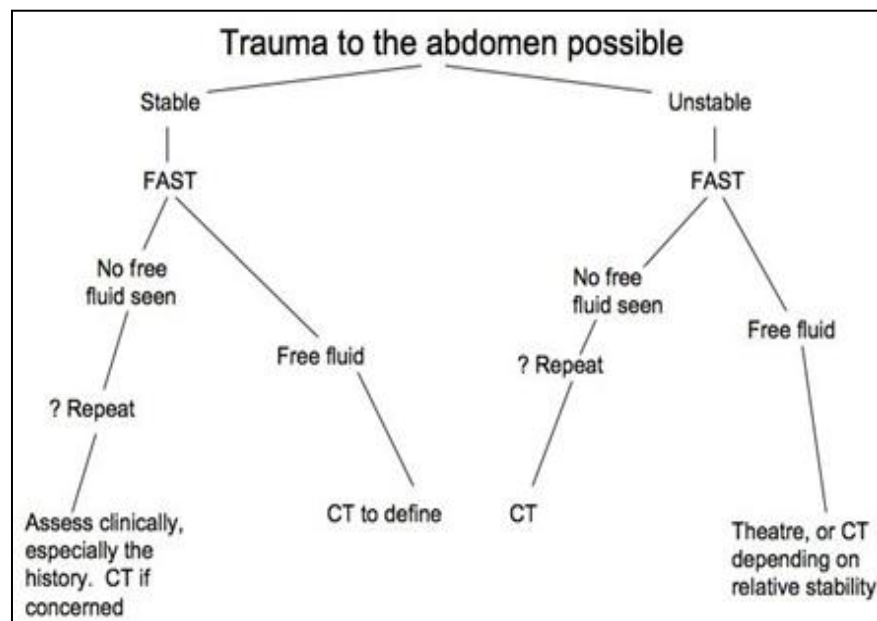


Key point

Don't assume free fluid is blood.

Algorithm for FAST

FAST is no substitute for CT and a more definitive assessment of the patient is obtained with CT. A positive FAST scan in a stable patient should always lead to a CT scan. This defines with precision where the pathology is within the peritoneal cavity, and furnishes the surgeon with as much information as possible. A positive scan in an unstable patient may indicate that immediate laparotomy is appropriate. However, the clinical experience and impression of the surgeon should not be ignored. Another consideration is the degree of confidence that the fluid is not due to pelvic venous bleeding.

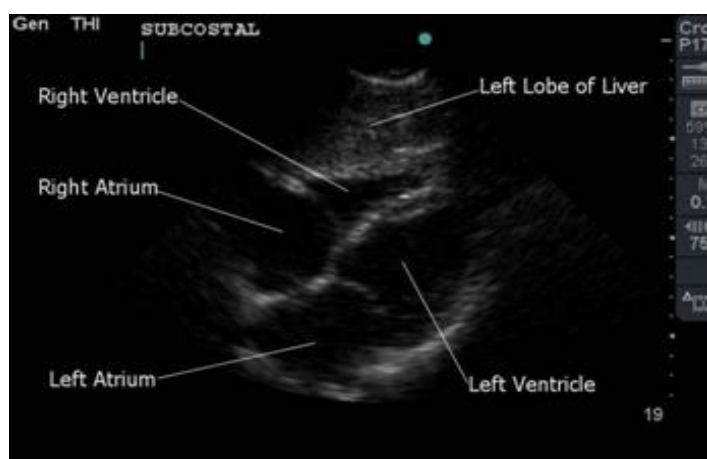
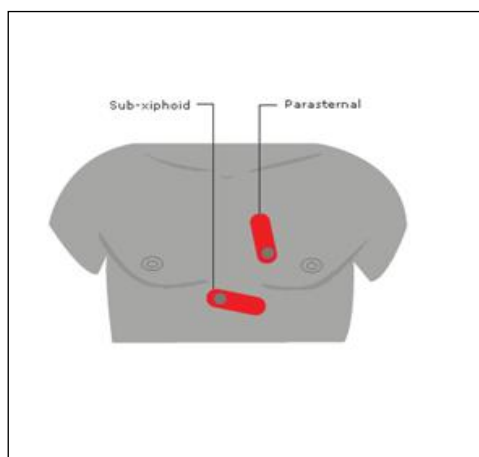




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Using FAST skills for Echocardiography in Life Support (ELS)

Echocardiography in Life Support (ELS) is learned alongside FAST. It requires careful timing with a CPR rhythm check. During this 10-second window the probe is often set to maximum depth and increased gain, to increase the likelihood of locating the heart rapidly. If the heart cannot be seen during the rhythm check, the probe should be removed at 10 seconds and CPR recommenced.



The technique of Echocardiography in Life Support (ELS), may be carried out with the probe in the sub-xiphoid position, but, in fact this view is often not satisfactory, and a switch to the parasternal long axis view can give better views, and is easier to carry out.

Key point:

In ELS there are two priorities, namely:

- (i) **to assess cardiac movement and**
- (ii) **to identify remediable pathology**

There are three possibilities when assessing cardiac movement:

1. There is no cardiac movement. If the heart is seen to be motionless and this corresponds with asystole on the monitor, survival is highly unlikely. Identifying this in the appropriate clinical picture can aid the practitioner to evaluate a cardiac arrest.
2. There is cardiac movement with sinus rhythm on the monitor. If the carotid pulse is absent, the patient has a condition known as 'pseudo-PEA' in which there is mechanical action of the heart, but of insufficient magnitude to



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generate a pulse.⁽¹⁵⁾ The importance of identifying this condition is that survival is higher in these patients.⁽¹⁶⁾

3. There is visible ventricular fibrillation. Patients thought to be in asystole have been found to have VF on echocardiography.⁽¹⁷⁾ Such patients require emergent defibrillation.

The two main conditions that may respond to immediate treatment are:

- Pericardial effusion sufficiently large to cause tamponade. Tamponade is a physiological diagnosis that is extremely difficult to make during cardiac arrest without the use of echo. If a large effusion is identified in the appropriate clinical context pericardiocentesis must be considered.
- Massive pulmonary embolism (PE) features on ultrasound include the presence of visible thrombus in the heart, a right ventricle diameter to left ventricle diameter ratio greater than one, and a dilated inferior vena cava (see the session Soft Tissue Musculoskeletal / Ultrasound / Skills of Carrying Out Assessment For Abdominal Aortic Aneurysm). If massive PE is strongly suspected, emergent thrombolysis may be indicated.

Assessment of the Abdominal Aorta and IVC

Standard Ultrasound is routinely used for the screening and monitoring of aortic diameter, and a limited ultrasound scan can reliably record the presence of an abdominal aortic aneurysm (AAA). As the clinical assessment of the abdominal aorta for AAA has shown to be unreliable¹⁵, a key for emergency physician

performed ultrasound is early identification of abdominal aortic aneurysms (AAA). Emergency physicians can accurately perform aortic ultrasound scans with relatively little training.^{16–19}

In the emergency setting it is usually difficult to define the limits or relations of the aneurysm; bedside ultrasound





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is useful to determine if aneurismal change is present or absent; however, it is not accurate in determining the presence of a leak from the aneurysm. The current evidence for the detection of AAA with PoCUS comes from several small cohort studies.¹⁶⁻¹⁹ These series report high sensitivities (94–100 %) and specificities (98–100 %).

In the acute setting an AAA is defined as a transverse aortic diameter greater than 3 cm. Approximately 90-95 % of abdominal aortic aneurysms (AAA) are confined to the infrarenal aorta. The risk of rupture within 5 years is 25 % at 5 cm diameter. AAA smaller than 5 cm have a 3 % risk of rupture over 10 years.

The role of ultrasound is to detect an enlarged abdominal aorta at the earliest clinical opportunity. If a normal aorta is clearly seen along its full extent, then an aortic aneurysm can be excluded. However, there are other, more rare aneurysms, e.g. splenic artery.

Emergency physicians can accurately and usefully undertake emergency ultrasound scans to detect AAA, with a sensitivity comparable to that obtained internationally. Emergency ultrasound, performed by UK emergency physicians, has been reported as having the following accuracy profile for the detection of AAA²⁰:

- Sensitivity of 96.3 % (95 % confidence interval (CI), 81.0 % to 99.9 %)
- Specificity of 100 % (95 % CI, 91.8 % to 100 %)
- Negative predictive value of 98.6 % (95 % CI, 88.0 % to 99.9 %)
- Positive predictive value of 100 % (95 % CI, 86.8 % to 100 %)



Sierzenski²² reported that emergency physician ultrasound decreased the time to diagnosis in ruptured AAA with a mean time of 180 minutes reduced to 80 minutes. Time to CT scan and to operative repair were also decreased.

Emergency medicine AAA assessment is a focused examination to answer a single clinical question, i.e. **“Is an abdominal aortic aneurysm with a diameter greater than 3cm present?”**



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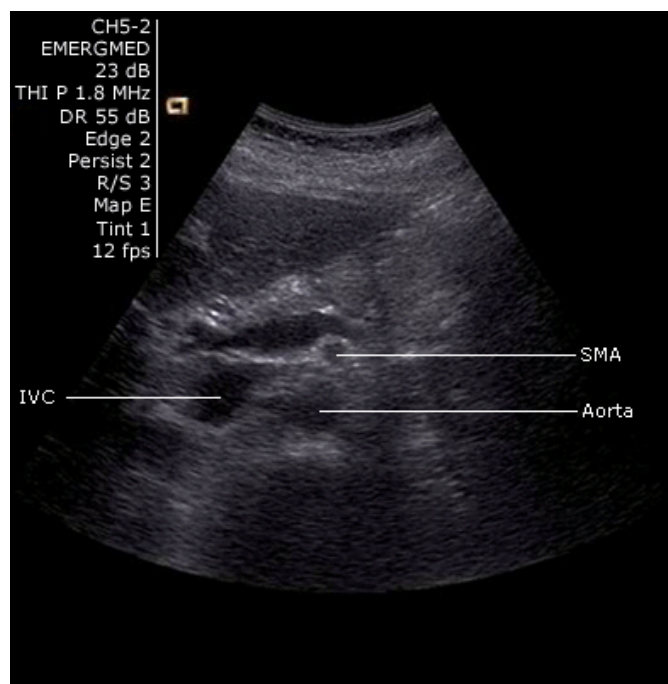
As in all areas of emergency medicine ultrasound we 'rule in' pathology rather than rule it out. Having said this, if the entire aorta is confidently seen, an AAA will not be present. The combination of an aneurysm on ultrasound, and an unstable or symptomatic patient, is enough to warrant an emergency vascular surgery opinion. Aortic aneurysm is more prevalent in elderly men (male:female ratio is 4:1), and the incidence has been estimated at 11 % in men over 65.²³ It is related to, and therefore may co-exist with, other atheromatous diseases, such as myocardial infarction, stroke and mesenteric ischaemia. Of those who suffer a ruptured aortic aneurysm in the community, only about 50 % reach hospital alive. Of those who reach surgery the 30-day mortality rate is also approximately 50 %. Thus short-term survival after a ruptured AAA is 1 in 4, whereas mortality following elective surgery is less than 5 %. Detecting a quiescent aortic aneurysm may therefore be lifesaving. The inferior vena cava (IVC) and aorta are both seen in most cases, as in this ultrasound scan. It is possible for a novice to confuse the two. The aorta is situated anterior to the vertebral bodies and left of midline, whereas the IVC lies to the right of midline. The aorta tapers and tends to be tortuous and move to the left. It can be calcified anteriorly which can make the ultrasound view more difficult.

The main features of the IVC are:

- Right side
- Thin walled
- Compressible
- Transmitted pulse ('double bounce')
- Almond shaped
- Shape varies

The main features of the aorta are:

- Left side
- Thick walled
- Will not compress
- Pulsatile
- Round in shape
- Constant shape
- Superior mesenteric artery (SMA) demonstrated

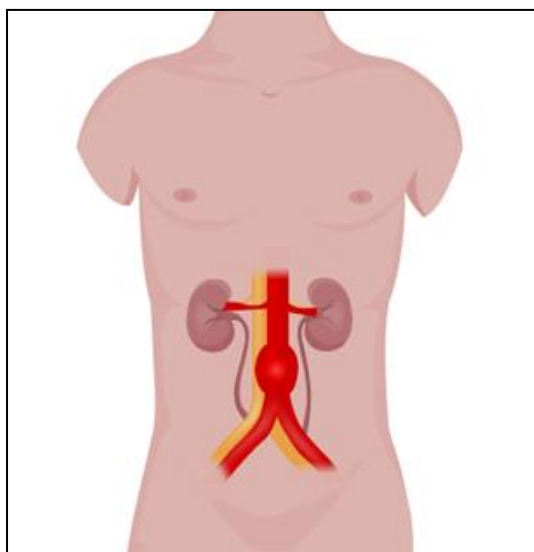
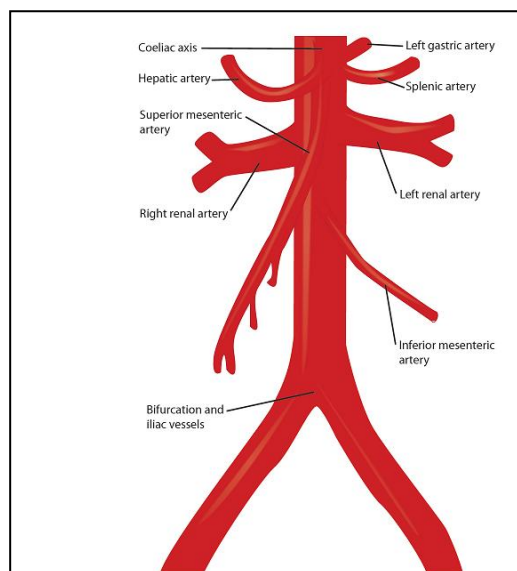




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Before starting to scan the aorta, it is helpful to understand the anatomy, which is shown in the image. Note the branches of the coeliac axis and its relationship to the superior mesenteric artery (SMA).

The coeliac axis is 1-2 cm below the diaphragm, the superior mesenteric artery is 2 cm below the coeliac axis, the inferior mesenteric artery is 4 cm above the bifurcation, the aorta bifurcates at, or immediately below, the umbilicus (L4), the maximum external diameter (measured from outer wall to outer wall) at different levels will vary, ie 3cm at the epigastrium, 1.5cm at the bifurcation.



Fusiform aneurysms are the type most commonly seen in the abdominal aorta. Most fusiform aneurysms are true aneurysms. The weakness is often along an extended section of the aorta and involves the aorta's entire circumference. The weakened portion appears as a roughly symmetrical bulge, as shown in the image.

Saccular aneurysms appear like a small blister or bleb on the side of the aorta and are

asymmetrical. They may be pseudoaneurysms caused by trauma, such as a car accident, or by a penetrating aortic ulcer.

Dissecting aneurysms occur when a tear begins within the wall of the aorta causing the wall layers to separate. Dissections can cause aneurysms, but an existing aneurysm can also dissect. This is more commonly seen in the thoracic aorta.

Traditional screening for suspected AAA has been physical examination plus further imaging for high risk cases. At best this method is only 68 % sensitive for AAA. Computed tomography is the gold standard investigation but can lead to a



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delay in definitive diagnosis and treatment. An early ultrasound scan is the primary investigation of choice. This is helpful for those patients who are requiring resuscitation, and also for early identification to assist with a management plan.

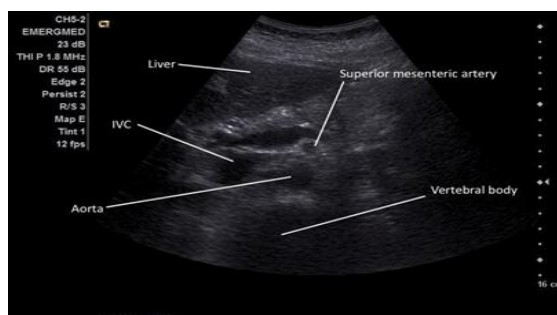
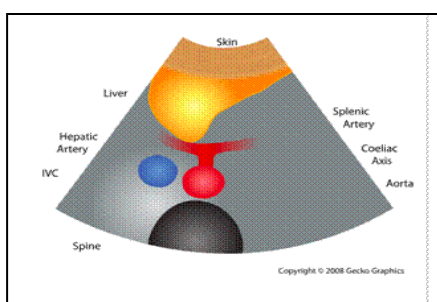
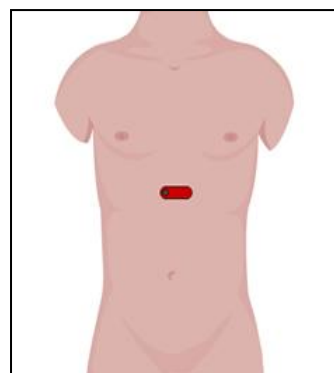
Key point:

Abdominal pain and collapse are common as is AAA; a low threshold should exist for scanning the abdominal aorta in emergency department patients.

A scan should always be carried out when an AAA is suspected. Clinical features may include:

- Unexplained back or abdominal pain in an older patient
- Renal colic in an older patient
- Syncopal episode or hypovolemic shock in an older patient
- Clinical findings demonstrating a pulsatile abdominal mass or abdominal bruit
- Risk factors - Ischaemic heart disease (IHD)/ Peripheral vascular disease (PVD)/age

Imagine the probe is a sword and imagine cutting through the internal area which you want to see. With the patient supine, start transversely at the epigastrium as cephalad as possible. If the patient has eaten recently it may not be possible to view beyond the stomach/duodenum. Start with a transverse section. Identify the vertebral body (pre-vertebral stripe and acoustic shadow). The aorta lies anterior to the echogenic pre-vertebral stripe. Use the left lobe of the liver as the initial acoustic window. You should image the coeliac axis, then the superior mesenteric artery (SMA). Lower you will find the renal vessels, and around the umbilicus the bifurcation and origin of the iliac arteries.





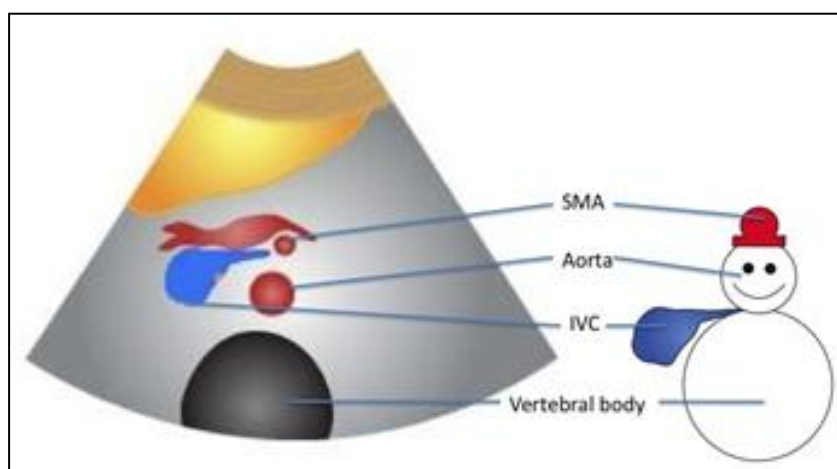
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Key point:

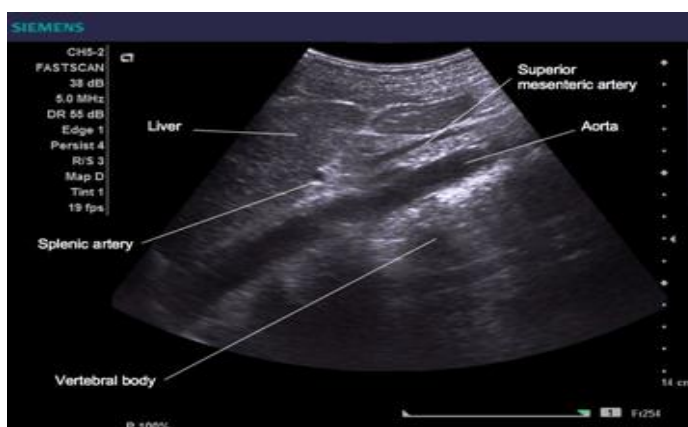
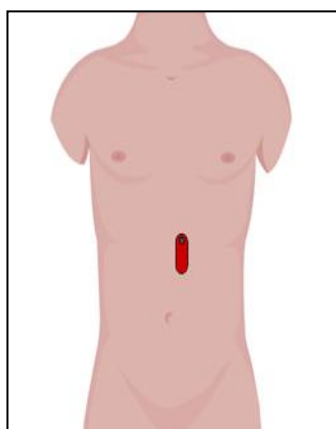
Start in transverse section before moving on to a longitudinal section.

The coeliac axis is seen high in the epigastrium. The division into splenic artery and hepatic artery is said to resemble the wings of a seagull, with each division appearing as a wing. Often bowel gas obscures the coeliac axis, and this view may be difficult to obtain.

Lower down is the superior mesenteric artery (SMA), which has a characteristic appearance. When seen in transverse section, it is important that the 'snowman' be recognised.



Secondly, obtain **longitudinal images** of the entire abdominal aorta. Notice how in the image the aorta moves from quite deep at the diaphragm, to much more shallow at the umbilicus. This is due to the normal lumbar lordosis. The SMA is readily seen, together with the lumbar vertebral bodies and discs in the background.



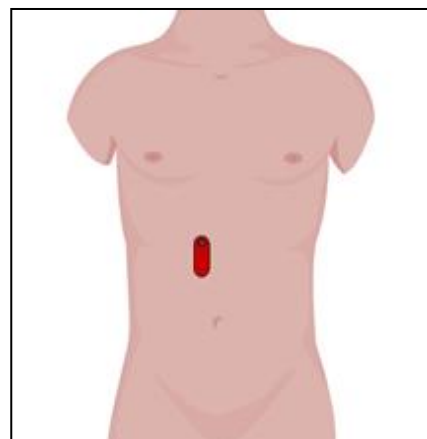
Thirdly, move the probe slightly over to the right to view the inferior vena cava (IVC) in longitudinal section. Viewing the IVC as it passes through the diaphragm can give an indication of the load on the right side of the heart. In unventilated patients, if the IVC diameter (IVCD) is $>25\text{mm}$ with minimal collapse, this is indicative of increased



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right atrial pressure (RAP) e.g. Cor Pulmonale, fluid overload. A diameter of $<15\text{mm}$ with complete collapse is indicative of being under filled²⁴.

In ventilated patients, the correlation between the IVCD and RAP is less reliable. Research suggests that assessment at end-expiration using ECG synchronisation improves correlation. Furthermore, diameters over 12mm appear to have no predictive value of RAP, whereas diameters below 12mm may. An IVCD that is seen to vary throughout the respiratory cycle has been associated with fluid responsiveness, whereas minimally varying IVCD has been associated with less fluid responsiveness.

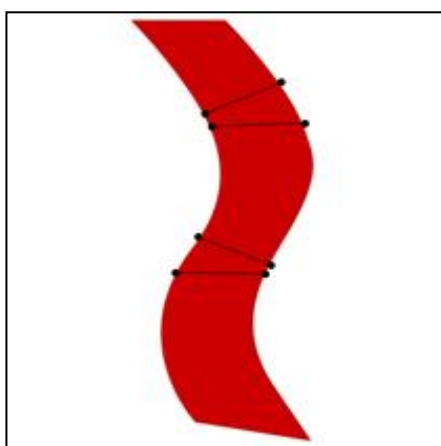
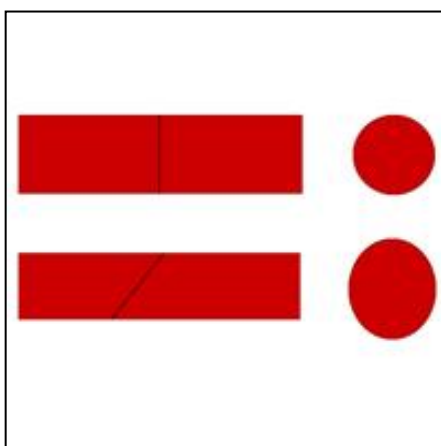


Key point:

IVC assessment can give an indication of hydration.

Finally, measure the antero-posterior diameter of the aorta. The measurements should be from outer wall to outer wall of the vessel. Any clot or false lumen should be ignored when measuring.

Be careful to avoid two pitfalls. One is taking a non-perpendicular view of the vessel, thereby creating a 'salami slice' with over-estimation of the diameter. As the aorta is angled against the lumbar lordosis, the probe often needs to point slightly caudally to overcome this. The other is failing to appreciate a tortuous aorta, though this only creates significant problems if transverse measurements are taken.



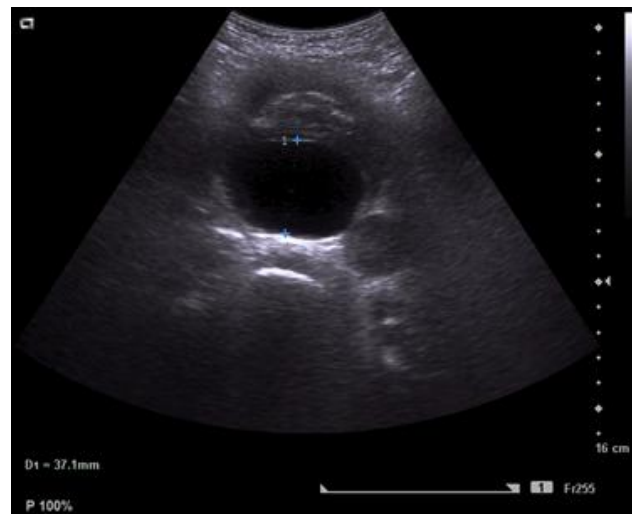


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Abnormal appearances can vary immensely, but one common appearance, besides a fusiform aneurysm, is the presence of clot within the lumen. This can easily lead to errors in measurement. In the case shown here, the antero-posterior measurement has been incorrectly assessed at 37.1 mm, whereas the aneurysm is actually around 60 mm in diameter. This is a serious error, as the risk of rupture at 37 mm is considerably less than at 60 mm.

There are many pitfalls in AAA scanning; most occur when the patient is not appropriately assessed clinically. Be wary of diagnosing 'renal colic' or musculoskeletal back pain in any patient over 60 years of age without first excluding AAA. Any patient, presenting with renal colic in this age group, should have an ultrasound scan to ensure that the aorta is non-aneurysmal.

Do not exclude an AAA unless the whole abdominal aorta and proximal iliac arteries have been visualised. At all times think about the history and context, and ensure you are attempting to answer a legitimate question.





Introduction to Point-of-Care Ultrasound

Ultrasound Guided Vascular Access

In routine Emergency Medicine practice, we use peripheral venous, central venous and arterial catheters in adults and children. Ultrasound has been used to assist line placement for over 20 years; it aids placement of central lines as well as peripheral lines, both in terms of speed of access and reduction of complications^{25,26}. The National Institute for Clinical Excellence (NICE)²⁷ has highlighted ultrasound to guide central venous access, this recommendation has been an important influence toward wider use of ultrasound in Emergency Medicine²⁸. This learning session will cover the indications and techniques for jugular, femoral and peripheral cannulation.

Indications

The indications for the use of ultrasound in vascular access vary. In central access, ultrasound should be used at all times²⁹ unless time-critical intervention mandates otherwise (eg in cardiac arrest)²⁷. In femoral access, it is a very useful adjunct. In peripheral access it has a use when conventional access fails. This may be in an



ill patient who is shut-down, or in an intravenous drug user whose veins are damaged. In both instances the basilic vein medial to the biceps above the elbow is usually accessible and patent. Peripheral cannulation, whilst invasive, does not carry the risks of air embolism, bleeding and damage to other structures that jugular and femoral cannulation carries.

The use of a central cannula is immensely helpful when assessing filling pressures in cases where there is significant potential for misjudging intra-venous fluid

resuscitation. This is particularly the case in the elderly whose physiology allows much less margin of error.





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Other sources of information are urinary output, and ultrasound assessment of the inferior vena cava (IVC). Viewing the IVC as it passes through the diaphragm can give an indication of the load on the right side of the heart. If the diameter is $>2.5\text{cm}$ with minimal collapse this is indicative of increased right atrial pressure (e.g. Cor Pulmonale, fluid overload). A diameter of $<1.5\text{cm}$ with complete collapse is indicative of being under filled, and a useful indicator of hypovolaemic shock³⁰.

Definition

For the purposes of this training document the following terms have these meanings:

- Central venous cannulation means internal jugular cannulation.
- Femoral cannulation means the common femoral vein (and not the great saphenous vein sometimes cannulated in error). This may be damaged in intravenous drug users (IVDU).
- Peripheral cannulation refers to basilic vein cannulation.

Basic science, anatomy and technical considerations

Ultrasound in Emergency Medicine facilitates identification of vascular anatomy and direct visualisation and cannulation of vessels.

The aim is therefore twofold:

- to identify relevant anatomy and pathology prior to cannulation
- to use ultrasound to guide the process of cannulation

Identification of structures

The difference between veins and arteries can be determined by compressibility, that is, veins compress and arteries do not. Here is the normal internal jugular vein (IJV)





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and carotid. When the probe is pressed into the neck to compress the structures, the vein is obliterated while the artery remains.

Meanwhile, if the patient carries out a Valsalva manoeuvre, the IJV dilates.

Furthermore, the shape of the vessels is different. Arteries tend to be circular in transverse view, with muscular walls, whereas veins are often oval.

Their flow dynamics differs, and if colour flow is available it can be utilised to determine this. With the probe angled so that flow is marginally towards, or away from the probe, the colour flow convention is:

Blue = Away

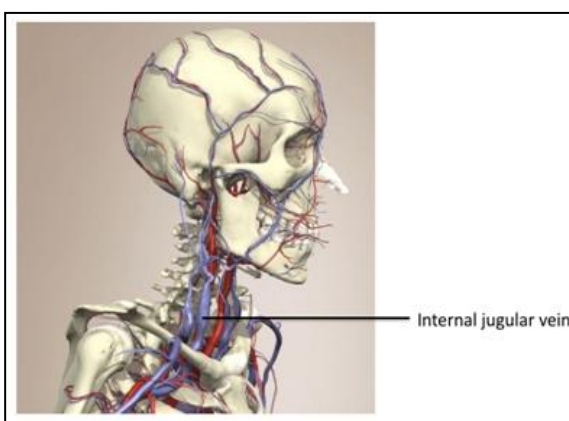
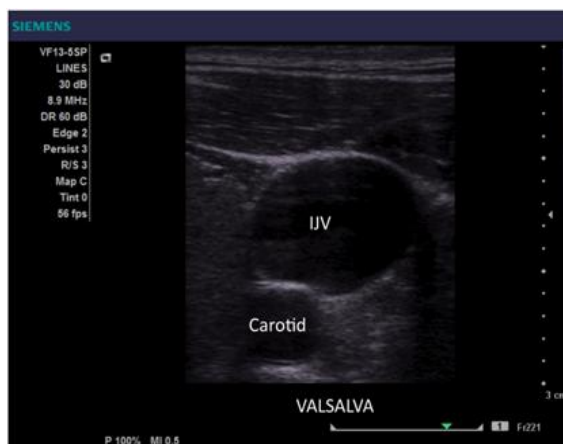
Red = Towards

This is easily remembered by the acronym B.A.R.T.

This image of a groin A-V fistula shows the value of colour flow.

Neck anatomy

The right side of the neck is usually selected to avoid theoretical risk of damage to thoracic duct, which lies on the left. The thoracic duct ascends through the mediastinum and enters to left internal jugular vein. While injury to the thoracic duct is unlikely, it can produce a chylothorax³¹. Traditionally the approach was defined by finding the apex of the triangle formed by the confluence of the sternal and clavicular parts of the sterno-cleido-mastoid muscle. Note that excess head rotation can reduce the IJV diameter and is best avoided. With ultrasound





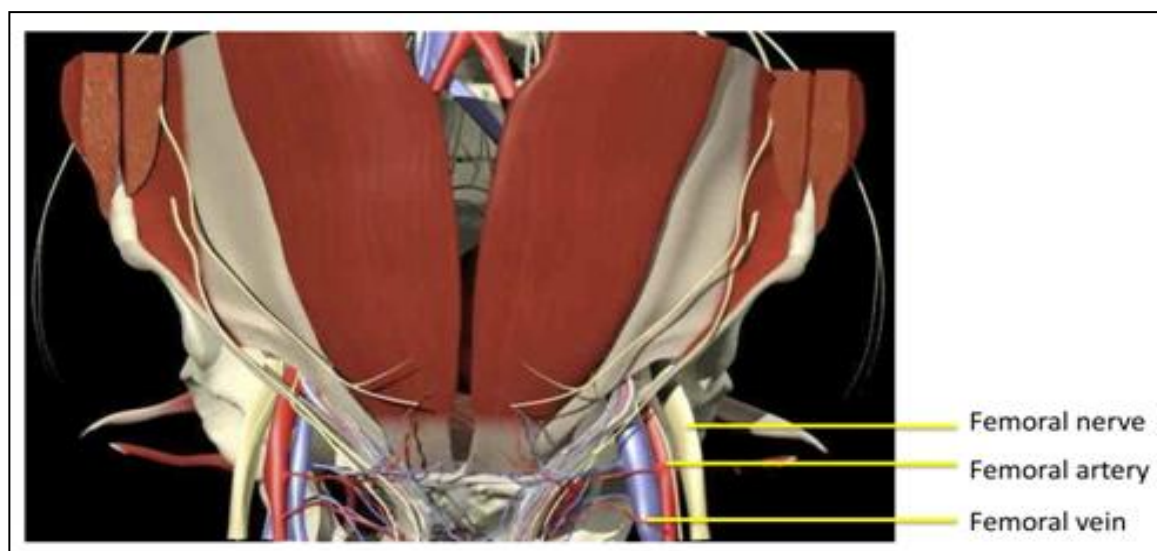
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guided CVC, the exact approach can be determined by direct visualisation of the anatomy. The approach is still within the triangle, but an optimal site can readily be selected. It is important to palpate the location of the two parts of the sterno-cleido mastoid muscle, and to recognise them by ultrasound imaging, as a needle should not be introduced through their muscle bulk.

Femoral canal anatomy

In the femoral canal the location of the femoral vein is medial to the artery (Nerve Artery Vein Lymphatics=NAVeL proceeding lateral to medial in the canal).

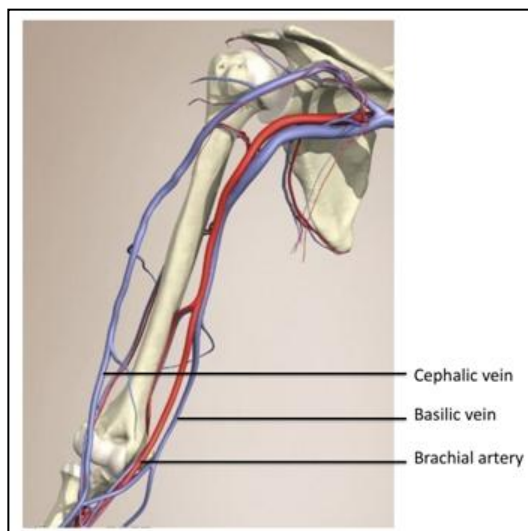
Its depth varies, and ultrasound location aids speed and efficacy of cannulation.



The inguinal ligament is an important landmark, as keeping immediately caudal will avoid cannulating the great saphenous vein, or entering the peritoneal cavity as the femoral dive posteriorly proximal to the inguinal ligament.

Basilic vein anatomy

Peripheral cannulation can be attempted at any site, but technical expertise in cannulation of the basilic vein is extremely valuable in Emergency Medicine, as this vein is almost always patent. It tends to lie at least 5 mm below the skin, and may be deeper. It is found in the recess created by the medial border of the biceps muscle.





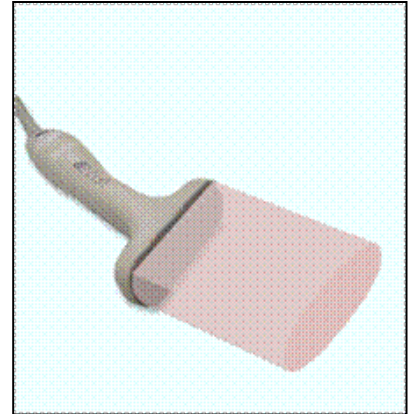
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Technical application of ultrasound when cannulating

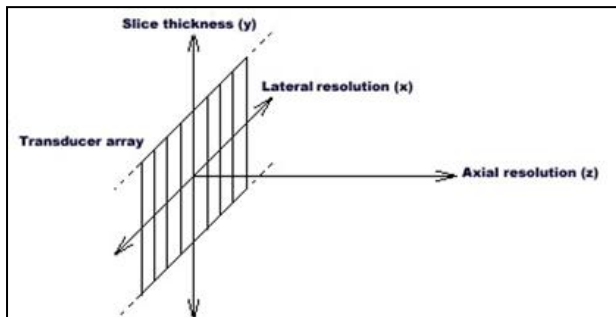
In all cases, a linear, high frequency probe should be selected. The machine should be set to a depth of around 5 cm for central access, 4 cm for femoral and 3cm for basilic cannulation. The TGC should be flat. In all cases avoid zoom or the skin surface will not be seen.

For a novice trainee, this may be the first use of ultrasound in order to carry out an intervention. There are new skills sets to learn, and two key technical issues when introducing a needle into tissue with the while viewing it on the screen. These are:

1. Parallelism
2. Angle of approach



Parallelism is a function of the physical characteristics of a linear probe. The transducer array will effectively “see” a needle only if it sits within the tolerances of the lateral and slice thickness resolution. This is illustrated left, and the typical



Axial 0.2-0.5 mm

Lateral 1-2 mm

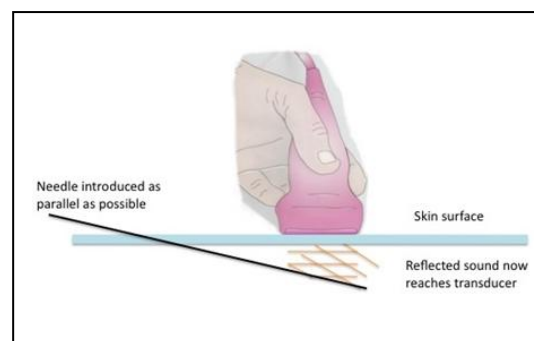
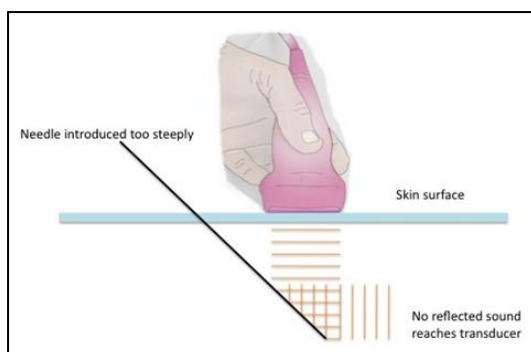
Slice thickness ≈ 5 mm

tolerances are shown in the table. This means that the operator needs to keep the needle within the very narrow slice

thickness of the probe, typically 5 mm or less.

The angle of approach of the needle into the tissue is critical. If this is too steep, the reflected sound does not return to the probe, and consequently no image is seen.

Angles less than 35 degrees to the skin are needed to see the needle, and the smaller the angle, the better the image, as shown here.





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Ultrasound can be used in one of two ways when carrying out invasive procedures:

- Static ultrasound assisted. Anatomic structures are identified, and an insertion position is identified with ultrasound. This may be marked on the skin. The cannulation then proceeds as it would without ultrasound and is not performed with the transducer imaging the needle being introduced or entering the vessel. Its use is merely to demonstrate the position of the vessel. In most instances this is sub-optimal, and not recommended.
- Real-Time ultrasound guided (recommended). The ultrasound transducer is placed in a sterile covering and the procedure is performed with simultaneous ultrasound visualisation of the cannulation.

Clinical assessment & risk stratification

All cannulations, ultrasound guided or otherwise, are undertaken in the light of the clinical setting. The clinician should be mindful of the fact that internal jugular and femoral cannulation are invasive techniques with an attendant risk of harm, and should have adequate justification. These techniques can also be used in children^{32,33}, and ultrasound guided femoral cannulation can be rapid and extremely helpful in the very sick child. The groin is often readily available if the neck is not due to airway manoeuvres. Consent should always be obtained and documented, subject to the degree of urgency and potential benefit versus risk.

The competent use of ultrasound will always make internal jugular and femoral cannulation safer. Its use decreases complications, increases the first-time success of line placement, decreases the number of efforts required, improves the efficiency of technique performance and helps improve success of resuscitation in otherwise difficult cases.

While in many EM ultrasound applications it is acceptable to learn using human subjects, the invasive nature of vascular access requires a proportion of training be performed using human patient simulators. The most basic of these is a thin tube in a block of soft gel. This type of simulator helps the trainee to gain the hand-eye co-ordination required, together with the angle of approach.

Several central venous simulators provide a life-like image of the anatomy, while allowing a simulation vessel to be cannulated. Internal jugular cannulation should be learned in this way if possible. The trainee who already has experience in central



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venous cannulation will be able to migrate to ultrasound-guided cannulation without a great deal of training compared to the trainee who has never carried out the technique. In all instances there is the need for sufficient one to one supervision by the trainer.

Precautions

Be cautious in significantly hypovolemic patients as negative pressures result in poorly filled veins, with increased technical difficulty. Treatment of hypovolemic shock has always been viewed as technically challenging to attempt to use a central line as the principal iv route. However, using ultrasound, CVC is not difficult in the hypovolaemic patient using 30° head down³⁴.

Technique

Select the correct probe and machine settings. All invasive procedures should employ standard sterile techniques to diminish the risk of infection.

For venous access using real time ultrasound, a sterile probe cover should always be used. Whilst it is reasonable to attempt peripheral and femoral access by skin marking and no real time ultrasound, (especially in cardiac arrest¹¹) this is not acceptable for internal jugular cannulation.

Basic tips

Some linear probes have their surfaces at right angles to the skin, while others are angled. In the case of the latter, it may be easier to hold the probe in the most natural way, and switch the marker from left to right on the screen. You will soon discover the need to stabilise the probe with the little finger touching the skin. Unless you do this, the slippery nature of the gel will inevitable mean that your probe slowly drifts and you loose the screen image. In all invasive procedures it is important to learn to watch the screen, not your hands. This involves an appreciation of which way to move the cannula to achieve the desired result.





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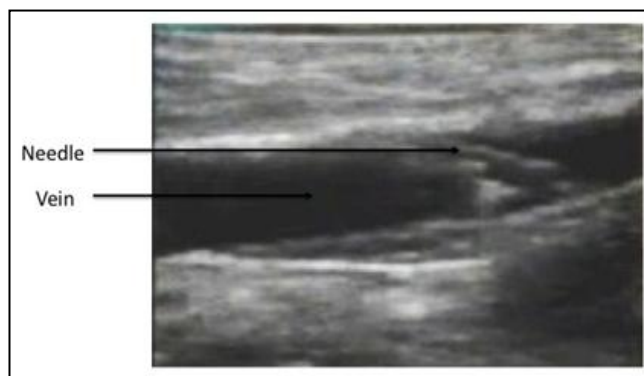
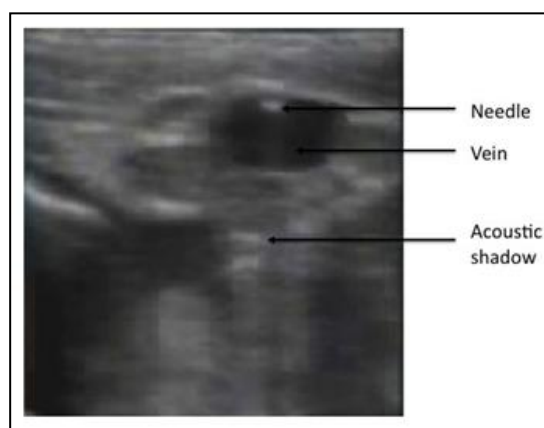
The first skill to acquire is to be able to recognize the vein in transverse section, and to distinguish it from the artery by virtue of its compressibility. Then learn to rotate the probe to view the vein in longitudinal section. This entails knowing which part of the probe corresponds to the marker on the screen.

Venous cannulation can be carried out using a single or dual operator technique. It is recommended that initially the trainee works with the trainer in a dual operator technique, with the ultrasound carried out by the trainer, and the cannulation by the trainee. This is of benefit for training purposes, but also frees up both hands for the trainee and reduces the risk of the probe sliding off the area of work and onto the floor. The consequences of dropping a probe are more than inconvenience and loss of sterility – crystals may be broken in the probe resulting in permanent damage.

Finally, be aware that soon after a vessel is entered, if successful cannulation does not occur, a small clot may form in the lumen of the cannula. This can result in subsequent failure to get flash-back, even when correctly placed. Priming the cannula with heparinised saline can reduce the risk but may not prevent it.

Real time guided cannulation is described in the following slides for each of the three areas (internal jugular, femoral and basilic). In real time cannulation there are two accepted approaches:

- The short axis, transverse approach allows only a cross section of the needle to be visualised by the ultrasound beam and may lead to errors in depth perception of the needle. The acoustic shadow can lead to confusion. The potential of the scan is not optimised by this approach.
- The long axis orientation allows the operator to trace the entire path and angle of the needle from the entry site at the skin and into the vessel.



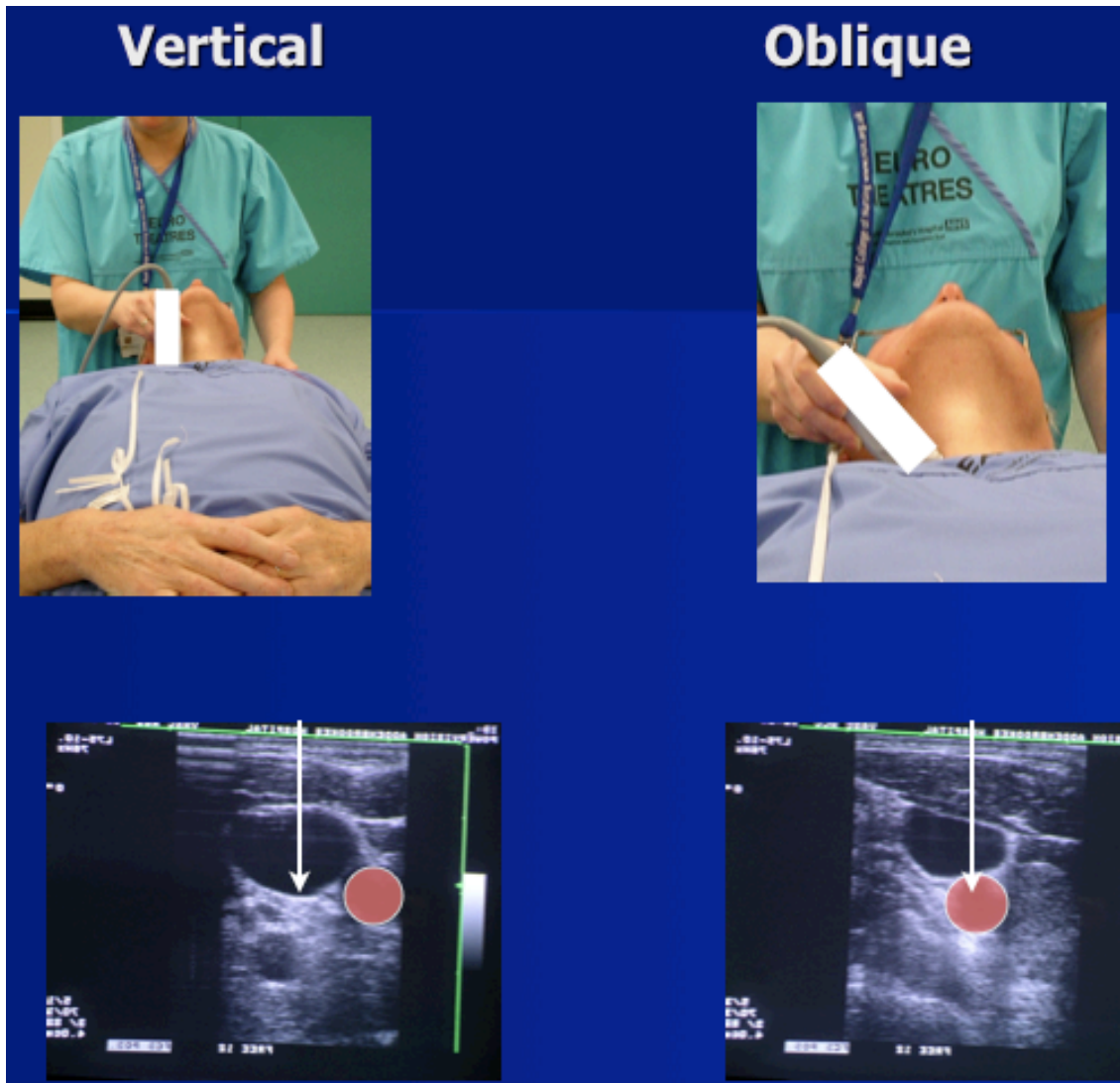


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Specific techniques

A. Jugular

Ensure that the probe is held vertically, not obliquely, as often happens when the contour of the neck is followed. A more vertical position should ensure that the carotid artery lies more laterally to the internal jugular vein.



Preparation

Sterile setting, drapes, gloves etc

Seldinger cannula of choice

Sterile sheath for ultrasound probe. Standard gel within sheath and sterile gel outside – can use catheterization lignocaine. Secure with a sterile band

Set ultrasound to 10MHz linear probe, should default to approx 4cm depth

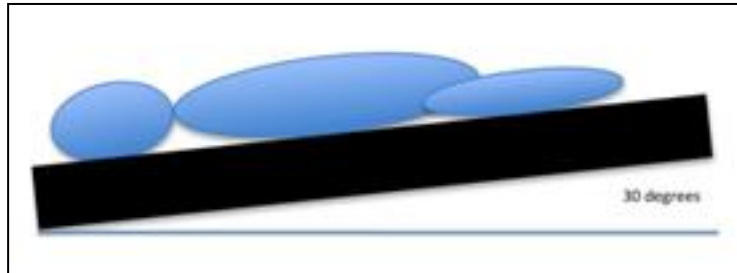
Use local anaesthetic.



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Positioning

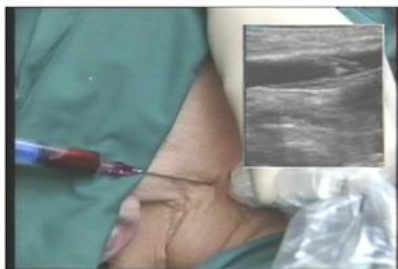
Patient 30° head-down,¹⁰
little neck rotation and no
extension¹². This maximises
venous filling and reduces
the risk of air embolism.



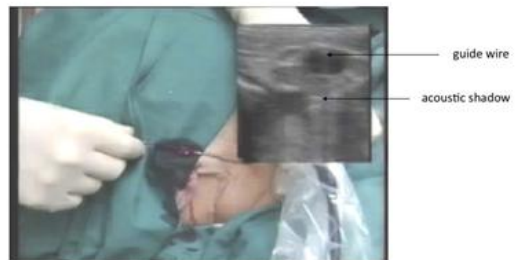
Procedural technique

- In cross section, find vein (80% over or lateral to artery and compressible)
- Rotate probe to see vein in longitudinal section. Check it is still compressible
- Introduce needle through the skin bevel upwards
- Watch it enter the vein
- When blood obtained feed in wire
- Check it is being fed caudally
- Observe progress on screen
- Check it remains in the lumen--Beware of acoustic shadow!
- Feed the cannula over the wire
- Secure the line. Check the line position with a CXR

Needle introduced bevel upwards



Feed cannula over wire



B.



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Femoral

Preparation

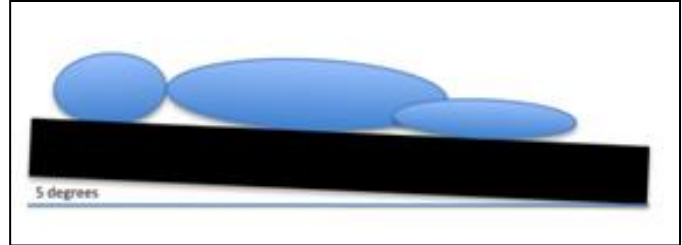
As for CVC

Positioning

Patient 5° head-up. This ensures filling of the vein without undue pressure.

Procedural technique

- In cross section, find vein (medial or med/ant to artery)
- Rotate probe to see vein in longitudinal section. Check it is still compressible
- Introduce needle through the skin bevel upwards
- Watch it enter the vein
- When blood obtained feed in wire
OR, if cannula over needle, thread cannula into the vein
- Observe the progress on screen
- Check it remains in the lumen--
Beware of the acoustic shadow!
- Secure the line



C. Peripheral³⁷

Preparation

As before

Positioning

The technique is most facilitated by the upper limb being extended and externally rotated, or by the hands being beneath the patient's head.

Procedural technique

- In cross section, find the basilic vein (in the recess medial to the biceps)
- Rotate the probe to see the vein longitudinally. Check it is still compressible
- Introduce needle through the skin bevel upwards
- Watch it enter the vein
- When blood obtained feed in wire OR, if cannula over needle, thread cannula into vein
- Observe progress on screen



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- Check it remains in the lumen
- Beware of the acoustic shadow!
- If Seldinger, feed the cannula over the wire.
- Secure the line



Line Care & Use

- Always maintain sterility
- Always maintain line security. Lines may be pulled out by accident, significant bleeding or air embolism may occur.
- In patients who are hypovolemic, once some fluid is introduced, the venous system becomes more accessible to conventional cannulation.

Pitfalls - all

Air embolism

Loss of sterility

Breakage of probe

Dropping the probe (so use a second operator/helper while gaining experience¹⁴)

L->R disorientation on screen

CVC

Not filling the vein by using head down

Vein compression by probe or too much neck rotation

Femoral

Haemorrhage

Peripheral

Damage to the brachial artery which is compressible if sufficient pressure is applied.



Introduction to Point-of-Care Ultrasound

Echocardiography in Life Support (ELS)

(see also under FAST)

The ELS exam is a limited echocardiogram used in the setting of non-shockable cardiac arrest rhythms (PEA and asystole) or shock. The heart is interrogated during a rhythm check for wall motion and the treatable causes of PEA (cardiac tamponade, hypovolemia, and pulmonary embolism). The operator will assess the pericardial space for fluid, look for the presence/absence and character of ventricular wall motion, and look for gross abnormalities of right and left ventricular size. The subxiphoid view is primarily used, augmented by a further view; most commonly the parasternal long axis view (other appropriate views include the parasternal short axis view and the apical four chamber view). The longitudinal subxiphoid view is used for visualisation of the inferior vena cava (IVC) for assessment of diameter and collapsibility.

Acquisition of the best possible image occurs through:

- Performance of the subxiphoid view and long axis parasternal view
- Identification of the pericardial space and any fluid that is present.
- Identification of the presence/absence of ventricular wall motion.
- Identification of right and left ventricular size.
- Identification of the IVC in LS and measurement of IVC diameter and collapsibility.

Focused Echocardiography

Hypotension is a common emergency presentation in the Emergency Department (ED) and Medical Admissions Unit (MAU). Due to the physiologic complexities of this state, the etiology is often unclear to clinicians at initial presentation. Clinical indicators such as vital signs and physical exam are often unreliable in distinguishing causes of hypotension; the correct etiology of hypotension is only identified 25-50% of the time during initial assessment. This is of obvious concern since hypotension in the ED can represent an in-patient mortality of up to 25%. Determining the cause of hypotension in the ED population can be a diagnostic challenge. Point of care ultrasound (PoCUS) of the heart can help differentiate between cardiogenic (congestive heart failure) and obstructive (cardiac tamponade, tension pneumothorax, pulmonary embolism) causes, or other causes such as sepsis



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(hyperdynamic cardiac function) and hypovolemia (poorly filling left ventricle).

Limited cardiac echocardiography or “Echo in life support (ELS)” can be performed as part of goal-directed protocols for undifferentiated, non-traumatic hypotension.

Use of such protocols early can significantly improve the diagnostic accuracy to 80%, reducing the time to diagnosis and therapeutic intervention.

ELS includes four views of the heart: the subxiphoid, the parasternal long, the parasternal short and the apical four chamber views. Although, it is important to know how to perform all views, the subxiphoid and parasternal long views of the heart tend to yield the greatest amount of information needed in the ED setting to rapidly and non-invasively assess for pericardial effusions, left ventricular function and right ventricular dilatation at the bedside..

The subxiphoid view of the heart is helpful to assess for pericardial effusions and global contractility. If a pericardial effusion is present, the clinician is able to consider an obstructive cause of hypotension such as cardiac tamponade. If there is compromise in global contractility of the heart, the clinician can consider pump failure as a cardiogenic cause of hypotension.

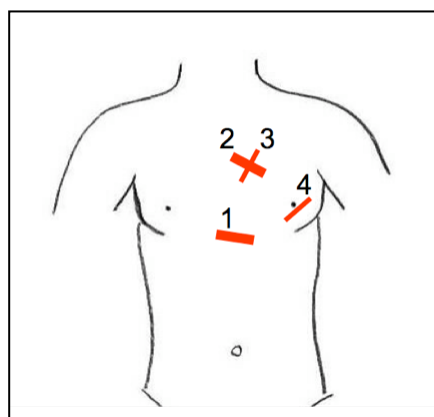
The parasternal long view of the heart can also identify pericardial effusions. However, its major benefit is in the assessment of left ventricular function. In the setting of pump failure, the left ventricle will have altered kinesis. If there is an acute obstructive cause of hypotension like a massive pulmonary embolism, there may also be evidence of right heart strain, manifested as right ventricular dilatation. The parasternal short axis and apical four chamber views aid further assessment of left ventricular function and right ventricular size.

Point of Care Cardiac Ultrasound

The four commonly used views used in PoC ultrasound of the heart are the Subxiphoid, Parasternal Long and Short, and Apical 4 Chamber views.

1. Subxiphoid view

This subcostal view is the easiest of the cardiac views to learn and perform and is often the most





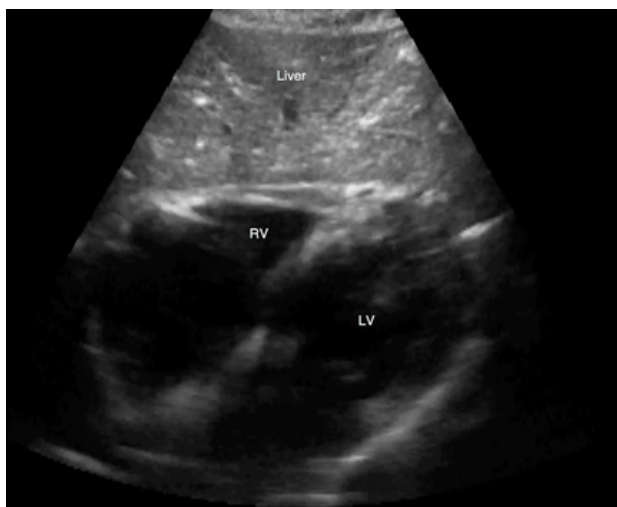
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practical. The sonographer will not interfere with any ongoing resuscitation, line insertion or intubation since the technique is performed below the chest. A curved array or phased array probe can be used starting with the initial depth setting set at maximum. The probe is placed in transverse orientation as for an abdominal examination, just caudal to the xiphoid process. The sonographer should hold the probe almost parallel to the abdominal surface (15° angle), pointing the ultrasound beam toward the left scapula. This cut “slices” the heart along its 4-chamber axis, “lifting the anterior section off,” revealing all 4 chambers.



The heart may not be visualized until the probe is swept anteriorly to a very shallow angle. Once the heart is visualized, magnify the image, adjust the gain and obtain the best view of the landmarks. This includes: the pericardium, the septum, the right ventricle and the left ventricle.

It is important to understand the visual-spatial relation of these structures to the screen. The sonographer can then interrogate the heart by slowly sweeping anteriorly and posteriorly until the organ disappears in both planes.

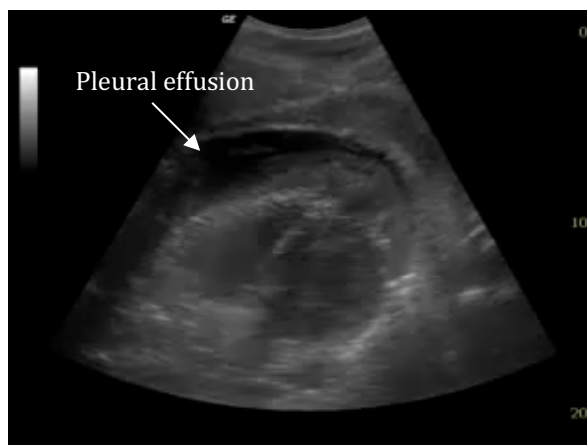


The sonographer would look for a pericardial effusion and presence of vigorous global contractility. A pericardial effusion will appear as anechoic or dark space inside the hyperechoic or white pericardium.



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It is vital to remember that PoCUS is used for focused clinical questions with binary answers. This is especially true in the subxiphoid view where it is to be determined if there is a pericardial effusion or evidence of vigorous global contractility (e.g., absence = cardiac standstill).



On occasion, it may be difficult to obtain good views of the heart due to body habitus or anatomic variation. There are techniques the sonographer may use to improve image generation. One method is to have the patient hold their breath in deep inspiration (either voluntarily or by mechanical ventilation). Flattening the diaphragm will push the heart lower in the chest and closer to the probe. Some difficulty with this method occurs with a patient in pain or unable to cooperate. A second method useful in obese patients is to flex their knees to relax the abdominal muscles. Third, some patients are amenable to using the liver as an ultrasound window by adjusting the probe to the patient's right upper quadrant.

The sonographer must also be aware of false positives while performing the subxiphoid view. Some patients may have normally occurring epicardial fat. This can appear as an echolucent stripe anterior to the heart. However, any clinically significant pericardial effusion present anteriorly will be also seen posteriorly due to the gravity dependent nature of fluid; the epicardial fat pad will disappear as the sonographer sweeps posteriorly.

2. Parasternal Long Axis View

The parasternal long axis (PLAX) view of the heart can be performed as an adjunct to the subxiphoid view, or where a subxiphoid image cannot be generated despite using the use of the above techniques or if the scan is indeterminate. The PLAX view is performed using a phased array or cardiac probe. It is possible to use the curved array probe; however the smaller footprint of the phased array allows an improved view between the ribs of the anterior thorax. The heart is "sliced" along its long axis, with the right ventricle anterior and the left ventricle deep and posterior.



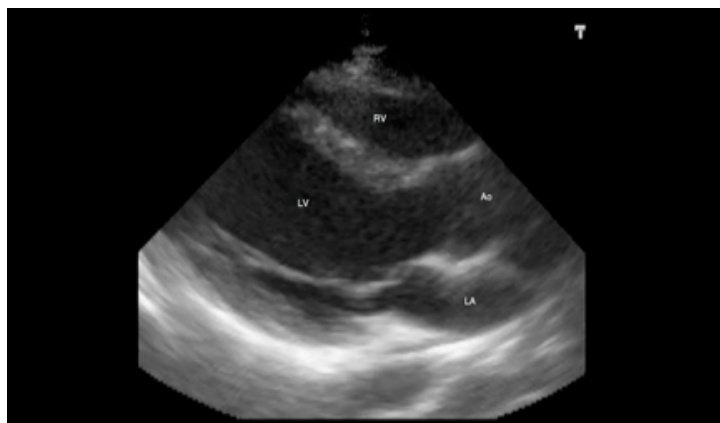
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The image orientation used in this view varies from site to site and with user preference/training. Traditionally, the cardiac probe is oriented with the indicator towards the right shoulder resulting in an image with the apex to screen left, aligning the probe with the long axis of the heart. To best understand this orientation, the sonographer should imagine observing the heart, sliced by the ultrasound beam along its long axis, viewed from a position behind the left shoulder of the patient. It also helps to recall that the right ventricle is an anterior structure and the left ventricle lies more posterior in the chest.

Starting with the transducer placed perpendicular to the skin in the third or fourth left intercostal space adjacent to the sternum - the probe can be rotated, and panned (slid) back and forth, parallel to the sternum to give the best view of the heart. It is usually helpful to roll the patient on to their left side, bringing the heart closer to the probe with less interposed lung to cause scatter.



Ideally, from near field to far field, the following structures will be seen: the right ventricular free wall, the right ventricle, ascending aorta between the right ventricle and the left atrium, the interventricular septum, and the left ventricle. The mitral and aortic valves should be seen in the inflow and outflow tracts respectively. The descending aorta will appear posterior to the heart.



The parasternal long-axis view should visualize the aortic root.

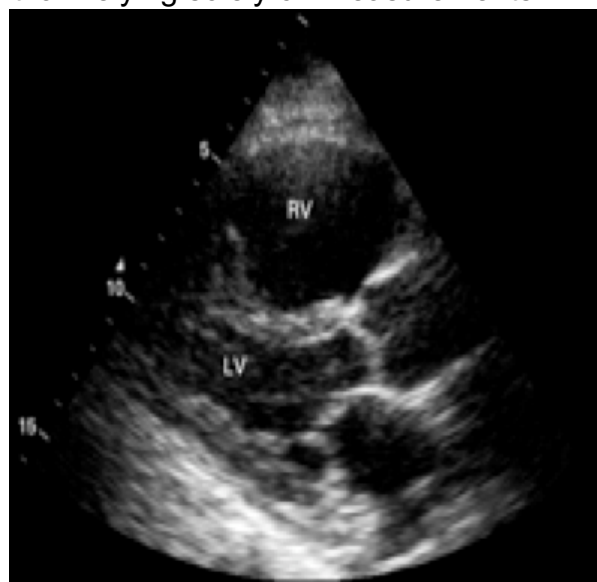
If the aortic root is absent, the image is most likely oblique. To resolve this, angle the transducer slightly in either longitudinal direction to improve the image. The orientation is: posterior in the far- field, anterior in the near field, inferior to screen left and superior to screen right.



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The PLAX view may also provide supportive evidence for the presence of a pericardial effusion, which is most likely to appear posteriorly, between the posterior pericardium and the descending aorta. Confusion can occur with pleural effusions, but pleural fluid can be differentiated by understanding the relationship to the descending aorta (pericardial effusion near field of the aorta and pleural effusion far field and without a surrounding echogenic pericardium). Tamponade may be suggested with RV diastolic collapse and RA systolic collapse, but it requires the clinical correlation of falling cardiac output.

In a 2007 study of critical care patients, Mark *et al.* concluded that the PLAX view is best for gross estimation of LV function. A change in diameter of about one-third at the mid LV level is equivalent to approximately grade 1 function. Lower contraction suggests decreased LV function. Dilatation above 5 cm at end diastole is consistent with LV systolic dysfunction¹¹. These findings can be used with clinical correlation to diagnose cardiogenic shock in the setting of undifferentiated hypotension. A qualitative approach is encouraged, rather than relying solely on measurements which are prone to error in the busy ED environment. Conversely, a left ventricle which appears to contract so vigorously that the walls appear to touch (small ventricle at the end of systole) may correlate with an ejection fraction greater than a 70%. A hyper dynamic heart in undifferentiated hypotension associated with tachycardia and a small IVC represents non-cardiogenic shock.



The right ventricle will usually appear to be between half to two-thirds of the left ventricle size. A large pulmonary embolism may result in a RV to LV ratio close to or greater than 1:1. This is most safely evaluated with a combination of the parasternal long, short and apical 4 chamber views, since on the subxiphoid view the size of the right ventricle can occasionally approximate this ratio without right heart strain being present, thus leading to a false positive result.



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3. Parasternal Short Axis View and 4. Apical 4 Chamber View

Two other less commonly used views in the emergency setting are the parasternal short axis (PSAX) and apical 4 chamber (A4C) views. To obtain the parasternal short axis view, begin in the parasternal LONG axis view. The transducer is then rotated 90° clockwise without changing the location. The probe marker should now point to the patient's left shoulder. The image produced is a slice through the transverse section of the heart allowing the sonographer to assess the concentric contraction of the left ventricle. By angling the probe, views of the aortic and mitral valves, papillary muscles and ventricular apex (in circular cross-section) are possible.

The apical window can be found by moving the transducer to the apex. This is usually made easier by positioning the patient in a steep left lateral decubitus position. The four-chamber view is obtained with the transducer dot pointing towards the 3 o'clock position. This view allows the length of the ventricles and atria to be seen in a plane perpendicular to both parasternal views. By angling the transducer acutely to the skin, without changing location or rotation, the aortic valve and root can be seen. If appropriate, further views (two chamber and apical long axis) can be obtained by rotating the probe 60° and 120° anticlockwise, respectively, without changing the location of the transducer.



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Summary of Cardiac PoCUS findings

Pathology	Sonographic findings
Right Ventricular strain	<ul style="list-style-type: none"> • Best seen on an apical 4-chamber view • The ventricular sizes can be compared • The RV will dilate and appear larger than the left with acute pressure overload on the RV, e.g., pulmonary embolism • In the unstable patient, thrombolysis (or thrombectomy if there are contraindications) should be considered.
Pericardial effusion	<ul style="list-style-type: none"> • Best seen on the subxyphoid or apical 4-chamber views (though any cardiac view may suffice) • Circumferential fluid around the heart raises concern for tamponade. As more fluid accumulates in the pericardial space, the pressure rises and the right side of the heart has difficulty filling • Right ventricular collapse is seen during diastole and is sometimes referred to as 'scalloping.' • In the setting of persistent hypotension and cardiovascular collapse, emergent pericardiocentesis or a surgical pericardial window is indicated.
Left Ventricular function	<ul style="list-style-type: none"> • Best assessed on the parasternal long or short axis view, but any cardiac view may suffice • LV contractility is one of the most important uses of ultrasound in the hypotensive patient • No mathematical measurements or calculations are necessary—simple visual estimation has been shown to be as accurate (an exact ejection fraction is not needed, but rather stratification into normal (>50%), decreased (30-50%), or severely decreased (<30%) groups) • Severely decreased LV function may signal need for inotropes • normal function means cardiogenic shock can be ruled out • Sepsis can present with any degree of LV function, but in one study a 'hyperdynamic' (>55%) LV had been shown to be 94% specific for sepsis • The degree of filling of the LV can also guide fluid management; an underfilled LV is likely to respond to IV fluids whereas a dilated LV may not.



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Evidence for use of cardiac PoCUS

“Can Cardiac PoC ultrasound be done without interfering with current guidelines for cardiac resuscitation?”

Although the studies are small there is increasing evidence to support the ability of emergency physicians to perform subxiphoid or PLAX imaging during the ten second pulse check of a cardiac arrest. The subxiphoid view is the preferred initial approach (gel on the chest makes compressions slippery) and if this fails then the PLAX approach may generate an interpretable image.

“Is PoCUS able to differentiate pulseless electrical activity (PEA)? “

PoCUS in the proper clinical context has utility in the diagnosis of PEA from mechanical, reversible conditions including severe hypovolemia, cardiac tamponade, pulmonary embolism, and tension pneumothorax. As part of the “C” in circulation of the “ABCs” of resuscitation, it can rapidly narrow the differential.

“Is PoCUS accurate for the assessment of left ventricular function?”

The subjective visual assessment of global systolic function correlates with more formal quantitative measurements of left ventricular ejection fraction and emergency physicians with limited training show high interobserver agreement with cardiology specialists. As part of a protocol driven approach to the evaluation of hypotension, appropriately trained emergency physicians can perform cardiac sonography rapidly and competently. It is most useful to answer binary questions as part of the initial physical examination and resuscitation.

Inferior Vena Cava (IVC)

In the hypotensive patient, one of the first questions a clinician must address is whether the patient requires emergency fluid resuscitation i.e. is the patient hyper- or hypovolemic. Hypotension evident in the emergency department is a predictor of in-hospital mortality, with rates as high as 25%. Clinical assessment alone can fail to determine the correct cause, with one study showing that the correct etiology in patients with undifferentiated hypotension is identified in only 24% of cases. Invasive monitoring techniques can be time consuming, costly and are not always easily performed in the Emergency Department. Non-invasive techniques, such as



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ultrasound are rapid and reliably taught to Emergency Physicians. Determining the underlying hemodynamic process in a more timely and accurate fashion may allow definitive therapeutic intervention and improve outcomes.

Inferior Vena Cava (IVC) collapsibility has been shown to correlate with central venous pressure (CVP) with the strongest correlation seen at extremes of the values in low or high-volume states. Time critical interventions are essential, and resuscitation of the hypotensive patient often cannot wait until formal cardiac imaging or invasive monitoring is available. Rapid, noninvasive, protocol based, focused bedside scanning of the venous capacitance vessels, especially the inferior vena cava (IVC) can help determine the underlying etiology while reducing delays to supportive therapy and appropriate early resuscitation. Assessment of CVP can also be estimated by the height of the jugular venous column (ultrasound measured JVP) in a patient who is able to sit at 45 degrees. This approach is less useful in the hypotensive patient who is supine.

Measurement of the inferior vena cava (IVC) and its collapsibility has been shown to be a valuable method of predicting fluid responsiveness. Fluid responsiveness describes the significant increase in cardiac output that results from volume expansion. The IVC is a major capacitance vessel, facilitating consistent venous return to the right heart. As such, it changes its diameter in a non-linear fashion in response to the filling status of the patient, increasing in diameter with increased filling pressure and volume. As well as the changes in the absolute diameter with changes in volume, in a hemodynamically normal, spontaneously ventilating patient, the IVC collapses slightly on inspiration. This is reversed in a mechanically ventilated patient where there is an increased diameter in the abdominal IVC during inspiration. The collapsibility of the IVC (or collapse index) is calculated as the change in diameter during ventilation (either spontaneous or mechanical) divided by the maximal diameter. This measurement is also used to estimate filling status.



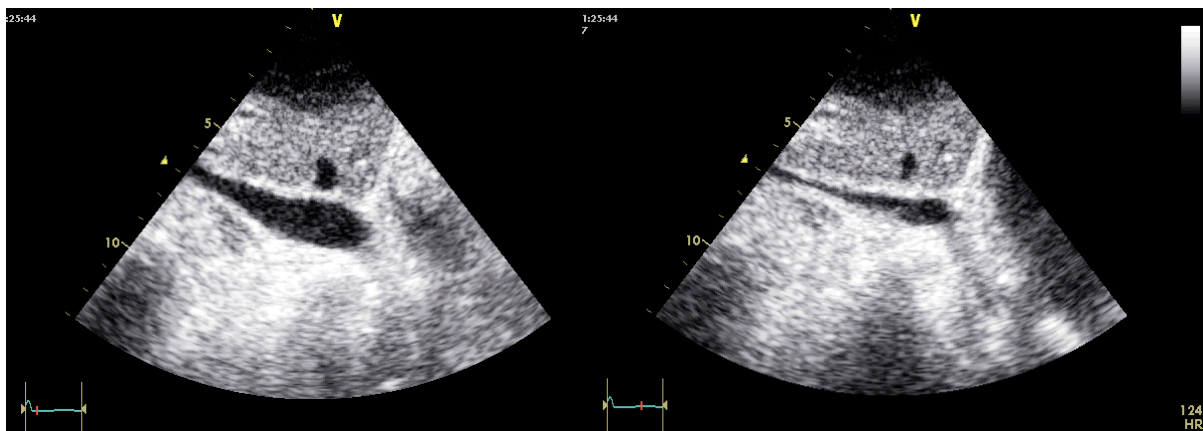
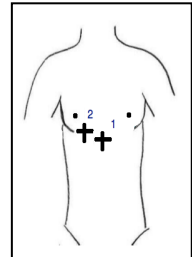
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Maximum IVC Diameter	Collapse Index (%) = $100 \times (\text{Max} - \text{Min Diameter}) / \text{Max Diameter}$	Estimated Right Atrial Pressure Estimated filling status
< 2 cm Small	> 40 to 50% Collapses	< 10 mmHg Empty (low volume state)
> 2 cm Dilated	< 40 to 50% No collapse	> 10 mmHg Full (high filling pressure)

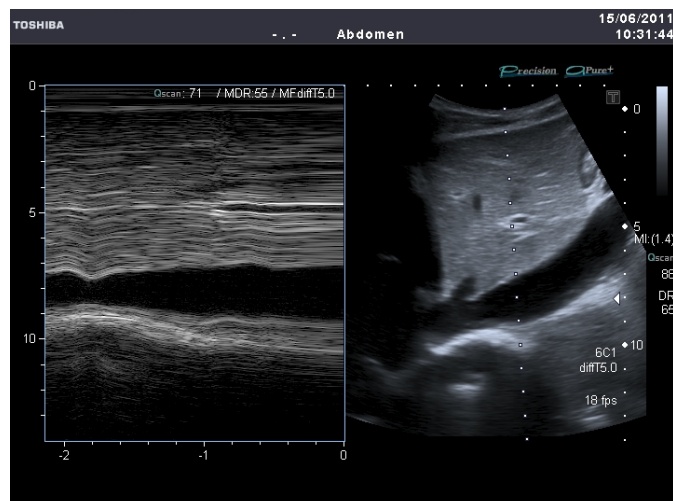
The examination

The IVC can be visualised by ultrasound using either a curvilinear or phased array probe, in both the longitudinal and transverse planes using a subcostal, or a transhepatic window.

The IVC is identified lying posterior to the liver receiving hepatic veins ventrally before it passes through the diaphragm and into the right atrium.



M (motion) mode measurements of minimal and maximal diameter can be made across the proximal IVC. *Does the probe or patient position matter?* There is evidence that movement of the diaphragm can influence the IVC measurement at the right atrial junction, and therefore measurements should not be made at that point.¹² Preferred sites are the junctions of the IVC with the hepatic vein and the junction at the left





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renal vein. Diaphragmatic movement may cause the IVC to move in and out of the longitudinal plane leading to a false impression of collapse.

While it may be more useful to measure trends of IVC diameter and collapsibility in response to fluid resuscitation, there is also evidence for cut-off values which indicate an under or overfilled status. A maximal IVC diameter of less than 2cm with inspiratory collapse of more than 40 to 50% indicates a right atrial pressure of less than 10 mmHg. Conversely a diameter of greater than 2cm with collapse of less than 40 to 50% suggests a pressure of greater than 10 mmHg (Table).

In terms of filling and fluid resuscitation, an initially small IVC diameter with significant or complete collapse indicates a low volume status that would respond to volume loading. A large dilated IVC with no or minimal collapse implies high central venous pressures and a state that would not respond to volume resuscitation alone. Further investigation and the use of other agents would be required to improve the cardiovascular status. Measurements should be repeated during resuscitation to guide optimal volumes and rates of intravenous fluid administration.

IVC size and collapse must be considered in association with ventricular size, wall motion and the presence or absence of pericardial fluid. A small chamber size with hyper-dynamic wall motion on the cardiac view is consistent with hypovolemia. Potential causes of hypovolemia can be diagnosed by further ultrasound views of the right and left flanks, pelvis and lungs, aiming to detect significant hemoperitoneum or hemothorax, and of the abdominal aorta to identify the presence of abdominal aortic aneurysm (AAA). As such, PoC assessment of the IVC is often incorporated into a shock protocol such as the Abdominal and Cardiac Evaluation with Sonography in Shock (ACES) protocol.

Potential pitfalls

Caution is required when comparing PoC ultrasound measurement of the IVC to CVP measurements, as CVP itself is a surrogate marker for filling status and can be unreliable as a guide. A systematic review to assess the techniques available for assessing intravascular volume found no correlation with circulating blood volume and stated that CVP did not predict fluid responsiveness. It is important to interpret these IVC signs within the clinical context and not as a definitive measure of right atrial pressure or intravascular volume, as there is lack of high-level evidence in the setting of critical illness.



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How easy is it to obtain adequate views?

In studies reporting IVC scanning in hypotensive patients in the trauma, emergency and ICU settings, the number of patients where the IVC could not be visualized ranged from 3% to 11% of their study population. The level of ultrasound experience was high; all of the sonographers had prior experience of bedside ultrasound and most had additional didactic teaching on the technique specifically.

Are the actual measurements made in the emergency setting accurate?

When comparing emergency physician IVC measurement with formal ECHO, there was only agreement in 68.1% of patients ($\kappa = 0.41$). These emergency physicians were all certified as proficient in ultrasound. This finding may be specific to the individuals' training, or may indicate the difficulties encountered in the emergency setting. It is important to recognize this limitation and understand the need to correlate ultrasound and clinical findings, repeat measurements and visualize the vessel in more than one plane.

How long does the measurement take?

No studies have formally assessed the time taken to perform IVC measurement, however anecdotal experience reported on average about three minutes. The IVC scan is an adjunct to the clinical exam useful in the first few minutes of assessment of the hypotensive patient.

Some disease processes can interfere with IVC measurements. Some examples are: moderate /severe tricuspid regurgitation, atrial fibrillation and raised intra-abdominal pressures. IVC compliance decreases with age, with a recent study showing a decrease in the maximal diameter of the IVC followed by a greater IVC collapsibility; however statistical variance was still within normal parameters.

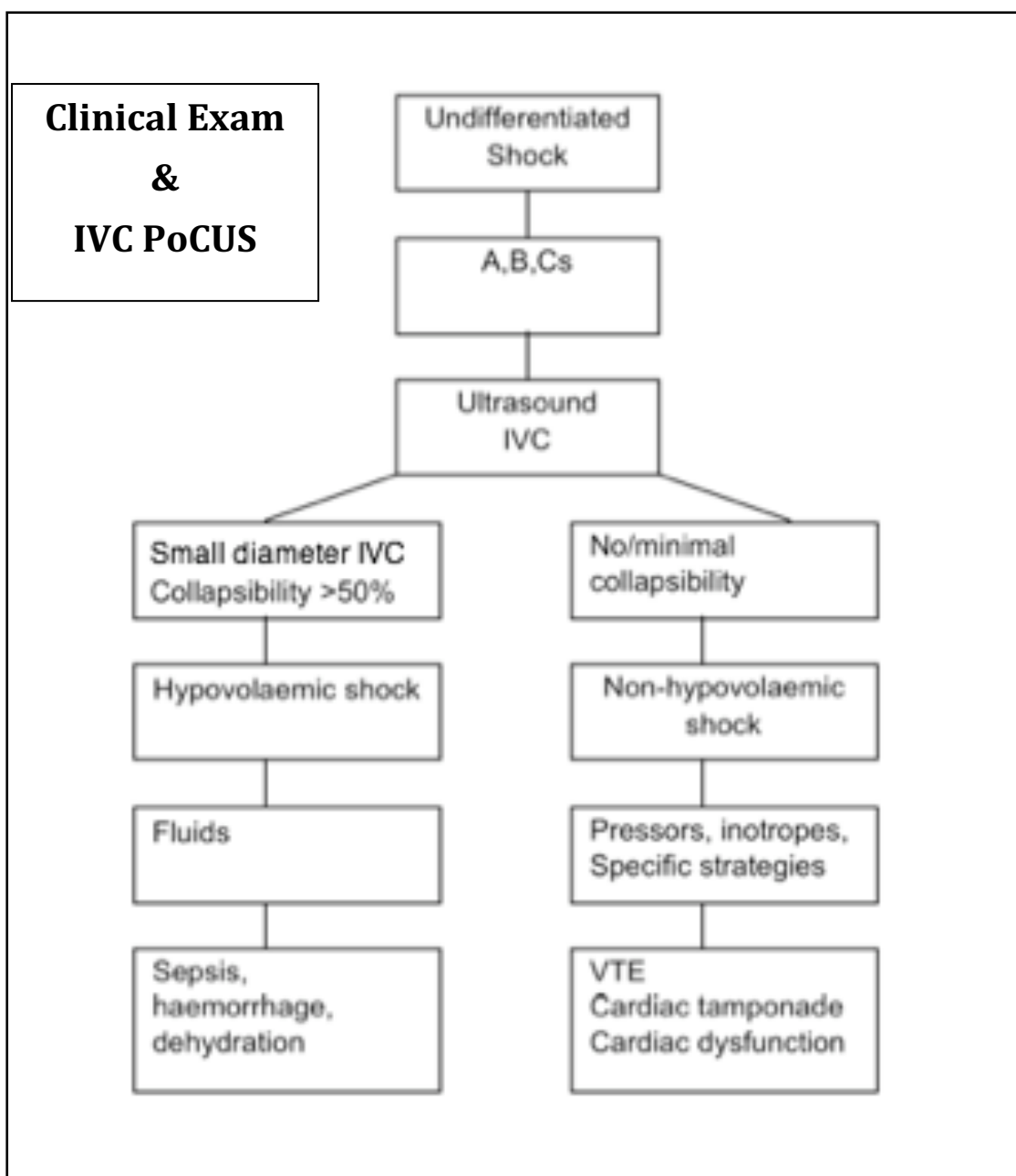
Therapy Directed Protocols

IVC measurement has its greatest value as part of a therapy directed protocol. The Abdominal and Cardiac Evaluation with Sonography in Shock (ACES) protocol and the similar Rapid Ultrasound in Shock (RUSH) exam both include elements of the FAST examination and a focused ECHO with IVC measurement included. There is evidence that early use of PoC shock ultrasound protocols leads to better differential diagnosis formulation and a more accurate final diagnosis.



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Integration of PoCUS of the IVC into a clinical algorithm may enhance performance; Figure 4 provides an approach currently under investigation. Resuscitation for undifferentiated shock is initiated following a standard “ABC” approach. A focused IVC ultrasound scan is performed, with measurement of the diameter and collapsibility if there is a diagnostic uncertainty. If the diameter is normal or reduced (< 2cm) and the collapsibility index is greater than 50% resuscitation with fluids for a hypovolemic state is commenced. If the diameter is increased, with minimal collapsibility, then other causes of hypotension should be sought.





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Ultrasound in Early Pregnancy

Emergency ultrasound can be of use in the assessment of pregnant patients who present in the first trimester with abdominal pain, vaginal bleeding, dizziness, syncope, shock, or risk factors for ectopic pregnancy. First trimester obstetric applications include:

- Identification of intrauterine pregnancy
- Identification of fetal heart rate
- Ectopic pregnancy
- Pregnancy loss (miscarriage)

Emergency ultrasound can also be used in non-pregnant women who complain of lower abdominal pain or vaginal bleeding. Applications include:

- Ovarian torsion
- Tubo-ovarian abscess
- Ovarian cyst
- Fibroids

Focused emergency ultrasound of the pelvis should be performed as a component of the clinical examination. Ultrasound findings must be considered in conjunction with history, physical signs, and other tests such as quantitative serum β -HCG. Pelvic ultrasound can be rapidly deployed, avoids radiation exposure and avoids the need for transfer of the patient away from a high dependency area.

Equipment should include the following essential components:

- Portable ultrasound system
- Curvilinear 3-5 MHz transducer
- Intracavity 5-7.5 MHz transducer (right)



Knowledge base and training

Interpretation of pathology related to the pelvis in both pregnant and non-pregnant women requires 1) A basic understanding of the normal anatomy of the female pelvis including bladder, uterus, fallopian tubes, ovaries, rectum, internal and external iliac vessels is necessary and 2) familiarity with the ultrasound appearances of the uterus



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and ovaries in the various stages of the menstrual cycle and the various stages of gestation of the normal pregnancy; 3) awareness of the differences in technique, and the advantages and disadvantages of transabdominal and transvaginal scanning for each clinical application; and most importantly, 4) appreciation of the limitations and pitfalls related to scanning of the female pelvis and the indications for requesting a formal Diagnostic Imaging Departmental scan.

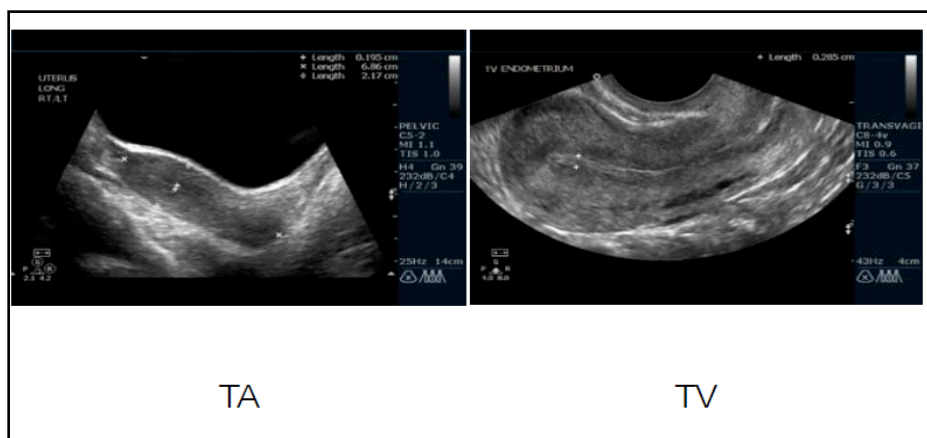
Competencies required

Structures are scanned systematically in real time ensuring the whole organ is seen in at least two perpendicular planes. The patient is examined supine with a full bladder for transabdominal scanning. The full bladder provides a window for greater resolution.

For transvaginal scanning the patient is supine with hips and knees flexed (frog-leg position), and the patient's pelvis should be lifted up from the examination trolley by placing a pillow or other pad beneath them (to allow room for manipulation of the transducer). An empty bladder is preferable for transvaginal scanning.

Transabdominal versus Transvaginal Scanning

- Complimentary Techniques
- The transabdominal approach offers a far wider Field of View allowing visualization of the entire pelvis and abdomen offering a global overview
- The limitations of transabdominal ultrasound include poor resolution in patients with empty urinary bladders, obesity or a retroverted uterus; and less than optimal characterization of adnexal masses
- Transvaginal sonography allows the use of higher frequency transducers producing much better resolution
- The limitation of transvaginal ultrasound is that the Field of View is limited





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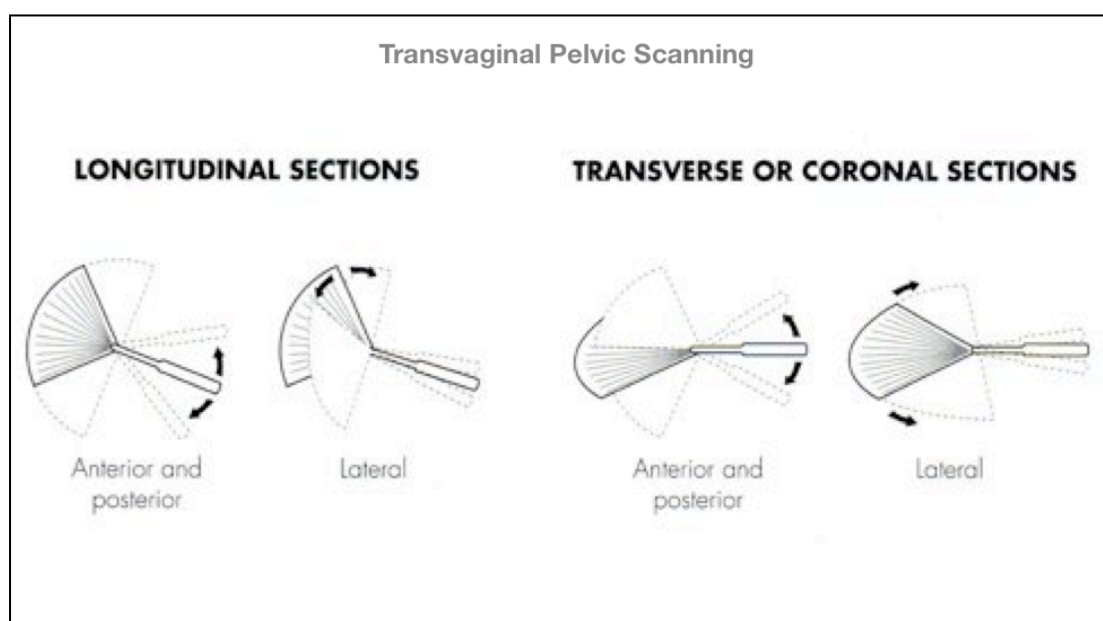
Transabdominal Pelvic Scanning

Transabdominal pelvic scanning is performed with a distended bladder which:

- Provides an acoustic window
- Displaces small bowel away from the pelvic viscera
- Partially retroflexes the normally antverted uterus to maintain the endometrial echo at a more perpendicular angle to the beam, improving definition of the endometrium and contents
- Serves as a reference standard for evaluating cystic structures

Transvaginal Pelvic Scanning

- Requires Verbal / Written Consent
- Have a Chaperone present
- Requires use of Infection Control measures—Protective Sheath (condom)
- Patient is supine with knees slightly flexed in a slight reverse Trendelenburg position
- Transvaginal pelvic scanning should be performed with an **empty** bladder
- Standard Sagittal and Transverse images should be obtained





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Anatomy

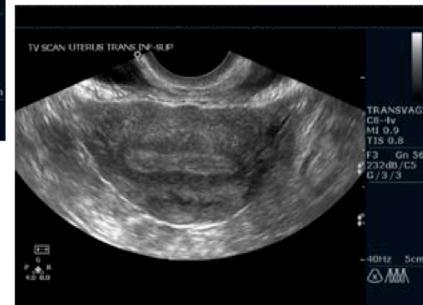
Uterus

- Identify the uterus lying against the bladder, and obtain both long and short axis views. Identify cervix, body and fundus.



TV Sagittal View

TV Coronal View



TA Sagittal View



TA Transverse View



Fallopian tubes

- Identify uterine cornua and follow fallopian tubes laterally

Ovaries and adnexa

- Identify ovaries. Identify external iliac vessels lying laterally, and the internal iliac vessels lying posteriorly to the ovaries

Pouch of Douglas

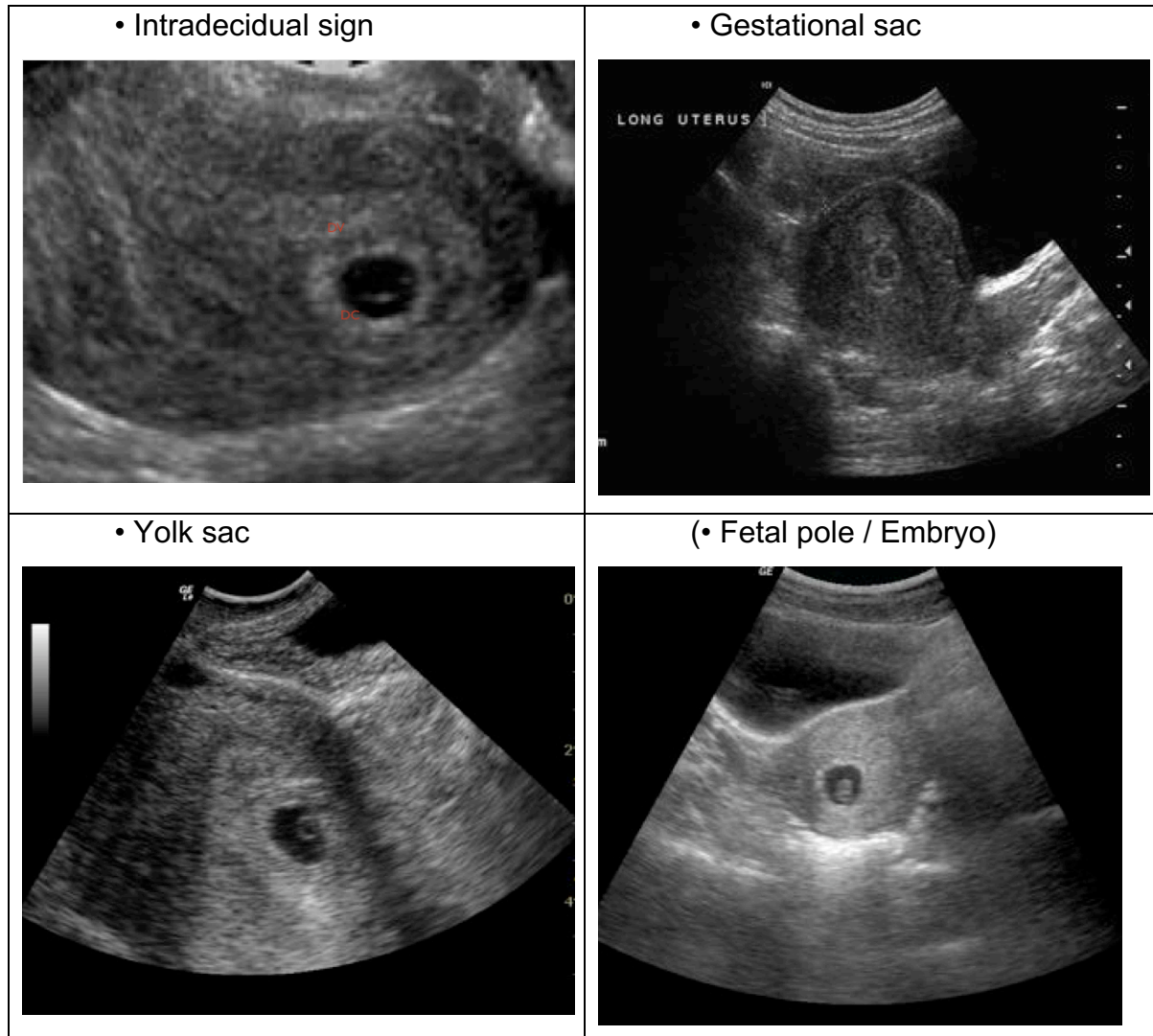
- Identify pouch of Douglas and assess in 2 planes for presence of free fluid.



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Normal first trimester pregnancy

- Detection of intrauterine pregnancy - Confirm the presence of:



• Confirmation of Live IUP

- Identification of fetal heart, FHR > 100

Pathology related to first trimester pregnancy

1. Pregnancy of Unknown Location

Empty uterus with a β -hCG below the discriminatory zone will become:

- Early IUP that continues (1/3)
- Miscarriage (1/9)
- 'Resolved' Pregnancy (1/2)
 - Early IUP that fails and Early ectopic that fails
- Ectopic 14-28%



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2. Ectopic pregnancy

Primary application: Absence of intrauterine pregnancy with positive β -hCG

+/- free fluid in pelvis or Morrison's pouch

Extended practice: Identification of definite ectopic pregnancy

Identification of nonspecific signs of ectopic pregnancy:

- Complex pelvic mass
- Tubal ring
- Free intraperitoneal fluid

Ability to interpret quantitative β -hCG level – understand that an IUP may not be detected on ultrasound until the β -hCG has reached over 1500 mIU/ml by the TV approach or 3000 mIU/ml by the TA approach (the “discriminatory thresholds”).

3. Heterotopic pregnancy

This is a Twin Pregnancy

- One Intrauterine
- One Ectopic

Previously 1:30,000, now up to 1:7,000

With fertility treatment may be up to 1:100

Sonographic features

Ectopic pregnancy

	<u>Accuracy</u>
Absent IUP	5%
Any free fluid (no IUP)	50%
Moderate - Large free fluid (no IUP)	60 - 85%
Adnexal Mass (no IUP)	75%
Ectopic Pregnancy Visualized	100%
Adnexal Mass + Free Fluid + no IUP	97%

In one reported series 34% of pregnancies had no adnexal mass or free fluid

Pregnancy loss= Embryonic demise

- Empty gestational sac
- Absence of fetal heart activity
- Absence or abnormal size yolk sac
- Distorted gestational sac



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Inevitable miscarriage

- Embryonic demise (as above)
- Cervical os assessment (transvaginal only)

Completed miscarriage:

- Measurement of endometrial stripe thickness

Key Point:

Absent IUP = Endometrial thickening without gestational sac, may be:

- ectopic,
- early pregnancy or
- failed pregnancy

Interpret in clinical context with quantitative β -hCG and other sonographic features

Must have timely follow up with gynecology, formal ultrasound.



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Competencies required: PoCUS

Competencies are threefold and require theoretical and practical training to achieve.

1. Theory – covered in this chapter.
2. Knowing how to interpret a scan – partly covered but hands-on required
3. Practical ability- can only be achieved by hands-on

OVERALL ASSESSMENT	BASED UPON;		
	<u>Knowing</u>	<u>Doing</u>	<u>Thinking</u>

(a) Competent to scan and interpret findings	Able to research and critique that knowledge and use it wisely	Learner doing: teacher available by phone	Excellent professional judgements
(b) Needs supervision and if scanning alone cannot rely on findings	Able to understand and use that knowledge	Learner doing: teacher within EM environs	Clinical reasoning and deliberation
(c) Not competent at this stage	Having to ask or be told	Teacher showing: Learner assisting	Clinical reasoning

Training

The training program is the same for both established practitioners and residents. This can be done “in house” or on approved courses. The Canadian Point of Care Ultrasound Society and the Canadian Association of Emergency Physicians have national networks of suitable courses published on their websites.



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Core training is seen as the standard of knowledge and practice that Acute Care physicians should have in the future. Practice at this level requires the following abilities:

- To perform common examinations safely and accurately
- To recognise and differentiate normal anatomy and pathology
- To diagnose common abnormalities within certain organ systems
- To recognise when a referral for a second opinion is indicated
- To understand the relationship between ultrasound imaging and other diagnostic imaging techniques

Theoretical training

Preliminary theoretical training should cover relevant anatomy, the physics of ultrasound, levels and sophistication of equipment, image recording, reporting, artefacts and the relevance of other imaging modalities to ultrasound. This element of training may be best delivered by use of course lectures or e-learning modules.

Practical training

Practical experience should be gained under the guidance of a named supervisor trained in ultrasound within a training department. The syllabus set out includes a competency assessment sheet for training. This should be completed during the course of training, to determine in which area(s) the trainee can practise independently.

- Practical training should include regular supervised US examinations. If a trainee is unable to access local opportunities, a regional ultrasound coordinator may be able to facilitate arrangements for further practicums.
- The goal of training is adequate competency, and this must be demonstrated rather than rigid adherence to a fixed number of training scans. The Canadian Point of Care Ultrasound Society (CPoCUS) stipulate a minimum of 50 scans for each clinical area for eligibility to be tested for independent practitioner status (Abdomen, Aorta, Cardiac, Pelvis, Obstetrical) plus 10 Pleural.
- Examinations should concentrate on the core clinical indications of trauma, abdominal aortic aneurysm, IVC and peri-arrest assessment in the context of benefit of an early focused ultrasound scan.
- All training scans must be logged in a logbook listing the types of examination undertaken. A pictorial record containing an illustrated description of 10



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cases in which the trainee has been personally involved is a useful confirmation of experience when moving between departments.

- PoCUS users who have achieved core competency in other jurisdictions may be eligible for transfer of registration
- The learning and practice outlined in this document refers to adults and children.

Assessment tool

CPoCUS IP examination – details at www.CPoCUS.ca or Residency Training program or local Triggered assessment tool e.g Dalhousie EM Competency Assessment

Maintenance of Skills

Having been assessed as competent to practice there will be a need for Continuing Professional Development and maintenance of practical skills. A trainee will need to continue to perform ultrasound scans throughout the remainder of the training programme and into independent clinical practice life. Further ultrasound practice may be intermittent, but no more than 3 months should elapse without the trainee using his scanning skills. If more than 3 months elapses there must be a brief re-assessment by a trainer, and a portfolio note made.

All practitioners should have regular meetings within the department to ensure appropriate focused emergency ultrasound use. The department lead for ultrasound practice will have regular contact with radiological colleagues and should have a named radiologist as an 'ultrasound mentor'.

Practitioner CPD:

- Include ultrasound in their ongoing CME/CPD
- Audit their practice
- Participate in multidisciplinary meetings
- Keep up to date with relevant literature

The minimum amount of on-going experience in ultrasound as outlined in each syllabus should be maintained. CME/CPD should be undertaken which incorporates elements of ultrasound practice. Regular audit of the individual's ultrasound practice should be undertaken to demonstrate that the indications, performance and diagnostic quality of the service are all satisfactory.



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