The Australian Institute of Ultrasound

Broadbeach
Gold Coast

Ultrasound in Intensive care Workshop

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INTRODUCTION

WELCOME

Continuing medical education in a practical manner

The aims of the Australian Institute of Ultrasound are to provide Ultrasound education in a focused, practical manner. We intend to accomplish this by using clinically oriented didactic presentations, Along with “hands on” tutorials, using state of the art equipment and real patients.

We could not accomplish this without the help of our visiting lecturers, who provide expertise in a wide range of ultrasound fields. We would like to take this opportunity to thank them for their support.

It is also necessary to have the support of the Ultrasound Equipment Manufacturers, since the practical tutorials are an important part of our programs. Our sincere thanks go to them for their help.

FACULTY

Mrs Cathy Low, RDMS (USA), AMS
Cathy has a broad general ultrasound background developed over a number of years. She has extensive experience in general, vascular and cardiac ultrasound and is a committed and enthusiastic tutor. Cathy has worked in many different countries around the world including Canada, NZ, Timor, Solomon Islands & Australia

Ms Joanne McBride Grad Dip Medical Ultrasound (Monash), AMS
Jo has an extensive background in medical imaging modalities, including ultrasound, predominantly in busy private practices in Melbourne. For the past few years Jo has combined specialising in tertiary level obstetric ultrasound with an impressive teaching and tutoring background at Monash University. She joins us as a full time sonographer / educator.

Mrs Claire Arrowsmith DMU (UK), AMS
Claire is a general sonographer with extensive experience both in the UK and Australia, who has joined us on a permanent part-time basis. She is particularly interested in education and holds a position with GCMI on the Gold Coast as a Senior Tutor Sonographer. Claire's enthusiasm is infectious and she is a great teacher

BASIC PHYSICAL PRINCIPLES OF ULTRASOUND

INTRODUCTION

Competent performance of an ultrasound examination of any type is reliant on an understanding of the basic physical principles that govern the production of ultrasound waves and their interaction with biological tissues of differing densities and consistencies. It is also necessary to understand the basic concepts of how the ultrasound systems work and the concepts underlying their manipulation of echoes.

Given a working knowledge of these various concepts and an understanding of how the theoretical principles can be put to use in a practical arena, physics of ultrasound becomes the bedrock upon which to build all the other knowledge necessary in becoming a competent sonographic diagnostician.

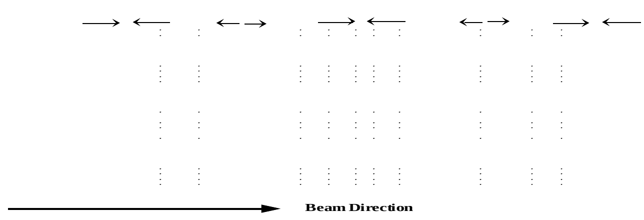
Lectures and notes provided during this course are the barest essentials of the learning you will require and our emphasis will be on the practical application of the principles involved. Further theoretical knowledge can be gained by wider reading and study. Recommended texts are as follows:

1. Applied Physics and Technology of Diagnostic Ultrasound; Author – Roger Gent
2. Diagnostic Ultrasound, Principles and Instruments (Fifth Edition); Author – Frederick Kremkau

WHAT IS ULTRASOUND?

Simply stated, ultrasound is sound whose frequency is above the range of human hearing. Diagnostic ultrasound is used to evaluate a patient's internal organs. Sound waves are transmitted into the body; then, because the various internal structures reflect and scatter sound differently, returning echoes can be collected and used to form an image of a structure.

Sound waves consist of mechanical variations containing condensations or compressions (zones of high pressure) and rarefactions (zones of low pressure) that are transmitted through a medium.



Unlike X-Rays, sound is not electromagnetic. Matter must be present for sound to travel, which explains why sound cannot propagate through a vacuum. Propagation of sound is the transfer of energy - NOT MATTER – from one place to another within a medium, some energy is also imparted to the medium.

Sound is categorised according to its frequency (number of mechanical variations occurring per unit time):

Human Audible range	20 – 20000Hz
Diagnostic Ultrasound	1 – 20MHz
	(3-12MHz being the most common range)

WAVE TERMINOLOGY

The characteristics of a sound wave can be described by the following parameters:

- Period (*T*) – the time taken for a particle in the medium through which the wave is traveling to make one complete oscillation about its rest position. (One oscillation is also referred to as a cycle)

- Frequency (f) – the number of cycles per second performed by the particles of the medium in response to a wave passing through it. Expressed in Hertz, where I Hz = 1 cycle passing a given point each second, therefore 3MHz = 3 million cycles per second

- Wavelength (λ) – the distance between two consecutive, identical positions in the pressure wave (e.g. between 2 compressions or between 2 rarefactions). It is determined by the frequency of the wave and the speed of propagation in the medium through which it is traveling. In diagnostic ultrasound, commonly used frequencies and their respective wavelengths in soft tissue are as follows:
  Frequency - 3MHz / Wavelength – 0.51mm
  Frequency – 5MHz / Wavelength – 0.31mm

- Velocity (c) – speed of sound with direction specified. When a sound wave travels through any medium it is certain parameters of that medium, which determine the speed of sound propagation. These determining factors are density and compressibility. Therefore, speed of sound is a characteristic of each material through which sound travels; e.g.

Material	Speed of Sound
Air	330 metres/second
Metal	5000 m/sec
Pure Water	1430 m/sec

  Speed of sound in various organs of the body also differs; e.g.

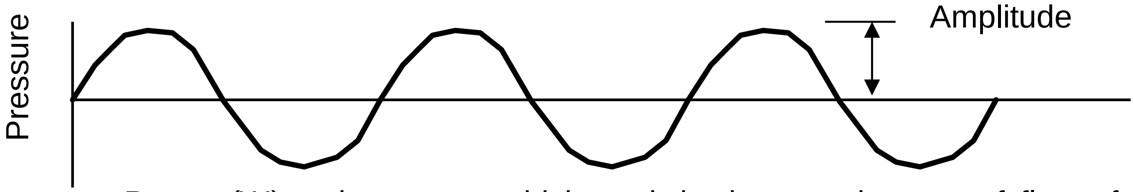
Soft Tissue Type	Speed of Sound
Fat	1450m/sec
Liver	1550m/sec
Blood	1570m/sec
Muscle	1585m/sec
Bone	4080m/sec

In practical terms, ultrasound machines need to operate on a single value for speed of sound in soft tissue; therefore an average speed for soft tissue is taken to be **1540m/sec**.

REMEMBER!!
Speed of Sound in Soft Tissue
= 1540m/sec

➲ *This can be extremely important when learning about artifacts later, since differences between the actual speeds of sound and those inferred by the ultrasound machine can cause misregistration of echoes on the image.*

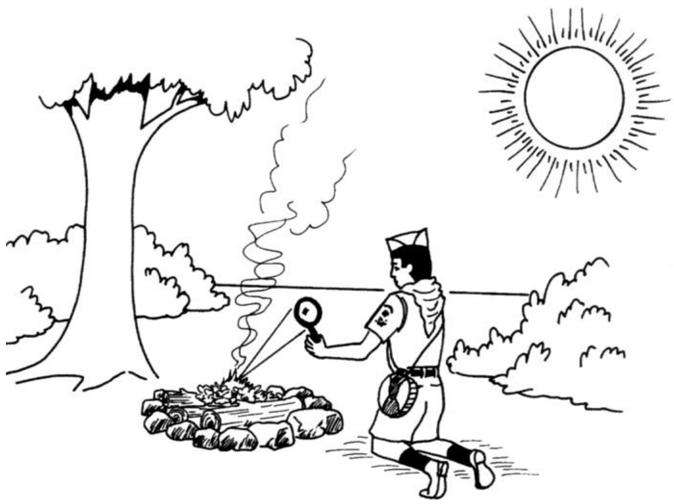
- Amplitude (A) – maximum variation of an acoustic variable, thus amplitude is a measure of the degree of change within a medium when a sound wave passes through it and relates to the severity of the disturbance. In this way, the amount of energy in a sound wave can be determined. Amplitude is expressed in units that are appropriate for the acoustic variable considered.



- Power (W) – the rate at which work is done or the rate of flow of energy through a given area. In diagnostic ultrasound energy is contained within the beam, so the power is the rate of flow of energy through the cross-sectional area of the beam. Power is expressed in Watts.

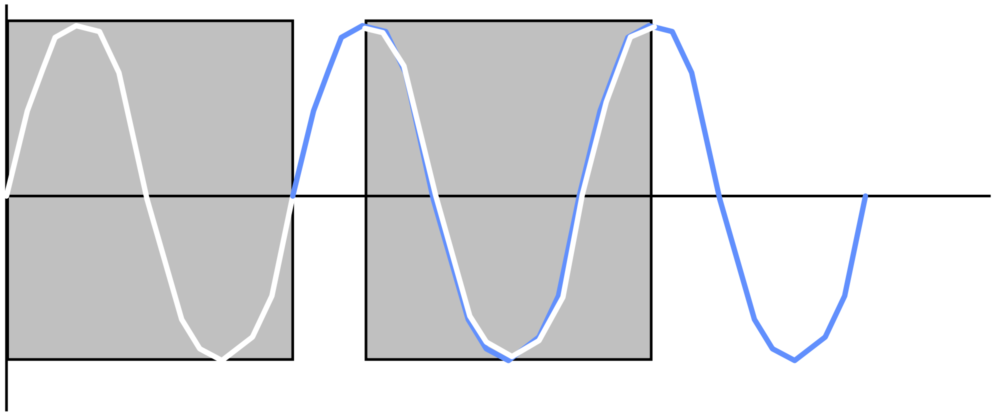
- Intensity (I) – power per unit area. Intensity is expressed in milliwatts per square centimeter ($mWatts/cm^2$). Intensity is an important parameter in describing an ultrasound beam and in the understanding of bioeffects and safety. The example of sunlight shining on wood shavings is often used to illustrate this phenomenon – Sunlight does not usually burn wood shavings but when the sunlight is concentrated into a small area (increased in intensity) by a magnifying glass, the wood shavings can be burnt. So, power remains the same, intensity is increased and an effect is produced (increased heat).

The scout can burn the wood shavings with the aid of a magnifying glass to focus the sun's rays, therefore increasing the intensity.

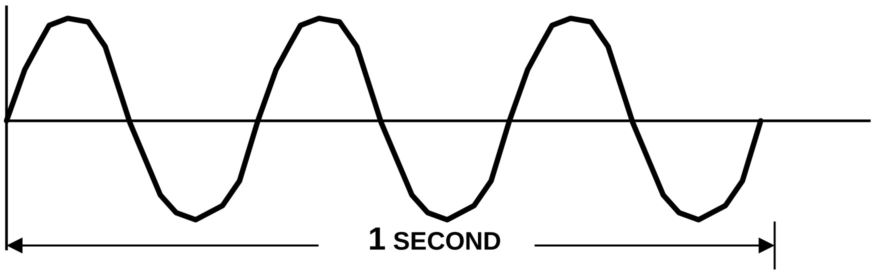


➲ IMPORTANT SUMMARY DIAGRAMS TO REMEMBER

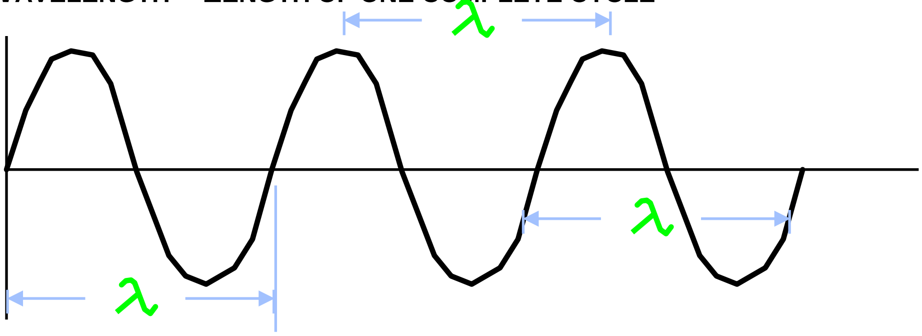
CYCLE – ONE COMPLETE OSCILLATION OF THE WAVE



FREQUENCY – NUMBER OF CYCLES PER SECOND OF TIME



WAVELENGTH – LENGTH OF ONE COMPLETE CYCLE

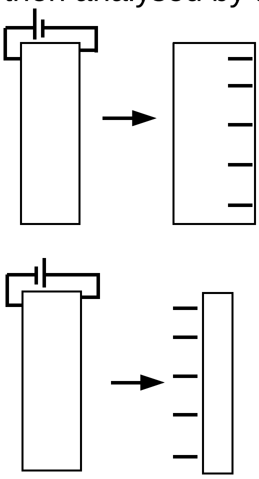


Frequency and wavelength have an inverse relationship shown in the formula $c = f\lambda$, where c is the speed of sound in tissue, f is the frequency and λ is the wavelength. Therefore, the higher the frequency, the shorter the wavelength. This relationship is fundamental to practical scanning since it has a considerable effect on the achievable penetration depth and resolution of the ultrasound beam.

THE PIEZO-ELECTRIC EFFECT

Artificially grown crystals are commonly used for modern transducers and are treated with high temperatures and strong electric fields to produce the piezo-electric properties necessary to generate sound waves

The principle of piezo-electricity is central to the production of ultrasound beams and states that some materials produce a voltage when deformed by an applied pressure and produce a pressure when deformed by an applied voltage.
Thus, when a voltage is applied to the faces of a crystal, it expands or contracts depending upon the polarity of the voltage applied. The crystal then resonates, converting electricity to ultrasound. The frequency of sound produced is dependant on the thickness of the crystal. Conversely, the when the crystal receives an echo, the sound deforms the crystal and a voltage is produced on its faces – this voltage is then analysed by the system.



Piezo-electric effect: Reversing polarity of voltage
Crystal undergoes expansion & contraction

If expansion & contraction occurs more than 20000 times per second, then ultrasound is being produced, which will continue until the applied voltage is discontinued (Continuous wave). If voltage is applied for an extremely short time, then the crystal resonates (rings) at its own frequency and the ringing gradually decays – a pulse is produced. The larger the voltage applied the greater the amplitude of the emitted sound (louder ringing).

Very short pulses are required for diagnostic ultrasound images to be produced, so the ringing of the crystal is stopped short by a damping material being applied to absorb vibrations (a hand placed on a bell will stop the ringing).

PULSE-ECHO IMAGING

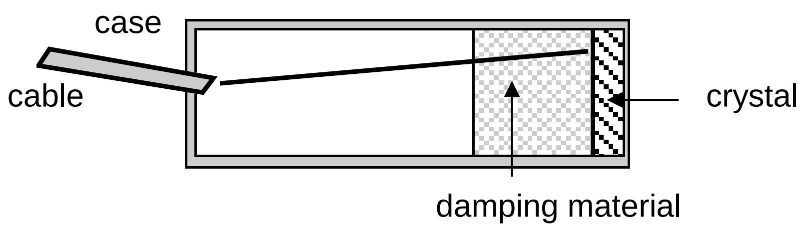
Images produced by diagnostic ultrasound systems are formed by sending out a short pulse of sound along a narrow beam path and waiting for return echoes to be collected from structures encountered along that path. The instrument generating and receiving those pulses of sound is the transducer, which is a critical component of the system due its profound effect on image quality.

BASIC TRANSDUCERS

Simply stated the basic transducer consists of three parts:

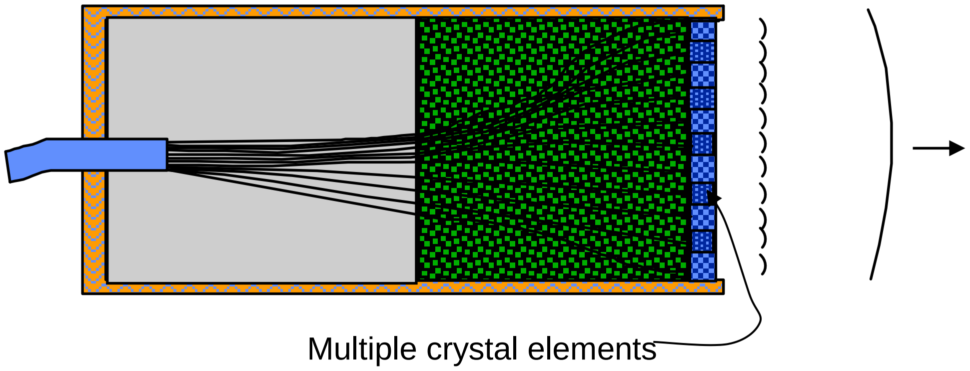
1. The Case
2. The Crystal
3. The Damping material

These are connected to the ultrasound system by electrical wiring.



Multi-element Transducers

Most real time transducers use many small crystal elements for the formation of each pulse.



These form a line of elements and the transducers are known as linear array transducers. The wave fronts from each element combine to form a single wave front; this is known as Huygen's Principle. Each individual element is acoustically and electrically isolated, allowing flexibility in beam formation.

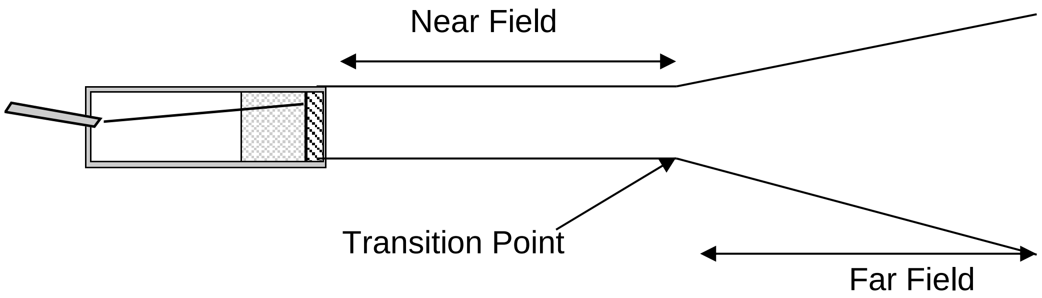
BEAM PROFILE

The shape of the ultrasound beam is important to the quality of the image it produces. The shape of the beam from a simple transducer is shown below.

The beam profile is made up of three parts:

1. Near Field (Fresnel Zone)
2. Far Field (Frauhofer Zone)
3. Transition Point – point at which near field ends and divergence begins

(The length of the near field is often termed the transition distance)



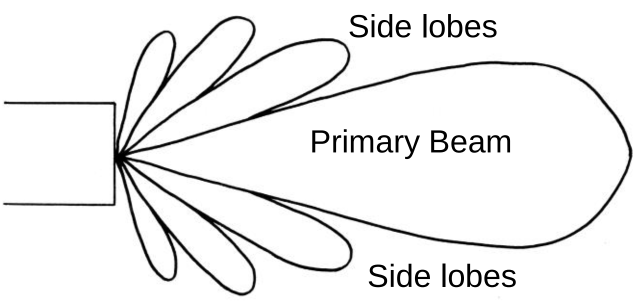
➲ All sound beams are three-dimensional

The near field is the part of the beam useful for imaging purposes; however this can be quite large in area, depending on the diameter of the crystal. Imaging requires a very narrow beam to produce high-resolution diagnosis. Focussing is used to achieve these narrow beams, there being various focussing methods in use throughout the manufacturing industry and new methods are being devised with each passing year.

Simple methods are to curve the crystal, add a curved lens in front of the crystal or focus by electronic means (the latter being the most common in today's transducers).

DIFFRACTION PATTERN

A beam profile of a simple transducer obtained by plotting the maximum pressure amplitude appears as in the diagram below and shows that the energy is not confined to a single lobe, but radiates off at various angles to the transducer face as "off-axis" energy. These off-axis areas are called side-lobes.



➲ SIDE LOBES ARE THREE-DIMENSIONAL & SURROUND THE PRIMARY BEAM

Array transducers also generate grating lobes which are defined as additional, weaker beams of sound energy travelling out in different directions from the primary beam as a result of the multi-element structure of transducer arrays.
Both side lobes and grating lobes are minimised as far as possible by the manufacturer during the design process but nevertheless still produce artifactual echoes within images. (See artifact section)

RESOLUTION

Resolution is defined, as the ability to distinguish echoes in terms of space, time or strength and good resolution is thus critical to the production of high quality images.

1. **CONTRAST RESOLUTION** refers to the ability of an ultrasound system to demonstrate differentiation between tissues having different characteristics e.g. liver/spleen.

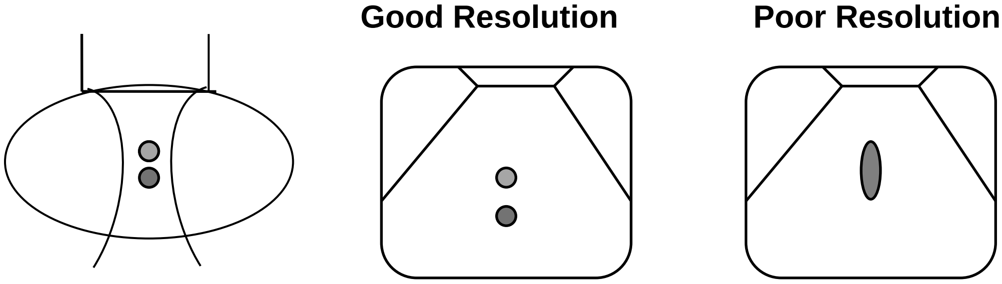
2. **TEMPORAL RESOLUTION** is the ability of an ultrasound system to accurately show changes in the underlying anatomy over time, this is particularly important in echocardiography.

3. **SPATIAL RESOLUTION** is the ability of the ultrasound system to detect and display structures that are close together. Since an ultrasound image displays depth into the patient and width across a section of anatomy it is therefore reasonable to consider two types of spatial resolution – Axial & Lateral.

AXIAL RESOLUTION

The ability to display small targets along the path of the beam as separate entities.

Good Resolution **Poor Resolution**



Axial resolution is dependent upon various factors, the most important of which being the length of the pulse used to form the beam. This is known as the spatial pulse length (SPL). The shorter the pulse length, the better the axial resolution. In fact the axial resolution limit is defined as being one half of the SPL.

➲ **AXIAL RESOLUTION LIMIT = ½ SPATIAL PULSE LENGTH**

The SPL is determined by the number of cycles in one pulse and the length of each cycle (i.e. wavelength - this cannot be changed by the operator). However, wavelength, as we have already said, is inversely proportional to the frequency, so higher frequencies generate shorter wavelengths and therefore shorter pulse lengths. So we can say that higher frequency transducers will exhibit better axial resolution.

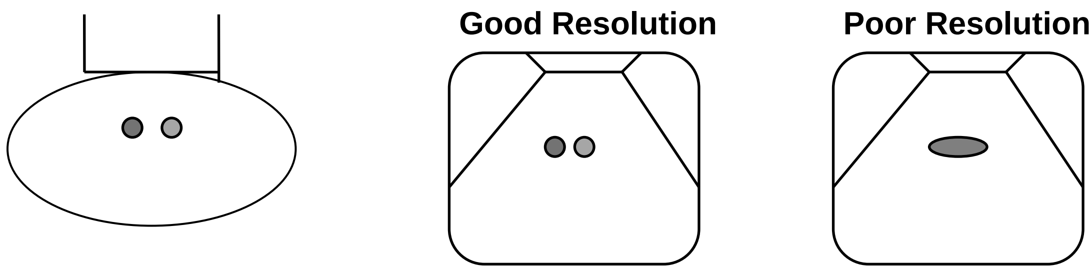
One note of caution should be that all transducers of a particular frequency will not necessarily have the same axial resolution, since other factors such as damping levels can have an effect on the SPL.

Other factors affecting the axial resolution, which the operator can control, are:

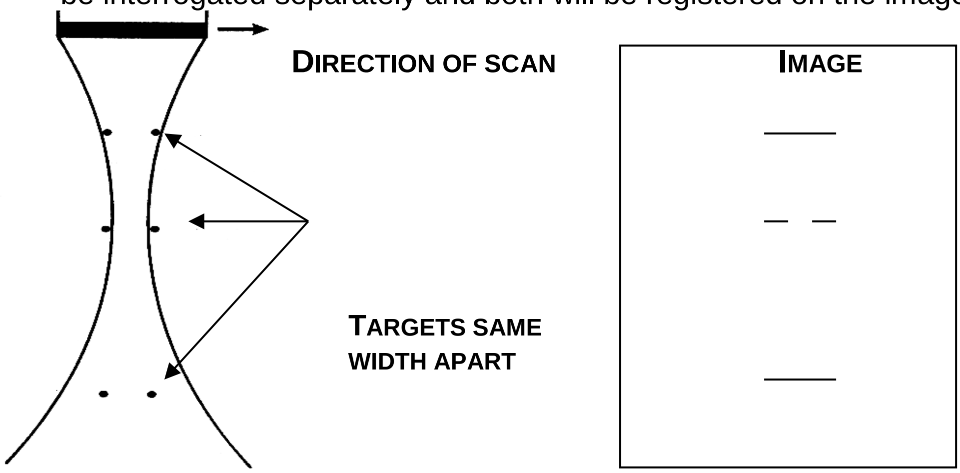
- Transmit power – the greater the amplitude of the voltage striking the crystal, the longer the ringing time and longer the SPL, leading to a slight decrease in axial resolution
- Received gain settings effect the length of the voltage signals generated by the returning echoes, the higher the gain – the poorer the axial resolution
- Field of view settings effect the display of pixels per unit area of the patient – smaller FOV setting makes best use of the available scan converter memory

LATERAL RESOLUTION

The ability to distinguish between two separate targets perpendicular to the beam path. (Same distance from the transducer)



Lateral resolution is dependent upon the width of the ultrasound beam, that is – the wider the beam, the poorer the lateral resolution. Ultrasound machines assume that all received echoes arise from the central axis of the beam, so if two targets are within the beam at the same point in time, the echoes are assumed to have come from the same target and only one structure is registered on the image. If the beam is narrower than the distance between the two targets, only one target is within the beam at one time and as the transducer is swept across the body, both targets will be interrogated separately and both will be registered on the image. (See diagram)



Where the beam width is at its narrowest, the targets are separated by a distance greater than the beam width and thus are resolved on the image.

As we can see, the lateral resolution is best where the beam is the narrowest and thus in the area of tightest focus in most transducers.

➲ **CORRECT POSITIONING OF THE FOCAL ZONES IS CRITICAL TO GAINING THE BEST LATERAL RESOLUTION FOR A GIVEN TRANSDUCER**

INTERACTION OF SOUND WITH TISSUE

ATTENUATION

As the sound beam traverses tissues within the body, various factors cause it to lose energy and therefore undergo a reduction in amplitude and intensity. This loss of energy is called attenuation. The amount of attenuation is determined by the tissue involved, the distance travelled and the frequency of the beam. The dependence of attenuation on frequency is of major importance in practical terms, since it is this dependence, which limits the penetration of an ultrasound beam of a given frequency and makes TGC controls a necessity in diagnostic ultrasound systems.

There are four main processes, which contribute to the attenuation of the sound beam, which are:

- **Reflection**
- **Refraction**
- **Absorption**
- **Scattering**

All of the above factors affect the echoes returning to the transducer as well as the transmitted beam.

- **The amount of attenuation depends on the total path length. (The time taken for the sound to reach the interface and the echoes to return)**
- **The approximate rate of attenuation in soft tissue is 1dB/MHz/cm**

REFLECTION

This occurs at interfaces between soft tissues of differing acoustic impedance, an alternative name for which is an acoustic impedance mismatch. Reflection occurs where the interface is large relative to the wavelength of the transmitted sound.

At tissue interfaces some of the sound is reflected and some is transmitted further into the soft tissue. The percentage of the sound reflected is dependent on the magnitude of the impedance mismatch and the angle of approach to the interface.

- **Soft tissue/air interface - 99.9% reflected**
- **Soft tissue/bone - 40% reflected**
- **Liver/Kidney - 2% reflected**

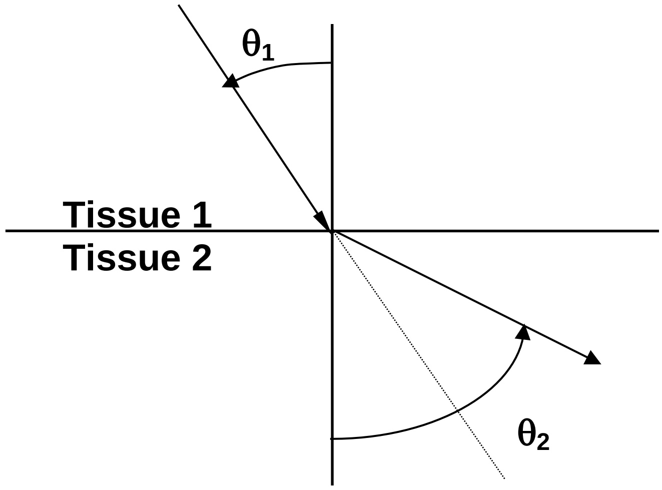
Specular Reflections occur at large, smooth interfaces (e.g. Diaphragm, organ margins), in these cases the angle of incidence equals the angle of reflection.

Clinical Note:

- **Avoid bone, gas and air interfaces with soft tissue - little sound is transmitted which produces shadowing of deeper tissues.**
- **Try to use a soft tissue "window" to view deep structures**

REFRACTION

Refraction is the deviation in the path of a beam, occurring when the beam passes through interfaces between tissues of differing speeds of sound, when the angle of incidence to an interface is not 90°



Refraction at an interface between tissues of differing velocities

Variations in velocity between soft tissue organs are generally fairly small (up to 10%). Deviations of the sound beam of up to 10° may occur, with resultant misregistration of echoes on the display.

➲ **Refractions can produce some recognised artifacts.**

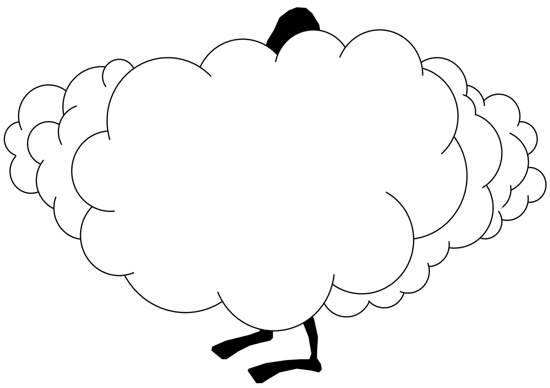
ABSORPTION

Transfer of some of the energy of the beam to the material through which the sound is traveling.

➲ **Absorption increases with frequency**

➲ **Absorption produces a heating effect**

➲ **<u>Clinical note:</u> The increase in absorption with frequency explains why high frequency transducers cannot be used for examining deep structures within the body.**



Understanding a little cloudy?

Absorption is a fairly complex subject, the physics of which we have not attempted to describe in detail.

Further reading from recommended physics text may blow away the clouds!

SCATTERING

Scattering occurs at interfaces within the sound beam path. The scatter pattern relies on the size of the interface relative to the wavelength of the sound.

- **Interface much larger than wavelength - Reflection (see page 10)**
- **Interface equal in size to wavelength – scatter in many directions with amount not being equal in all directions. (sometimes termed non-specular reflection)**

➲ **<u>Clinical Note:</u>**
Provides much of the textural information present in images and is dependent upon:

a. **Frequency**
b. **Angle of approach**

- **Interface much smaller than wavelength - Rayleigh scattering, which is equal in all directions (not angle dependent)**

➲ **<u>Clinical Note:</u>**
This type of scattering is caused by red blood cells and provides signals for Doppler assessment of blood flow.

IMAGE PRODUCTION

The images we use in diagnostic ultrasound are produced with B-Mode or brightness mode techniques. This can be described as a pattern of dots positioned on the monitor, as a result of the signals caused by returning echoes being processed by the system. The brightness of each dot is in proportion to the strength of the echo received.

As each pulse is emitted, its line of sight is known accurately and therefore the resulting echoes from sound/tissue interactions along this line are represented on the monitor in accurate spatial position.

Multiple lines of sight produced at known angles from the transducer then construct an image of the underlying tissue, composed of multiple thousands of dots. This image is known as a frame. Multiple frames produced in rapid succession form the moving or real-time image we see on the ultrasound monitor. Frame rates in modern systems are typically 10 – 30 frames per second and a flicker free image is achieved using electronic smoothing techniques.

TRANSDUCERS

Several types of transducer are available and their construction varies depending upon the type of examination they have been produced to facilitate. Some of these are:

- Mechanical sector
- Electronic sector (phased array)
- Annular array
- Linear array
- Curved array

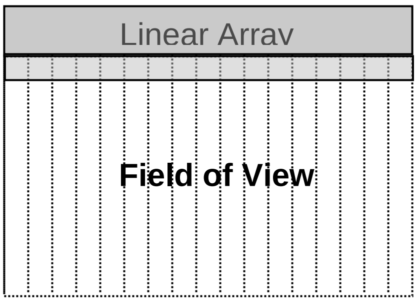
- Specialised (intracavitary, intraoperative)

The types of transducer we use the vast majority of the time in general ultrasound practice are Linear and Curved arrays.

LINEAR ARRAY

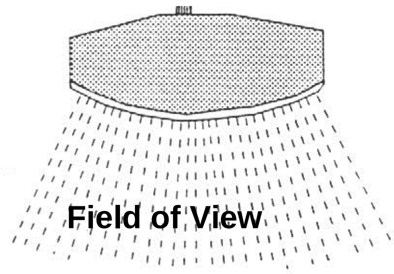
The transducer is constructed with multiple small crystal elements arranged in a straight line (thus linear) across the face of the probe. These elements are pulsed sequentially in groups in order to produce a wider aperture and resultant improved beam shape.

The beams generated by these transducers travel at 90^0 to the transducer face. Thus the lines of sight are parallel, the line density is uniform from top to bottom of the image and the field of view is rectangular.



CURVED ARRAY

Similar in construction to the linear array excepting that the face of the transducer is convex. Since the beam paths remain at 900 to the transducer face, the resulting field of view is wider at the bottom of the image whilst remaining a reasonable width in the near field of view



Transducers produced by different manufacturers may have similar frequency, size and shape, but can have quite different beam shapes and focussing due to the particular construction used by the manufacturer. They can have widely varying numbers of elements and so aperture widths.

➲ **Get to know your transducers and their capabilities**

ARTIFACTS

Ultrasound systems operate on the basis of certain assumptions relating to the interaction of the sound beam with soft tissue interfaces, such as:

1. A constant speed of sound in the body (assumed 1540m/s)
2. All echoes detected by the transducer originate from the central axis of the beam
3. The ultrasound beam travels in straight lines
4. The time taken for an echo from a given interfaces to return to the transducer is directly related to its distance from the transducer
5. The rate of attenuation of the beam is constant with depth and throughout the field of view

These assumptions are often incorrect, resulting in images that do not accurately reflect the anatomy of the scan plane. Several effects of these incorrect assumptions result in artifactual echoes with the display, these effects can produce:

1. Echoes in the display which do not appear in the correct position
2. Absence of echoes from parts of the image representing tissue which would normally generate echoes
3. Structures which are anatomically separate being displayed as joined
4. Brightness of echoes which may not correspond to that expected from a particular organ
5. Single structure being displayed as two separate structures
6. Thin membranes appearing thicker than they really are.

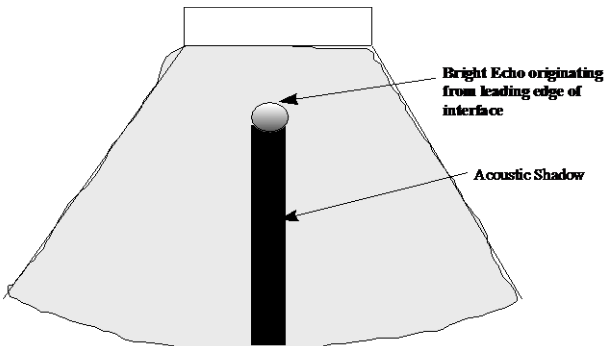
The list below describes, in simplistic form, some of the common artifacts, some of which offer useful diagnostic information.

Acoustic Shadowing

If the proportion of the beam energy attenuated at a given interface is high, little sound will be transmitted deeper than the interface, and then echoes will not be received from tissue deep to the interface. When this occurs, an acoustic shadow is produced.

Some interfaces causing such effects are:

- **Soft tissue/gas (bowel, lung)**
- **Soft tissue/bone, calcium (ribs, calculi)**
- **Normal tissue/fibrous tissue (scars, ligaments)**

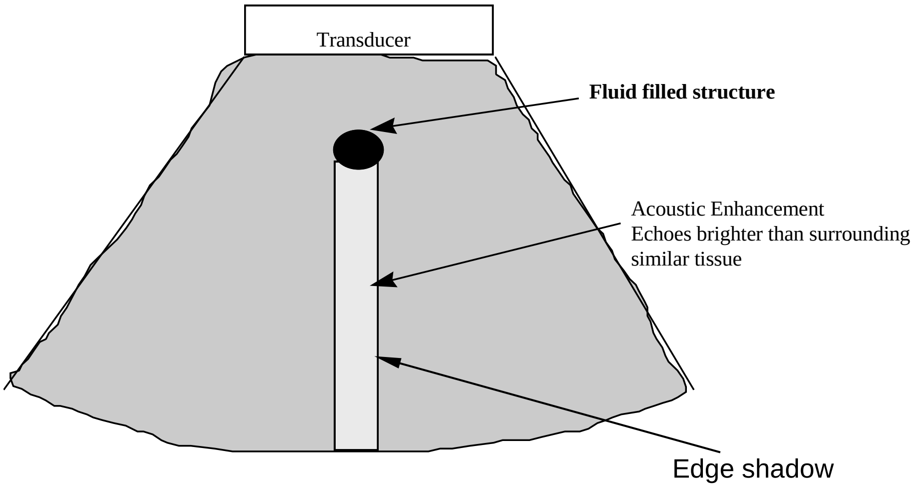


- **Shadows from calcium and bone are usually echo free ("clean")**
- **Shadows from gas are often partially filled with reverberations ("dirty")**
- **Focal zone MUST be set at depth of calculus to clearly show a shadow**

Acoustic Enhancement

Acoustic enhancement is an attenuation phenomenon resulting in an area of increased brightness (amplitude) in the display, relative to echoes from adjacent similar tissue.

The basis for this artifact is that fluid filled structures (cysts, gall bladder etc) attenuate sound to a much lesser degree than solid organs (liver, spleen etc). Therefore there is more sound transmitted to structures deep to the fluid filled structure and the resulting echoes from this deeper tissue are brighter than those from a similar depth in adjacent solid tissue.



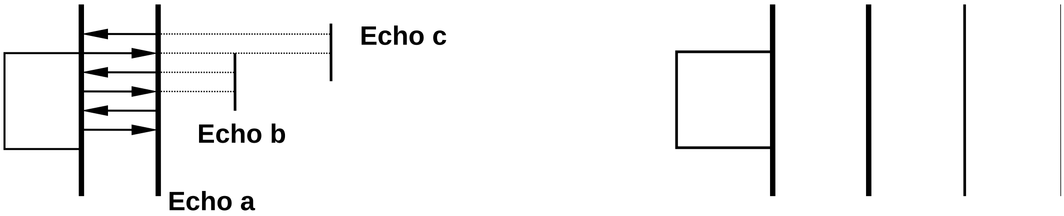
- **Acoustic enhancement is one of the criteria for classification of cysts (the others being smooth walls and echo free interior).**
- **The margins of the area of enhancement are usually sharply defined and may be parallel or divergent, depending on the transducer used.**

Edge Shadowing

Commonly seen deep to the edges of rounded structures when the velocity of sound in the rounded structure is different from that of the surrounding tissue. This results from a combination of reflection and refraction occurring at the edge of rounded structures.
(See diagram above)

Reverberation Artifact
The multiple representations in the display, of the same interface. They occur because of repeated reflections of sound between two interfaces and are usually generated by high-level mismatch interfaces when the echo amplitude is very high.

Echoes are placed in the display according to the time taken for their return to the transducer after their emission. If an echo repeatedly reflects (reverberates) between two interfaces each successive returning echo will be perceived as coming from twice the distance as the reflection before, and will be placed at twice the distance on the display.



- ➲ **Reverberation echoes are evenly spaced, because the time for each additional echo is a multiple of the time of return of the first echo.**
- ➲ **Reverberation artifacts are commonly seen in many situations, such as;**
  - a. **Deep to bowel gas**
  - b. **Deep to subcutaneous fat and muscle layers, these are easily seen in a distended urinary bladder but may be masked by the parenchymal echogenicity of solid organs such as the liver**
  - c. **Foreign bodies, multiple reverberations arising from small, superficial foreign bodies often merge and are displayed as a "comet tail" artifact**

Beam Width Effects
There are several artifacts that occur due to the reality that the ultrasound beam is not a single line of site, but that the system sees it as such.

This group of artifacts can cause much difficulty to the beginner, in that they display echoes generated from the edge of the beam, as though they were generated from the central axis of the beam. These echoes are therefore incorrectly placed in the image and can give rise to "pseudo pathology".

This group of artifacts includes:
- a. Beam width
- b. Side lobe
- c. Grating lobe
- d. Slice thickness

Common examples of this type of artifact encountered in general scanning are:

- ➲ **Urinary bladder - "false" echoes within the bladder, arising from surrounding bowel gas, can be mistaken for pathology**

- **Gall bladder - "pseudo sludge", echoes within the gall bladder lumen arising from adjacent bowel or liver**
- **Obstetrics - "false" echoes at the side of fetal head or femur length, can cause inaccurate measurements**

The examples above are, obviously, a minute portion of the hundreds of effects that artifactual echoes of these types can cause.

It must be emphasised that these explanations are simplistic, since the causes and effects of many of these artifacts are often complex and variable.

Velocity Artifacts

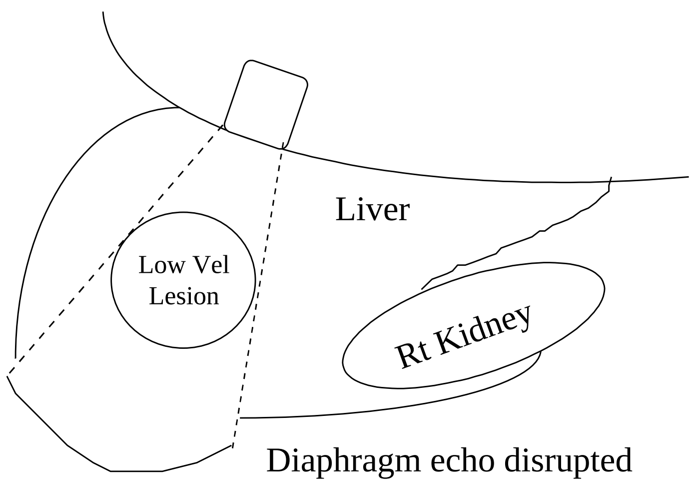
This group of artifacts occurs because various tissues have velocities different from the assumed 1540m/sec, which results in incorrect placement of echoes in the display.

The two main types in this group are;

a. inaccurate depth calculation effects
b. refraction effects

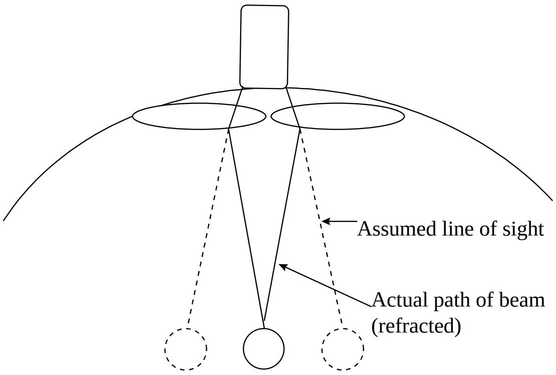
Examples of these are as follows:

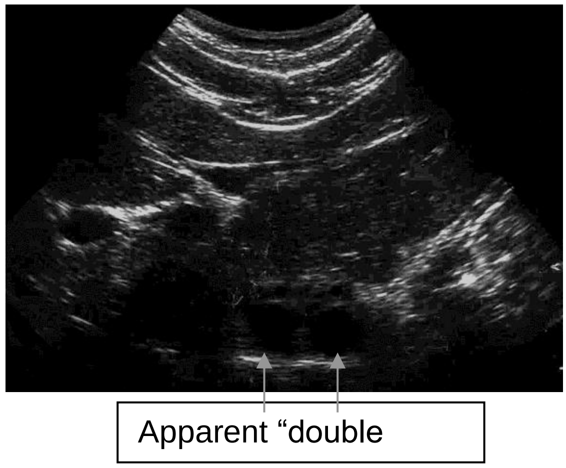
a. Low velocity lesion within the liver - causing displacement of the diaphragmatic echoes, deep to the lesion



- Low velocity in lesion, compared to surrounding liver
- Causes echoes to take longer to return to the transducer
- Therefore, the structures deep to the lesion are displayed erroneously deeper in the image

b. Refraction effects such as “lens effect” caused by well developed rectus abdominus muscles. Results in two images of the same object, displayed side by side in the transverse plane.
E.g. aorta, early gestation sac.

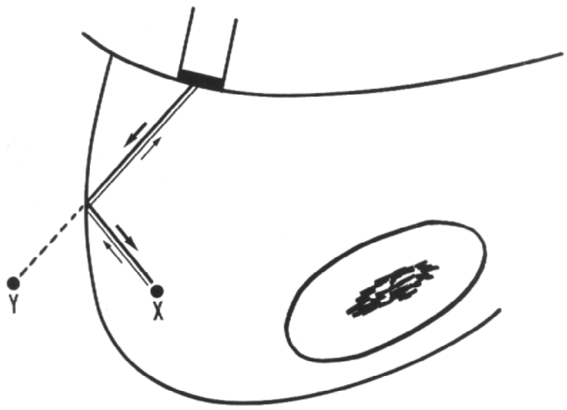


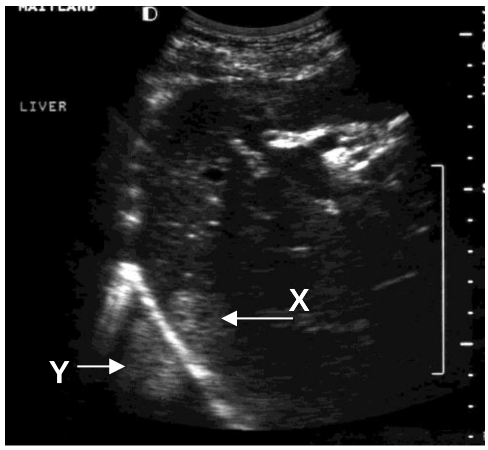


Mirror Image
Structures displayed twice, with one being a mirror of the other. These occur where there is a strong specular reflector, which acts as a mirror.

Examples of these are:

- **Diaphragm/lung interface (show mirroring of the liver texture, above the diaphragm.**
- **Bladder/rectum interface, when the rectum is gas filled (bladder wall is mirrored together with any bladder contents, such as ureterocele, catheter balloon, mass etc)**

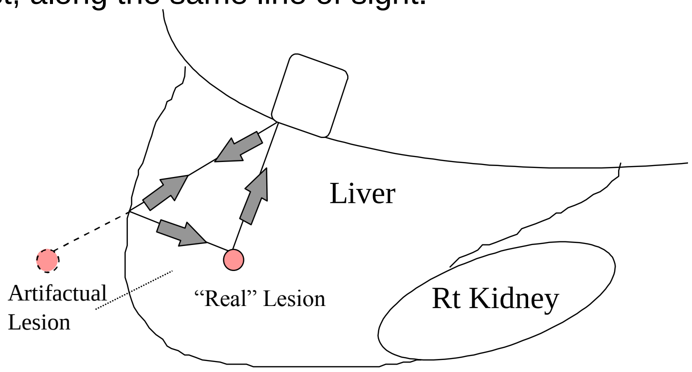




The echo from X is displayed at position Y

Multipath

The placement of echoes in the display is based on the assumption that they return directly to the transducer after reflection, but this is not always the case. Echoes can be reflected and refracted. The component of the echo that is reflected can then reflect off a second interface before returning. This results in additional path length and time; the second echo is therefore displayed deeper than the first, along the same line of sight.



Operator Produced Artifacts

Inappropriate setting of gain and TGC and lack of contact can cause confusion; this is a problem common to beginners and can easily be overcome by careful manipulation of these controls.

➲Overall Gain
It is a great temptation to turn up the gain, with the expectation that things will become clearer! However, over use of gain will merely add noise to the image.

➲TGC
Similarly, if one of the TGC slider controls is misaligned, the slope will be uneven, possibly causing a band of bright or low level echoes within the field of view.

➲Contact
The most common of all artifacts produced by the beginner, is that of a lack of adequate contact between the transducer face and the skin surface. A liberal use of ultrasound gel and reasonable pressure on the transducer will overcome this.

PROBLEM SOLVING

Now that we have identified many of the common artifacts occurring in ultrasound images, we need to learn how to overcome or minimise them and to definitively recognise them as artifactual echoes and not pathology.

The simple scanning techniques required to contend with artifacts are easily acquired and can be listed as follows:

- **TURN DOWN THE GAIN**
- **ALTER ANGULATION OF PROBE AND WATCH THE EFFECT ON THE ARTIFACT**
- **SCAN IN TWO PLANES**
- **MOVE PATIENT**
- **HAVE PATIENT USE DIFFERENT BREATHING MANOEUVRES**
- **CHANGE TRANSDUCER FREQUENCY**

These manoeuvres, taken in order will usually be effective in minimising artifacts or at least working out what is artifactual and what is real.

At the beginning of the learning curve there is no substitute for practicing on fellow colleagues or yourself. This will enable the beginner to feel confident with machine controls and basic scanning techniques, before being confronted with a patient in an emergency situation.

SCANNING PRINCIPLES

IMAGE OPTIMISATION & KNOBOLOGY

Throughout any ultrasound examination the operator should be constantly monitoring the image quality with a view to improving it. Sometimes better scanning techniques are required and sometimes optimisation of the image by changing system controls can cause the necessary improvement in the image.

A thorough knowledge of the system controls and what effect they have upon image quality in various scanning scenarios is one of the most fundamental parts of becoming a good sonographer

TRANSMISSION POWER

Regulates the amount of energy exciting the crystal, and therefore the strength of the ultrasound beam

- ➲ **This should be kept to the minimum for required depth penetration, to minimise exposure**

DEPTH

The depth control alters the depth of the field of view. The number of pixels in the image area is fixed so setting the field of view also sets the number of pixels used to represent each square centimetre of the patient

- ➲ **Use smallest depth of field necessary to image structure of interest**
- ➲ **Small depth of field - superficial structures**
- ➲ **Large depth of field - deeper structures**

FOCUS

Modern transducers use excellent focussing technology to achieve good resolution throughout the depth of field. Ultrasound systems normally have user controlled focal zones, giving best definition at the designated depth of focus.

On some systems, it is possible to expand the focal zone by adding more than one focal point, this will allow focussing over a larger portion of the depth of field but has the trade off of slowing the frame rate.

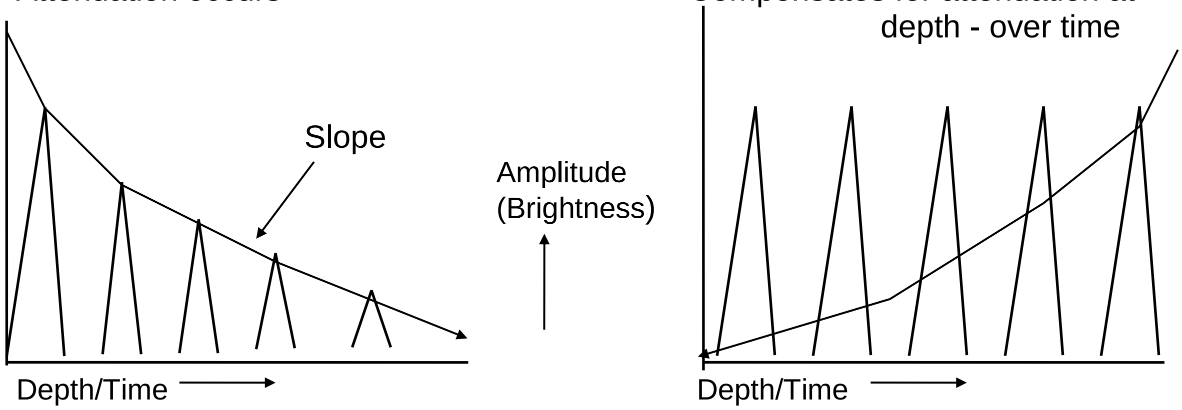
- ➲ **Position focal point at area of interest.**
- ➲ **Practice using more than one focal zone to watch effect on frame rate.**

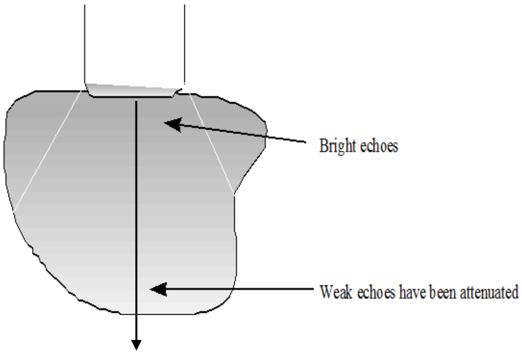
TIME GAIN COMPENSATION (TGC)

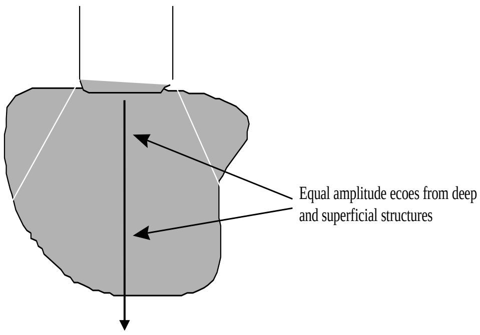
As the sound beam passes through the body its strength is attenuated (diminished) by various factors as discussed above. The echoes returning from deeper structures are weaker (of lower amplitude) than those from more superficial structures. Applying gain to returning echoes from deep structures compensates for this. The operator decides at what rate this gain will be applied by the use of the TGC controls.

NO TGC Applied
Attenuation occurs

TGC Applied
Compensates for attenuation at depth - over time







Brightness of echo decreases with depth

Brightness of echoes equal throughout depth of field

<u>NO TGC Applied</u>

<u>TGC Applied</u>

Ultrasound systems have user operated TGC controls which can be either slide pots, with each slider regulating one section of the image or rotary controls regulating near gain, slope and far gain. (N.B. Some systems only offer near gain and far gain control.)

- ➲**TGC adjustments vary with transducer frequency**
- ➲**TGC adjustments vary for each organ/system being imaged**
- ➲**TGC adjustments vary patient body habitus type being imaged**

OVERALL GAIN

Amplification of the <u>Received</u> signal

- ➲**Increasing the gain does not increase exposure**
- ➲**Affects the whole image equally**
- ➲**Undue increase in gain may obscure subtle changes in texture, or produce artifactual echoes in fluid filled structures (e.g. gall bladder, cysts etc)**

DYNAMIC RANGE

The term refers to the range of echoes from strong to weak, available to be displayed on the monitor at a particular time.

- ➲**Decreasing dynamic range gives fewer grays and increases contrast**
- ➲**Increasing dynamic range gives a wider range of grays and decreases contrast.**
- ➲**Practice observing changes in dynamic range**

ZOOM

This control is used to magnify structures of interest and is best used in real time or write-zoom mode. Write-zoom affects image quality because the line density and pixels / unit area are increased. The consequence of these benefits is a decreased field of view. (Read-zoom is purely a magnification of a particular part of the field of view and does not affect image resolution)

- ➲**E.g. easier to measure small luminal diameters**

FRAME AVERAGING

Sometimes called persistence or smoothing, this control allows the accumulation (or averaging) of echo information over two or more frames. Increasing the amount of frame averaging can enhance subtle textural differences but can cause blurring of the image and will result in a reduction in effective frame rate.

Decreasing or removing frame averaging is recommended when scanning highly mobile tissues (e.g. cardiac structures) since the effective frame rate will be higher.

CINE MEMORY

Storage of a number of previous image frames on system freeze. The number of frames retained varies with manufacturer and with memory requirement per frame stored.

The benefits of cine memory will rapidly become apparent on use of the control; the saved sequence of frames can be reviewed at will, manipulated and imaged. This can be particularly useful when scanning the very young or the very old patient, who may be uncooperative.

B-MODE COLOUR

Many modern systems allow the echoes (normally displayed in shades of gray) to be displayed in hues of colour. This can be useful in apparent enhancement of contrast resolution, since the human eye can more readily discern small changes in colour hue than in shades of gray. The choice of colour map appears to be quite subjective; most manufacturers offer a range of different maps for individual preference.

- ➲**Useful practically in many different types of scan**

TERMINOLOGY

There are other controls available on ultrasound systems, many of which are different depending on manufacturers' range of technologies and many of which are labeled using different terms but in fact have the same operational use. Two terms that are used frequently in discussion of ultrasound image production are pre and post processing.

- Pre-processing controls are those that involve manipulation of echo data before it is stored in the scan converter memory.. Those that can be changed by the operator are TGC, FOV, Frame Averaging, Dynamic Range and digitisation. Pre-processing controls are those that require re-scanning of the image with a different control setting if the image produced is not suitable or satisfactory.
- Post-processing controls are those that involve manipulation of the data after it has been stored in memory, such as greyscale maps, B-colour etc. The original data can be restored after manipulation with post-processing controls.

OTHER FACTORS AFFECTING THE IMAGE

FREQUENCY

Frequency is defined as the number of ultrasound cycles generated per unit of time.
E.g. 1MHz = 1 million cycles per second.

Many systems have transducers with the capability of being switched from one frequency to another. ("Wide bandwidth", "Frequency domain imaging transducers" etc) The technology involved in producing these transducers varies between manufacturers and the precise physics involved can be learned from pertinent texts.

The important practical facts to note about the frequency of a transducer are how changing frequency affects image acquisition and resolution.

- **Higher frequency - greater resolution, poorer penetration**
- **Lower frequency - poorer resolution, greater penetration**
- **Use the highest frequency possible to reach the necessary depth.**

e.g. Heart -	**2.5-3.5 MHz**
Abdo -	**3.5 - 5.0 MHz**
Pancreas, G.B. -	**5.0 MHz**
Foreign bodies etc	**7.5 - 12.00 MHz**

ANGLE OF INCIDENCE

The largest reflection of sound will occur at 90° to an interface; therefore the best images will result from a sound beam projected at 90° to the main area of interest.

PRACTICAL PHYSICS OF SPECTRAL & COLOUR DOPPLER

INTRODUCTION

It is essential to understand that both Spectral and Colour Doppler operate under the same physical laws. So the statement, “Colour is Doppler and Doppler is Colour”, is accurate and should always be remembered. Therefore one should have a sound understanding of the principles of spectral Doppler, before progressing to colour Doppler.

It is important to understand that these two technologies share controls, terminology, limitations and artifacts and we will discuss these along the way.

THE DOPPLER EQUATION

The basis of all colour and spectral Doppler physics is encompassed in the Doppler equation.

$$\triangle f = \frac{2foV}{c}(\cos \varphi)$$

Where:

- $\triangle f$ = The detected Doppler Frequency Shift
- fo = Initial Doppler Frequency
- V = Velocity of Moving Blood
- c = Speed of Sound in Tissue
- φ = The Angle between the ultrasound beam and the flow direction

All this means is that the initial (or, incident) frequency of the sound beam is different from that which is received from a moving reflector (blood) and that difference varies with

- the velocity of the moving reflector
- the angle between the ultrasound beam and the flow
- Initial (operating) frequency

DIRECTION AND THE DOPPLER EFFECT

Using the Doppler effect we can indicate the direction of the moving reflector.
A practical, well-known description of the Doppler effect is that of the change in pitch of a train whistle or siren as they come towards or away from you when you are standing still. The pitch increases as the train is coming towards you and decreases as it is moving away.

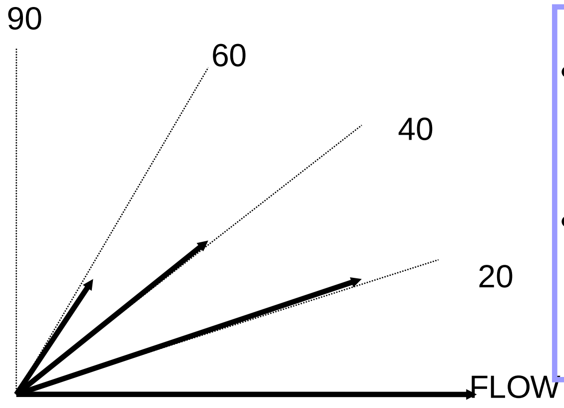
This, of course, holds true for frequency shifts detected by an ultrasound machine when the moving reflector, blood, is moving in respect to the transducer.

If the blood is moving towards the transducer then the received frequency will be higher than the initial frequency. Conversely, if the blood is moving away from the transducer, then the received frequency will be lower than the initial frequency.

However, if the blood is travelling at 90 degrees to the transducer then the received frequency will be equal to the initial frequency and therefore there will be no discernible frequency shift.

CONSEQUENCES OF DOPPLER ANGLE CHANGES

As we have seen in the Doppler equation, the dependence on the Doppler angle is in the form of a cosine. For a given flow, the greater the Doppler angle is, the lesser the Doppler shift is. A zero degree angle gives the greatest Doppler shift and at ninety degrees the Doppler shift is reduced to nil.



- With constant flow, as the Doppler Angle increases, the frequency of the echo Doppler shift decreases
- The direction of the arrows indicates the beam's direction. The length of the arrows indicates the magnitude of the Doppler shift.

Flow speed calculations based on the Doppler shift measurements can only be accomplished correctly with knowledge of the Doppler angle. It is obviously important to estimate this angle as accurately as possible. This is normally accomplished by placing the Doppler angle bar, on the anatomical display, so that it is parallel to the assumed direction of flow. In straight vessels with no flow obstruction this can be assumed to be parallel to the vessel wall, however, in tortuous or obstructed vessels, this may not be the case.

Examples:

Example 1		**Example 2**	
Initial Frequency	- 1MHz	Initial Frequency	- 1MHz
Speed of Sound	- 1600 m/s	Speed of Sound	- 1600 m/s
Velocity of reflector	- 16m/s	Velocity of reflector	- 16m/s
Angle	**- 0 deg**	**Angle**	**- 6 0 deg**
Doppler shift	**- 0.02MHz**	**Doppler shift**	**- 0.01MHz**

CONSEQUENCES OF INITIAL DOPPLER FREQUENCY CHANGES

We must also remember the proportional relationship shown in the Doppler equation of the initial, or operating, frequency of the transducer and the Doppler shift measured by the system.

Doppler shifts measured for a given flow in a vessel, using two transducers of 3MHz and 6MHz would be different. The Doppler shift from the higher frequency transducer would be double that of the lower frequency transducer.

In the clinical situation it is then important to select the transducer frequency suitable for the particular application. In venous work, we need a higher frequency to detect the low velocities which will produce small frequency shifts.

Example 3		**Example 4**	
Initial Frequency	- 1MHz	Initial Frequency	- 2MHz
Speed of Sound	- 1600 m/s	Speed of Sound	- 1600 m/s
Velocity of reflector	**- 40m/s**	**Velocity of reflector**	**- 40m/s**
Angle	**- 0 deg**	**Angle**	**- 0 deg**
Doppler shift	**- 0 .05MHz**	**Doppler shift**	**- 0.10MHz**

DOPPLER INSTRUMENTATION

There are three types of Doppler equipment used for the detection of flow in the body, continuous wave and pulsed wave spectral instruments and colour mapping instruments.

CONTINUOUS WAVE DOPPLER

These instruments include a continuous wave generator and a receiver that detects the change in frequency (Doppler shift) which results from reflector motion. The information received is presented as an audible signal and a spectral display. A continuous wave instrument detects flow occurring anywhere in the overlapping region of the transmitting and receiving beams. Because there is no depth range gate, the signals can be very confusing and include a broad range of frequency shifts.

Advantage	**Disadvantage**
• Excellent detection of high velocity flows	• No range gate location
• No aliasing limits	• Spectral broadening

PULSED WAVE

The transducer assembly in these instruments functions both as a transmitter and a receiver. Once the magnitude and direction of the Doppler shift have been derived they are presented as both audible and spectral displays. The receiver gate (sample volume) is set by the operator at a given depth on the ultrasound display and only echoes arising from moving reflectors at that depth are displayed as a spectrum.

The upper limit of the Doppler shifts which can be detected by a pulsed Doppler system is equal to one half of the number of pulses per second (**P**ulse **R**epetition **F**requency) , e.g. PRF - 1000Hz = maximum detectable Doppler shift of 500Hz. When this limit is exceeded, aliasing occurs. (This limit is sometimes known as the Nyquist Limit.) Thus higher PRFs permit higher Doppler shifts to be detected.

Advantage	Disadvantage
• Single sample volume • Accurate range location • Quantitative spectral analysis	• Aliasing - dependent on the PRF

SIGNAL PROCESSING - PUTTING IT ALL TOGETHER!

A pulsed Doppler system must receive the last echo from each pulse before it transmits the next burst. The system automatically calculates the round trip time of this burst, by knowing where the sample volume has been placed, and analyses the signals at that point in time.

Using a method called Fast Fourier Transform, which rapidly assesses all the different frequency shifts from the sample site, the system produces a spectral display on the monitor. A mathematical algorithm then completes the Doppler equation, correcting for the angle between the blood flow and the sound beam, converting the frequency shifts (KHz) to a velocity (M/s). Most modern systems will not complete this conversion if the Doppler angle is greater than 70 degrees, since the resulting velocity would have a large degree of inaccuracy.

COLOUR DOPPLER IMAGING

Colour Doppler is a display of **mean frequency**. Data from hundreds or thousands of sample volumes is processed, using a system called autocorrelation. A very simple explanation of this is that all the frequency shift data obtained from these multiple sample volumes is analysed for mean frequency , amplitude and turbulence.

This allows us to use colour Doppler information to quickly appreciate haemodynamic events occurring in the region of interest in a qualitative manner, such as -

- Existence of flow
- Direction of flow
- Existence of turbulent flow

thus providing a "road map" for pulsed Doppler spectral analysis.

Perhaps the most important point to remember is that colour Doppler is a **QUALITATIVE** analysis of data and does not provide velocity information.

COLOUR DISPLAY

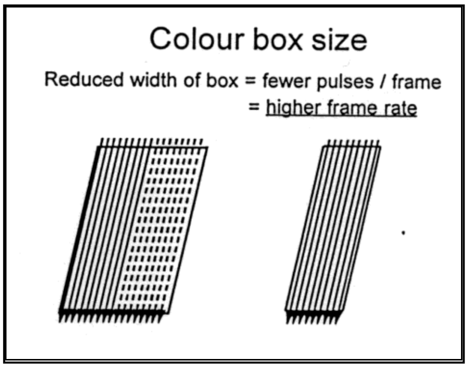
A colour wheel or colour bar is used in most equipment to display the direction, amplitude and turbulence data in a colour Doppler signal. These displays indicate direction of flow (positive or negative frequency shift) as red or blue, dependant upon allocation or encoding by the operator. The highest amplitude is displayed as the brightest colours with areas of turbulence being displayed as green (the brightest green being the most severe turbulence).

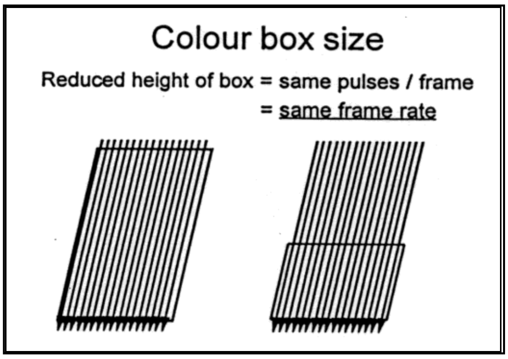
REGION OF INTEREST BOX (ROI)

The size of the colour box should be adjusted to optimise the frame rate, but still allow a suitable area of the field of view to be covered. The box may be adjusted in:

- width
- height
- depth into the patient

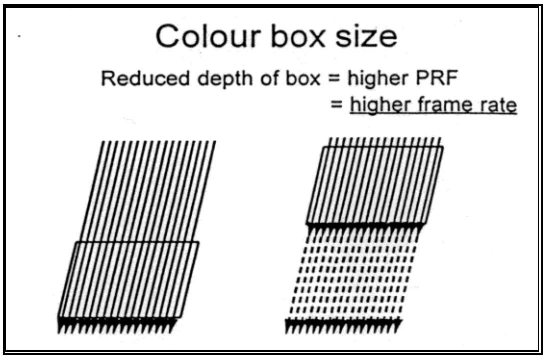
By reducing the width of the box, fewer colour lines of sight are required (and remember that each of these lines requires several pulses). By reducing the width, each frame can be completed in much less time therefore significantly increasing the frame rate.





If the height of the box is reduced but the width is maintained, the same number of beam paths is still required; therefore the effect on frame rate is minimal.

If the depth of the colour box in the patient is reduced, then for each pulse sent into the patient, the computer does not have to wait as long to receive the echoes. Each line of sight can then be completed in a shorter period of time, making the entire frame completion time somewhat faster. Frame rate therefore increases.



CONTROLS

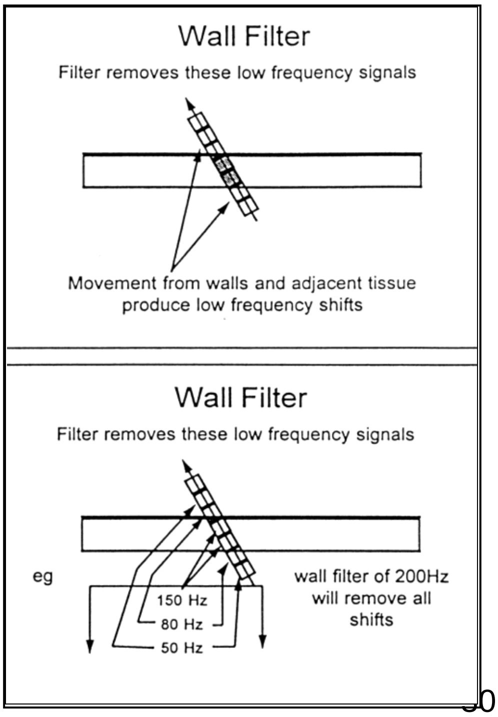
Spectral and colour Doppler controls are often not properly understood by the operator because the modern systems available have excellent applications software to set the parameters for differing flow situations within the body. Most of the time, these set ups are more than adequate; however, it is necessary to understand the functions of these controls in order to optimise the system for individual, difficult cases. Ultrasound equipment manufacturers have different names for many of these controls, so it is also important to find out what terms are used in your particular system.

PULSE REPETITION FREQUENCY (PRF)

Other terms for this are flow rate or scale. This determines the sampling time that is required to process the Doppler information. Since low flow must be sampled for a longer period of time to accurately analyse the information for colour display, low PRF must be selected for these situations. Higher flows can be sampled more quickly so high PRF can be selected in these situations.

Whilst the system preset will be adequate as a beginning don't forget that changes may be necessary during an examination. E.g. Vertebral flow is often slower than common carotid flow - lowering the PRF when looking for vertebral arteries in a carotid exam can assist in speedy recognition of the vertebral artery.

FILTERS



There are numerous terms used, such as high pass filter (HPF), wall filter or thump filter. Their function is to eliminate strong, low frequency Doppler shifts arising from tissue or vessel wall motion. Another way of remembering this function is to think of them as "electronic erasers ", in that the filter will eliminate or erase any frequency below that set.

Doppler shifts (= colour signals) are produced not only from blood flow, but also from any other moving structure, including solid tissue.

Tissue motion is very slow velocity, but the Doppler signals are large amplitude compared to blood flow signals because of the large reflections from the tissue interfaces. These low velocity signals cause colour flashes to occur in the presence of moving tissue, and these can greatly degrade the quality of the colour image.

The wall filter causes the computer to completely ignore Doppler shifts (= velocity) below a set limit.

Because vessel walls are a major cause of these unwanted signals, the filter to remove them was called a "wall filter". However these filters will remove all frequency shifts below the selected limit, whether they are caused by wall motion, adjacent soft tissue movement or blood flow.

Although prudent use of a wall filter will produce a more diagnostic colour image, overuse (i.e. setting the cutoff limit too high), may remove significant blood flow echoes, and in extreme cases all flow representation.

When attempting to visualise slow velocity flow such as that seen in peripheral veins, the wall filter must be set very low to prevent removal of the echoes. In this case a conscious effort must be made to minimise tissue movement by careful transducer and hand movements.

In fast flow areas, such as arteries, increase the filter setting to produce an image with little colour produced over the vessel walls or adjacent tissue.

COLOUR & SPECTRAL DOPPLER INVERT

This simply allows the operator to make a negative spectral Doppler shift appear above the baseline, which can be helpful when interrogating a vessel from differing Doppler angles.

In colour, this allows arteries to be displayed in red and veins in blue, regardless of the angle of interrogation. In carotid or peripheral studies, where the vessels are mostly straight, this is fairly simple to understand and control but care must be taken in abdominal studies, where the vessels are often tortuous. The operator must have a good knowledge of vascular anatomy to avoid interpretive mistakes.

STEERING

Spectral Doppler - As we have seen, a 0 degree interrogation angle will produce the highest frequency shift. Steering allows us to place the sample volume at the best angle possible in a particular vessel and will provide directional information.
Colour Doppler - Steering the ROI will provide information on the direction of flow with respect to the transducer; however, steering also reduces the sensitivity of the system (due to refraction, scattering and aperture reduction). Therefore, when small vessel flow detection is necessary e.g. Thyroid or Testicular studies, the ROI should not be steered, allowing optimal system sensitivity.

COLOUR QUALITY

Other terms for this are packet size or length and ensemble length or sensitivity. This is simply the number of times and for how long, the system samples each line of sight in the ROI. Higher numbers will require longer sampling time and therefore reduce frame rate, but will result in a more homogeneous colour display. Lower numbers will result in higher frame rates but more pixilated colour, with a more accurate display of haemodynamic changes.

It is up to the operator to decide the quality of the colour display for each application and patient.

B-SCAN/COLOUR PRIORITY

This is a decision circuit, which allows the system to overlay colour information on areas of the greyscale image where there is no greyscale information. (That is to say, not over pixels displaying greyscale information) In large vessels, this is simple, since it is easy for the system to differentiate between the vessel and surrounding tissue. However, in vessels that are too small to be resolved on the greyscale image (testis), the moving blood detected by the Doppler cannot be written as colour in the vessels since the system does not “see” them as “black”.

By reducing the priority of greyscale in the decision circuit, the operator can override the preset levels and allow this colour data to be written over pixels containing greyscale information.

ARTIFACTS

As in any other ultrasound modality, spectral and colour Doppler both have artifacts to be used or overcome. Doppler artifacts tend to be common to both colour and spectral, being displayed in different formats.

ALIASING

This is probably the most common artifact occurring in Doppler studies. The important thing to remember here is that aliasing is NOT a disease indicator. It simply means that the speed of the flow being examined is faster than half of the PRF set. Colour aliasing can be useful in certain applications to map changes in frequency shift, in a vessel with blood flowing at a constant angle with respect to the transducer.

In colour, the aliasing will be displayed as the wrong colour. Colour changing from red, through yellow and green, to blue is caused by aliasing. Colour changing from red, through black, to blue is caused by a change in direction.

In spectral Doppler, aliasing will be displayed by spectral data being wrapped around the base line. Increasing the PRF will “unwrap” the spectrum and display it in the correct direction, either above or below the baseline.

Switching to a lower Doppler frequency will also serve to decrease aliasing.

MIRROR IMAGE ARTIFACT

Presents information as flow on both sides of the baseline in spectral Doppler. This can happen when the Doppler gain is set too high or when the Doppler angle is near 90 degrees. Using electronic array probes, this artifact can become apparent when the Doppler cursor is positioned too close to the centre of the crystal.

To minimise this artifact in spectral Doppler:

- Lower Doppler gain
- Lower Doppler angle of incidence
- Reposition probe so that cursor is between the middle and edge of the crystal

Mirror imaging can occur in colour Doppler; being depicted as opposing colours in unidirectional flow or as a mirror of a vessel on the opposite side of a particularly strong reflector (Diaphragm).

- Correct angle selection will minimise colour mirroring.

ANGLE OF INCIDENCE

A vessel curving through the colour ROI makes it possible for the Doppler to interrogate unidirectional flow in two different directions, towards the transducer and away. This commonly occurs when curving vessels are interrogated at or near 90 degrees.

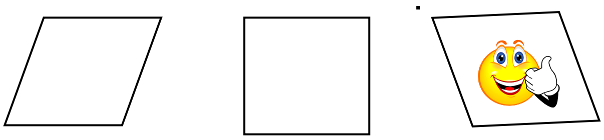
- Correction of the angle of incidence will eliminate this artifact

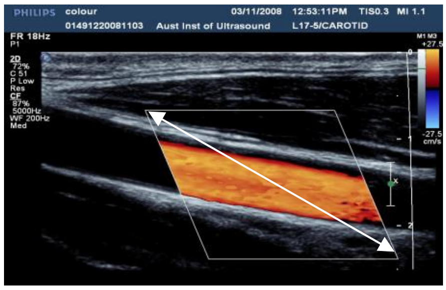
In curving or tortuous vessels changes in the angle of incidence towards 0 degrees along the vessel may display frequency shifts that appear accelerated or even aliased. This may be misinterpreted as an area of increase in velocity, but is, in fact, artifactual.

- Understanding of the physics of the effect of the angle of incidence on colour display will eliminate misinterpretation of this artifact.

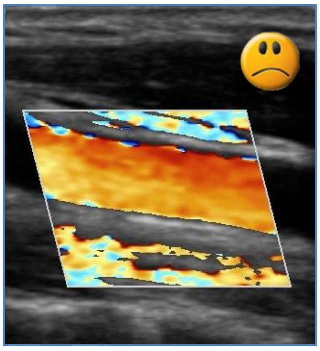
OPTIMISING COLOUR DOPPLER

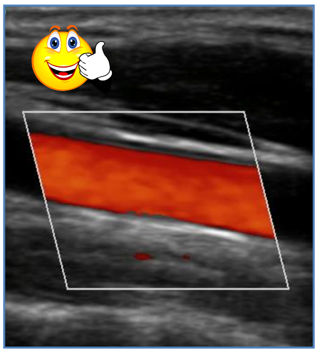
1. Choose a box whose long axis parallels vessels walls as closely as possible. In the case of a horizontal vessel either of the angled boxes works. Adjust the box size appropriately.



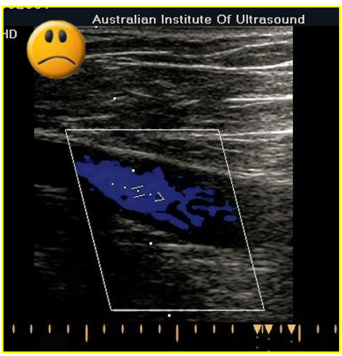


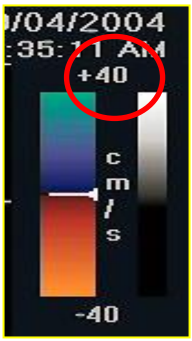
2. Increase the colour gain , until colour 'bleeds' outside the vessel and then turn it back down.

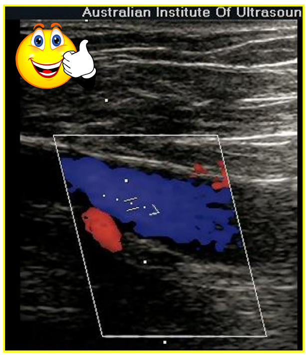


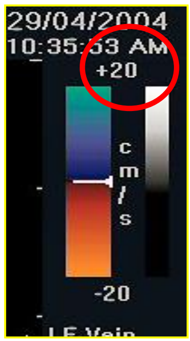


3. If there is no filling or inadequate filling in the vessel, decrease the PRF (scale).

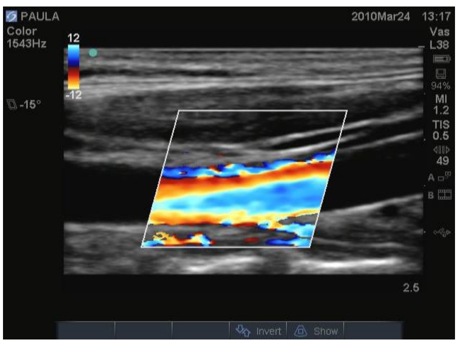


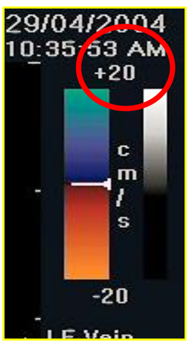


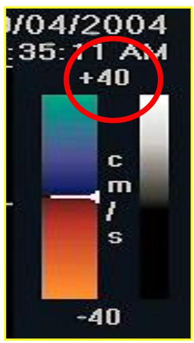




4. If there is Aliasing (multiple shades of colour), increase the PRF (scale).







PROBE MANIPULATION TECHNIQUES

Once the machine controls have been mastered, scanning skills need to be acquired in order to continue upward on the learning curve. The beginner can often find manipulation of the transducer a difficult and painful process (the fingers and wrist become locked and sore!!).

Recognising the orientation of the transducer is probably the most important factor to begin with. Most transducer manufacturers provide an orientation mark, usually a small raised bump or light on one side of the transducer handle. In general, this mark should be towards the patient's head for sagittal sections and towards the patient's right for transverse sections.

The transducer should be used as an extension of your hand and visualised as a torch, with the ultrasound beam as the light emanating from the torch. The anatomy must be visualised as three-dimensional and not just the two-dimensional view seen on the monitor, point the transducer at the organ you wish to image, remembering the three dimensions.

The probe should be held with the operator's fingers close to the transducer face and with the little finger resting on the patient's skin, so that maximum control is exerted. In this way, the transducer will not slide off the scan plane needed and can be kept steady on the patient's skin, at the correct angle.

- ➲ **Orientate the transducer correctly**
- ➲ **Remember the body is three-dimensional anatomy**
- ➲ **Use the ultrasound beam as a torch, pointing at what you need to see**
- ➲ **Hold the probe so that the fingers control the transducer face properly**

SCANNING TECHNIQUES

1. Work Station

Operator comfort is an important factor in successful image acquisition. The operator should be positioned so that the forearm and hand are gently resting on the patient, with the spine erect and eyes at the level of the system monitor.

- ➲ **Scanning can be undertaken either seated (adjustable chair with wheels) or standing, depending on the height of the operator.**
- ➲ **If the patient trolley is adjustable, adjust the height to suit the operator.**

Whilst this is not always possible in venous scans, the benefits accrued in operator comfort and improved scans are well worth the few moments it takes to set up a reasonably ergonomic workstation for each scanning situation.

2. ULTRASOUND GEL

For a variety of reasons, it is important to use sufficient gel over the proposed scanning area. A common mistake made by beginners is to use insufficient gel, thereby making poor contact with the skin surface (producing artifacts and poor imaging) and reducing the mobility of the transducer face over the skin (producing patient discomfort and operator frustration).

➲ **Too much gel is far better than not enough!**

➲ **Spread out the gel over the proposed scanning area, before beginning your survey scan**

3. SURVEY SCAN

Always perform a swift survey of the area in question, before focussing on the point of clinical question. This will serve to orient you to the anatomy under review and identify good sonographic "windows".

➲ **Perform a survey scan first**

SONOGRAPHIC "WINDOWS"

A sonographic window can be described as a path for the sound beam into the body, to reach the organ in question, avoiding areas of bone, bowel, or lung. An example of this is:

➲ **Using muscle bellies to view veins from different approaches & to avoid shadowing from ligaments or fascial planes.**

A large part of the sonographic art is an intuitive grasp of finding good sonographic windows. Visualising the body in three dimensions and applying logical thought to the best approach for a particular organ, vessel or lesion will quickly lead to this intuitive grasp.

5. TRANSDUCER MOVEMENT

Transducer movements should be smooth free flowing, allowing proper time for the operator to view the real time image on the monitor without constant checking of transducer position. When the area of interest has been reviewed and the sonographic window decided upon, the transducer movements should be slowed and small movements made in one plane at a time, otherwise it is easy to become confused and lose sight of the organ, vessel or lesion in question.

Transducer movements are:
1. Rotate
2. Fan (with long axis of transducer)
3. Heel / Toe (H=non-marker / T=marker)
4. Slide (towards or away from marker)

➲ **Make one movement at a time, with logical forethought**

➲ **Slow movements down when focusing on area of interest**

GRADED COMPRESSION

The use of firm pressure on the transducer can significantly improve images of deeper structure by several means:

a. decreasing the distance of the target to the transducer, thus bringing the target into the main focal area of the beam or
b. allowing the use of higher frequency transducers or
c. pushing loops of gas filled bowel out of the field
d. improving skin/transducer contact
e. minimising some artifacts

The emphasis should be on gradual, graded compression - since this is well tolerated by most patients, even those experiencing significant pain.

➲ **Use graded compression, increasing and decreasing pressure gradually**

8. MULTIPLE SCAN PLANES

Structures should always be viewed in at least two different scanning planes, with longitudinal and transverse sections being the minimum. It is preferable to view from two different approaches as well, e.g. anterior & coronal. This can easily resolve confusion concerning the nature of some structures e.g. cyst versus tube, aorta versus inferior vena cava.

➲ **Always view structures from at least two different approaches and in two different planes.**

DYNAMIC TECHNIQUES

Holding the transducer steady and watching muscles & tendons move in and out of the field as the patient gently moves can often elicit a large amount of information as to the best window to use.

THE TRANSDUCER AS A PALPATION TOOL

Using the face of the transducer to gently palpate an area of pain will often elicit clinically useful information, e.g. acute pain on direct palpation of superficial thrombophlebitis. The benefit accrued from this is being able to view the area being palpated to be certain of cause of pain.

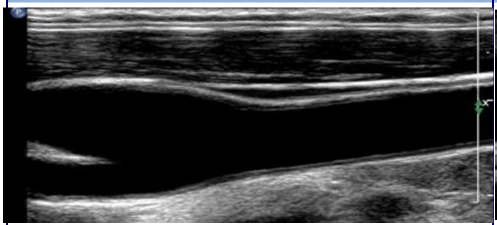
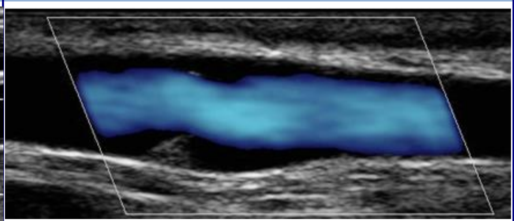
PROTOCOLS AS A USEFUL TOOL

Departmental protocols are an extremely useful tool during the learning curve and should be used regularly until they are second nature. A simple way to enhance memory of different scanning techniques is to make up your own protocols using your own words.

FINDING THE VESSELS

The initial concern on utilizing ultrasound for localizing and needling vessels is to ensure a confident recognition of the ultrasonic differences between arteries and veins.

The criteria governing these differences are simple and easily demonstrated.

<table>
<tr><th>ARTERIES</th><th>VEINS</th></tr>
<tr><td>Thicker walls – 3 layers</td><td>Very thin walls</td></tr>
<tr><td>Anechoic - Pulsatile</td><td>Anechoic - compressible</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>No valves</td><td>Valves</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Arterial spectrum on PW</td><td>Venus spectrum on PW</td></tr>
<tr><td></td><td>
</td></tr>
</table>

It is always preferable to begin examining vessels in the transverse plane. A “black hole” (anechoic vessel) is easier to follow and examine than a tortuous “black tube” (anechoic longitudinal vessel).

Steps to finding specific vessels are as follows:

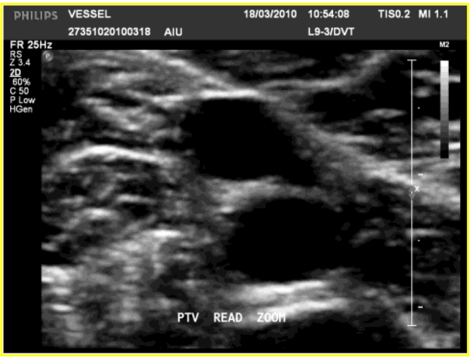
1. review anatomy
2. choose relevant landmarks that will be reliably recognized on the ultrasound scan e.g. bony structures
3. look at patient with “x-ray glasses” on – try to imagine the relational anatomy under the skin
4. carefully place probe transversely over the expected position of the vessel in question
5. look at the monitor; what do you see?
6. plan the movements required to reach target

VESSELS OF INTEREST

➡ JUGULAR VEIN (JV)

- This is one of the easier veins to access and is usually examined with the operator behind the head of the bed and the patient supine or in the Trendelenburg position (this is not as critical when using ultrasound guided techniques as the vessel is easily located)
- **Preset** - venous
- **Start position**
  - Patient supine, chin rotated away from side to be examined
  - Transducer (probe) in transverse plane
  - Mid neck, marker end oriented to operator's preference
  - Anterior approach
- **Landmarks** – common carotid artery (CCA), thyroid gland, trachea
- **Relations:**
  - JV – anterior to or slightly lateral to CCA
  - JV – deep to strap muscles

BE AWARE OF CORRECT PROBE GRIP TO ENSURE NO PRESSURE EXERTED ON JV



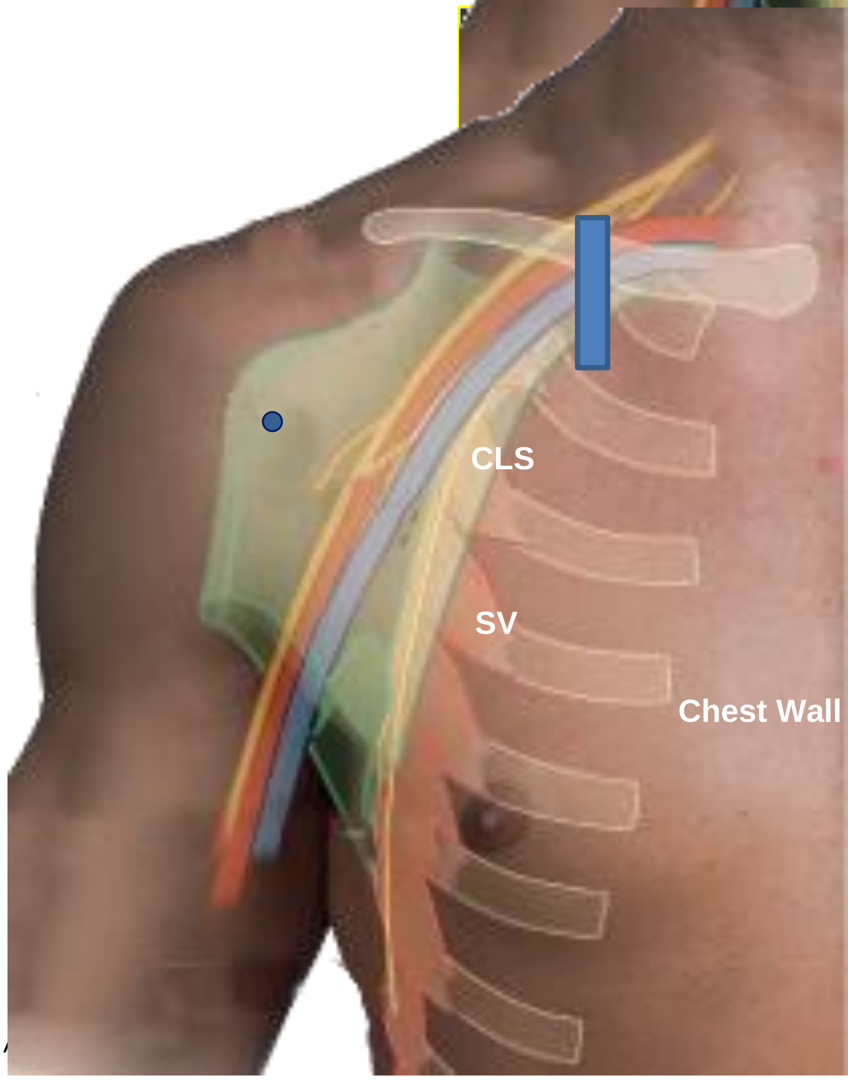
- **Optimise image** – Depth, Focus TGC
- **Examine the vessel**
  - Slide probe up and down the neck to visualise course of vessel
  - Check patent lumen with compression
  - Slide probe medial or lateral in order to centre the JV on the monitor

  - Rotate probe to longitudinal with marker end towards you.
  - Slide transducer medial to lateral, centering the vessel under the beam
  - Note depth of vessel from skin & angulation of needle approach

- **Set up needling position**
  - Slide probe towards the base of the neck until it rests against the superior border of the clavicle
  - Curl 4th & 5th fingers around clavicle to assist stability
  - Mark probe position
- **NB:** Needling can be transverse or longitudinal approach depending on patient habitus and room dynamics

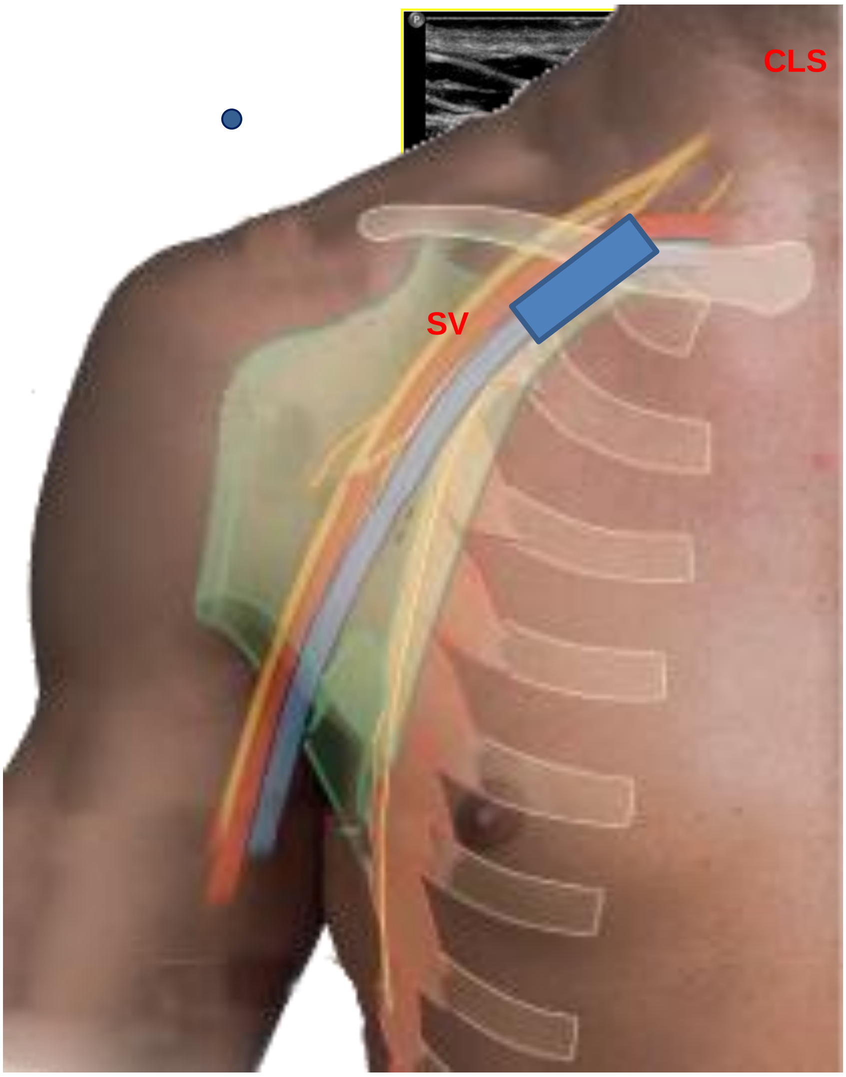
➡ SUBCLAVIAN VEIN (SV)

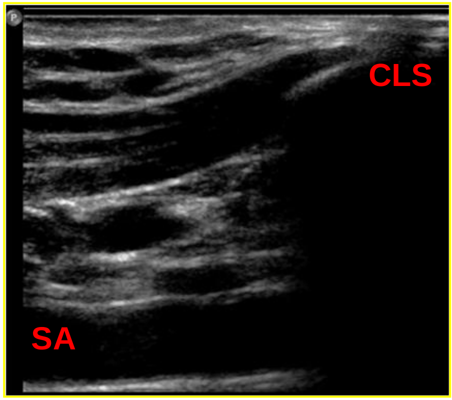
- This is a vein that is often ignored for the purposes of line placement, since it is deemed difficult and hazardous to needle, with the possibility of causing pneumothorax hanging over the operator. Using ultrasound guidance here enables the operator to place a line in the subclavian vein quickly, easily and safely; since the needle tip is visible at all times.
- **Preset** - venous
- **Start position**
  - Transducer (probe) in longitudinal plane at sterno-clavicular joint
  - Marker end oriented to patient's head ( )
- **Landmarks** –Clavicle, chest wall
- **Relations:**
  - SV – Deep to clavicle
  - SA – Superior & Deep to SV
- **Finding the Vessel**
  - Slide probe along the clavicle (DO NOT FAN) until the SV is seen emerging from under the clavicle shadow (CLS)



  - Use sniff to check vessel is a vein
  - Mark transducer

position on clavicle with finger of left hand
- Rotate probe to place non-marker end on clavicle and marker end pointing towards the axillary crease
- View monitor – fan towards head to find artery, fan towards feet to find vein





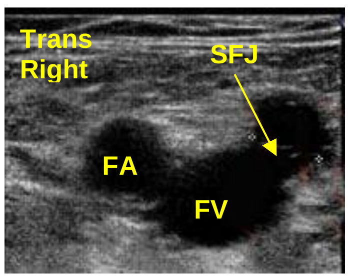
- Use sniff response or PW Doppler to confirm the vein and assess angulation of needle required

FEMORAL VEIN (FV)

- One of the easier veins to use for line placement, due to its superficial positioning in the groin and to its ease of accessibility to the ultrasound probe.

- **Preset** – venous

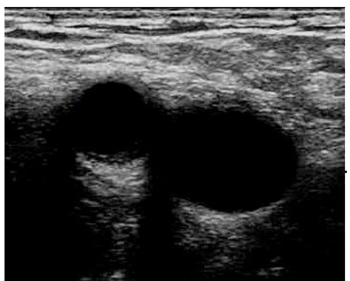
- **Start position**
  - Transducer (probe) aligned along the groin crease, transverse to the femoral vessels
  - Marker end oriented to patient's right



- **Landmarks** –Femoral artery (FA), sapheno-femoral junction (SFJ)

- **Relations:**
  - CFV – Superior to SFJ
  - CFA – Lateral to CFV

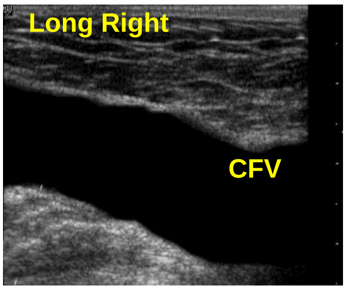
- **Finding the Vessel**
  - Slide probe medially along the groin crease



- Locate vessels
- Slide superiorly to identify SFJ
- Slide superior to SFJ then slide medial or lateral to position the vessel in the centre of the monitor

- **Optimise image** – Depth, Focus, TGC
  - Compress to assess patency of vessel

  Rotate probe through 90^0 with marker end towards you
  - Slide left/right to ensure probe is centred on the vessel
  - Mark position of probe
- **Set up needling position**
  - Measure distance from skin
  - Assess needle angulation required



DIFFICULT PERIPHERAL VEINS

- Ultrasound is extremely useful in those patients, who for what-ever reason, have compromised veins.
- An inflated cuff or distal augmentation may be necessary to distend veins
- Very light transducer pressure is essential (just a small amount of pressure will flatten veins)
- Operator positioning is important to diminish inadvertent probe pressure
  - Forearms should be supported , elbows wide
  - Probe gripped low down
  - 4th & 5th fingers in contact with patient
  - Needle gripped like a dart

ARTERIES

When examining arterial structures, the approach is similar to that of venous structures. Basically the protocol should have a systematic approach which takes into consideration:

- The anatomy of the area
- Ultrasound recognisable landmarks (e.g. bones)
- Patient position
- Transducer start position
- Normal ultrasound appearances
- Movements necessary to achieve goal
- Operator position

FEMORAL ARTERY

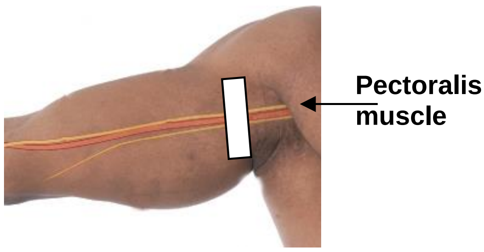
- Use arterial pre-set, otherwise see femoral vein (page 40)

AXILLARY ARTERY

- **Preset** – Upper extremity artery

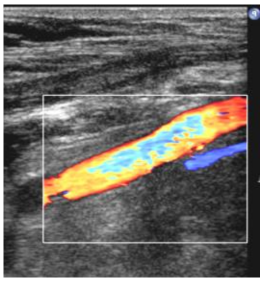
- **Start position**
  - Transducer (probe) along the axilla, transverse to the axillary vessels
  - Marker end oriented to patient's head (superior)

- **Landmarks** –Humerus; Lateral edge of pectoralis muscle



- **Relations:**
  - Axillary Artery (AA)– Superior to axillary vein (AV)

- **Finding the Vessel**
  - Slide probe medially and laterally along the arm – up towards the axillary crease
  - Locate vessels
  - Slide superiorly to inferiorly to centre the vessels on the monitor



- **Optimise image** – Depth, Focus, TGC
  - Compress to assess patency of vein
  - Rotate probe through 90^0 with marker end towards you
  - Slide left/right to ensure probe is centred on the vessel
  - Mark position of probe

- **Set up needling position**
  - Measure distance from skin
  - Assess needle angulation required

RADIAL ARTERY

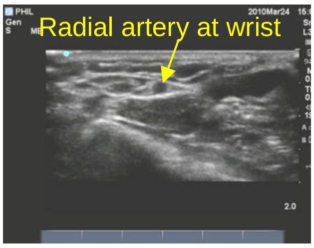
- **Preset** – Upper extremity artery

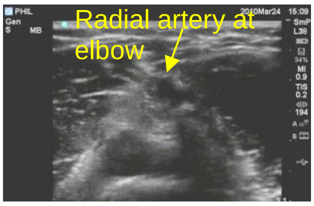
- **Start position**
  - Transducer (probe) in a transverse plane at the wrist
  - Marker end oriented lateral

- **Landmarks** –Radius and ulna, superficial fascia

- **Relations:**
  - Artery is immediately deep to the superficial fascia

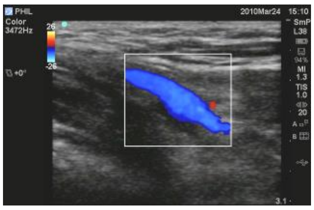
- **Finding the Vessel**
  - Slide probe medially and laterally across the wrist
  - Locate vessel
  - Slide superiorly, following course of vessel to the required position on the arm





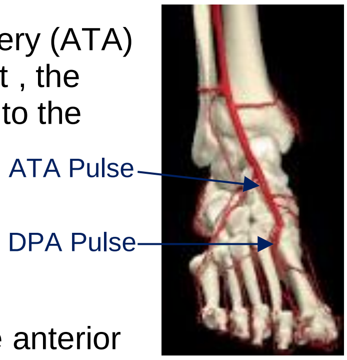
- **Optimise image** – Depth, Focus, TGC

  - Rotate probe through 90^0 with marker end towards you
  - Slide left/right to ensure probe is centred on the vessel
  - Mark position of probe



- **Set up needling position**
  - Measure distance from skin
  - Assess needle angulation required

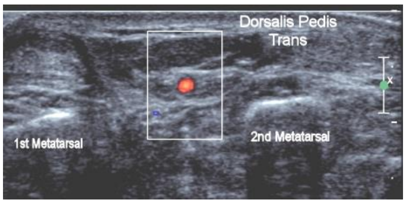
DORSALIS PEDIS ARTERY (DPA)



- This artery is the extension of the anterior tibial artery (ATA) which can be palpated at the front of the ankle joint , the dorsalis pedis pulse can be palpated just proximal to the first web space

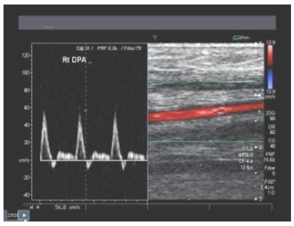
- **Preset** – Lower extremity artery

- **Start position**
  - Transducer (probe) in a transverse plane at the anterior ankle
  - Marker end oriented lateral



- **Landmarks** –Talus, palpable pulsations, metatarsal bony contours

- **Optimise image** – Depth, Focus, TGC
  - Rotate probe through 90^0 with marker end towards you
  - Slide left/right to ensure probe is centred on the vessel
  - Mark position of probe



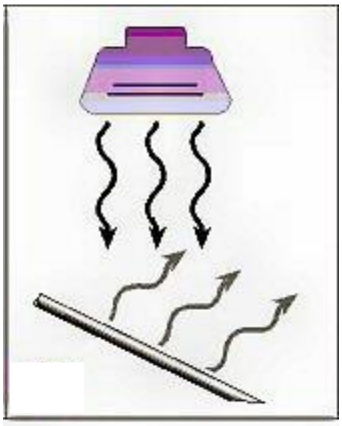
- **Set up needling position**
  - Measure distance from skin
  - Assess needle angulation required

ULTRASOUND NEEDLE GUIDANCE TECHNIQUES

PHYSICAL PRINCIPLES

As we know ultrasound images are created by sending a sound beam into a patient and displaying the returned signal. The returned signals are reliant on the sound wave's interaction with internal tissue and the subsequent reflection being created. The larger the reflection, the strong the signal returned, and the brighter the image displayed. The best reflection from any structure occurs when the beam intersects the structure at 90^o so the best image of the needle will be when the needle is paralleling the transducer face so the beam intersects at 90^0

90^0 – best to see needle



A needle approach that parallels the transducer face is often not anatomically practical, particularly at depth. Ultrasound has a 5^0 margin of error, in that the needle is still well visualized within 5^0 of parallel. Between 5-20^0 the needle becomes increasing harder to identify as more of the reflected sound wave is deflected away at a tangent and does not return to the transducer face. Angles of approach greater than 20^0 make normal needles near impossible to identify. This is an important principle to remember when in the clinical setting. If you can't see your needle-tip…What is your angle of approach?

CLINICAL INDICATIONS

Ultrasound needle guidance enables accurate needle positioning in a wide array of previously blind techniques. It can be used to

- Assist in real time canalisation under direct ultrasound
- Confirm normal anatomical positioning of structures prior to performing the blind "landmark' approach
- Minimize the number of attempts to canalise a difficult venous access patient
- Establish the viability of vessels in patients that are intravenous users or have known thrombosis in vessels
- Identify and access alternative vessels when a vessel is consider not appropriate
- Improve physicians confidence in tracking the advancement of wires and catheters
- Assist arterial puncture
- Identify best site for insertion of drains and diagnostic taps by locating the largest pool or easiest access

- Ensure a safe biopsy or drainage route, avoiding large blood vessels, overlying bowel and aerated lung to decrease the risk of hemorrhage & puncture
- Ensure accurate placement of needle tips in biopsies to provide accurately obtained cytology and histopathology samples
- Enable accurate needle positioning in small or difficult to approach lesions with localisation in real time & in multiple non-standardised planes
- Decrease procedure time in critically ill patients
- Generally, improve efficiency, contain costs and reduce complications

STERILE PROCEDURE

As in any interventional procedure, sterility is a major consideration. Sterility when performing ultrasound guidance may be maintained by one of several methods of probe preparation.

1. COMMERCIALLY PACKAGED KITS.

These, while being the most expensive, provide the best fitted cover and are the

least troublesome, avoiding problems with baggy covers getting in the way, air pockets forming artifacts in ill fitting covers, and wrinkles and folds causing contact problems. These packs are usually created by the probe manufacturers and fit the probe and its cable exactly. The cable portion of the cover can often be purchased in different lengths dependant on use and technique i.e.: how much cable will lie across the patient during use. Most commercially available packs also contain sterile gel satchels so the kit is supplied inclusive and may be opened onto a sterile setup trolley

2. PLASTIC BAGS STERILISED BY CSSD.

A more cost effective method of sterility is to purchase retail available plastic bags (i.e. GLAD OPEN MOUTH SANDWICH BAGS). The hospitals CSSD department can individually sterilize and pack each bag with elastic bands to secure the bag. These internally produced sterile packs can be used with sterile satchels of KY jelly. When choosing the bag to use, consider the one that fits your probe in the closest manner. The bags must be made of fairly durable plastic to withstand the sterilisation process. Make sure the bag does not have a seam at the bottom, as this will be positioned directly across the transducer face and cause contact problems. Be aware that elastic bands often lose their stretch after sterilisation, so include 2-3 in every pack as spares. Plastic bags will often only cover small

portions of the cable so great care must be taken to avoid cable contact with sterile drapes.

3. STERILE GLOVES

The use of a sterile glove over the probe is a common practice. The transducer face goes into the palm of the glove and the fingers folded up out of the way. The use of steristrips or some form of sterile tape is recommended to secure the fingers out of the way. Sterile KY jelly satchels provide the sterile gel.

PROBE PREPARATION

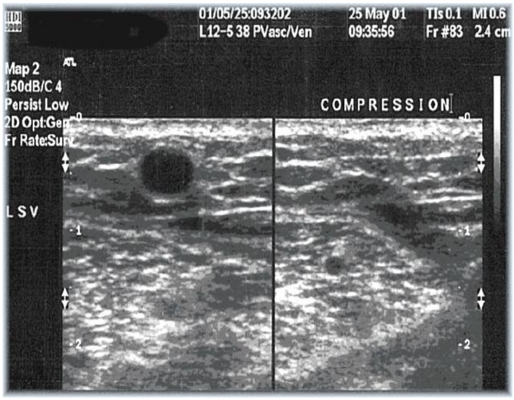
When dressing the probe, make sure ample gel is applied to the transducer face. It is advisable to apply gel both to the transducer face and to the bottom of the bag to ensure a thick coupling of gel inside the bag. Smooth out any air bubbles before securing the cover. Sterile gel will then need to be applied to the outside coupling surface with the patient. Once the probe has been dressed and the procedure commences it will be necessary to put down the probe on multiple occasions during the procedure. This becomes even more critical when using probe cover methods 2 or 3 where the cable is not sterile. The easiest way around this is to position a drip stand next to the patient and hang the cable over the hook at the top of the stand. This supports the cable away from sterile areas and allows the sterile probe to hang freely until required again.

ULTRASOUND ANATOMY – VEIN VS. ARTERY

One of the benefits of ultrasound needle guidance is the ability to distinguish between arteries and veins, something that is not possible using the palpation 'landmark" approach. Depending on the machine and users' capabilities, there are several methods of distinguishing arteries from veins. Good anatomical knowledge will assist in all of these methods.

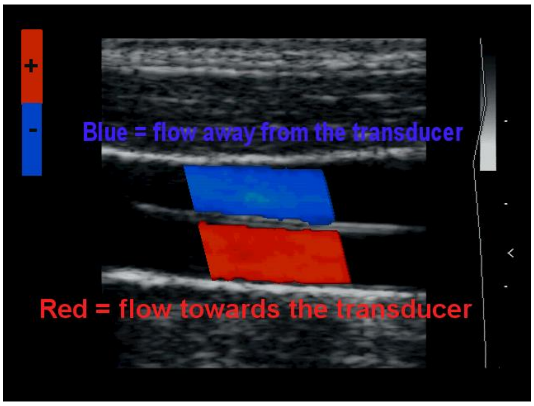
1. B MODE

- When compared to arteries, veins are more compressible. Be aware that superficial peripheral arteries, particularly in the arm are also compressible if firm pressure is applied -so watch your probe pressure
- Veins have thinner walls than arteries
- Veins have no real time arterial pulsations. Be aware that the closer



you scan to the heart, the more transmitted pulsation the vein displays and this can be confusing.

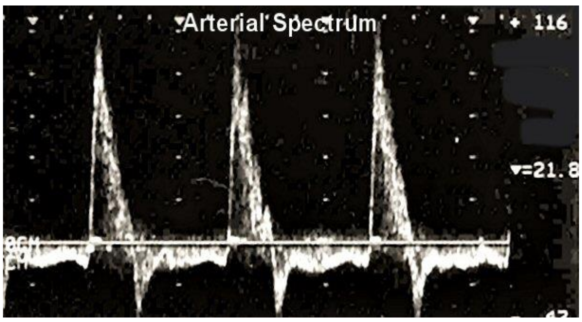
2. Colour

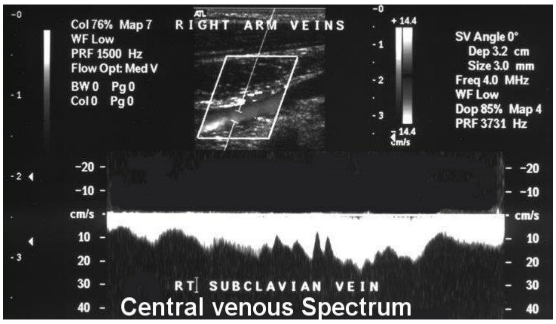


- Colour demonstrates change in direction. Arteries and veins should flow in opposite directions to each other and therefore be different colours on colour flow mapping. Be careful of the "arteries are red; veins are blue" theory as this is a control which can be changed to suit the situation. Also be careful of tortuous vessels that have multiple changes in direction as this can be displayed as multiple changes in colour and can cause confusion (see physics of colour & Doppler material)
- When examining peripheral vessels, augmenting the distal portion of the vein of interest will create a flash of colour in a vein which previously demonstrated minimal flow

3. Doppler

- Arteries and veins have quite distinctive vascular flow patterns on Doppler
- Veins generally demonstrate lower velocities than their counterpart artery due to the lower pressure system
- Veins don't usually display a clean spectral window due to the spectrum of velocities traveling at any given time. The spectrum usually extends to the baseline
- There is usually very little variation in venous velocity over time, making their spectral trace fairly flat relative to their arterial counterpart. Be careful of the IVC and hepatic veins as right heart pressure can significantly change the pulsatility of their signal
- The Doppler trace is the most reliable of all three methods and should always be used if available





TRANSDUCER ORIENTATION

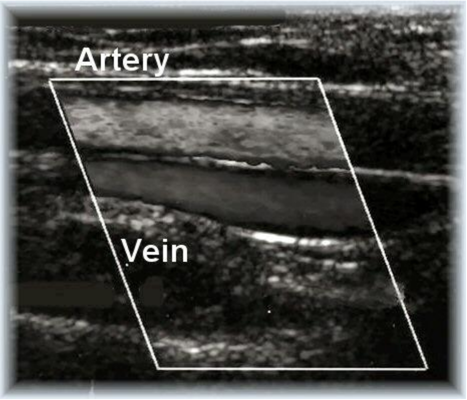
Once vessels have been imaged and the vein positively identified via at least one of the above techniques, image the vessel of interest in a longitudinal plane.

Check the orientation of your probe relative to the screen. Needle recognition is much quicker if you know from which side of the screen it will be advancing. Longitudinal scanning of the vessel with the needle approach along the transducer face has several advantages.

- It shows the longest portion of the needle, which makes it quicker to visualise and easier to stay on the needle during manipulation into the vessel.
- Longitudinal imaging also provides visual perception of depth and slope requirements to penetrate the vessel.
- Once the needle tip has been seen to pierce the vessel, confirmation is gained by turning the probe through 90º to transverse to ensure the needle has entered vessel.
- Be careful of slice thickness artifacts on small peripheral vessels. This can display needles inside vessels when they have slipped off the side and are sitting laterally.
- Always gain confirmation of needle in-situ via visualisation in 2 planes or back flow of blood before advancing wire or lines through the stilett.

TECHNIQUE

1. PERIPHERAL



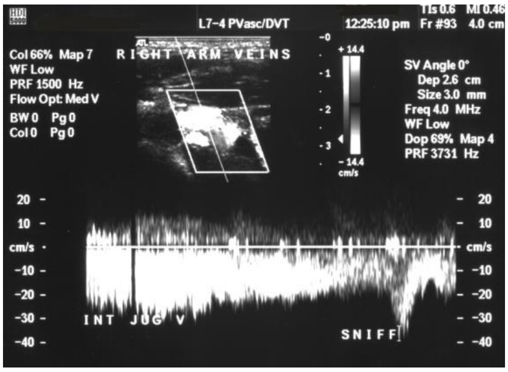
Canalisation of peripheral vessels is often difficult in patients who have had multiple venipunctures. In these difficult patients even ultrasound guidance can be challenging, particularly if the machine doesn't have colour facilities to highlight the vessels.

Applying a tourniquet on the upper arm will facilitate visualisation of the small peripheral veins by venous engorgement. When establishing the difference between arteries and veins in peripheral structures, remember that an artery may collapse with applied pressure due to being so superficial, and veins often demonstrate no flow, especially with a tourniquet on, unless augmented from below

2. CENTRAL

Central venous access can be assisted with ultrasound by demonstration of anatomy, which is often variant, to identify previously thrombosed vessels and the path of subsequent collateral formation and for avoidance of other major structures in the region. Vessels in this region often have a fairly tortuous path, ultrasound monitoring of catheter advancement provides increased confidence of tip location and safer, more accurate positioning.

Identifying veins of the upper thorax can be difficult due to difficulty of compression caused by overlying bony structures and limited window access.



This can be overcome by asking the patient to sniff.

In spectral Doppler mode, this will generate a short, sharp increase in velocity, enabling the operator to confidently identify the vein. Visualisation of veins in difficult cases may be enhanced by slight Trendelenburg positioning of the patient to encourage venous engorgement.

Due to the path of subclavian veins, colour filling of this vein may be poor due to poor angle of insonation. Try power Doppler to overcome this if the approach angle cannot be improved (i.e. best colour is achieved at 0˚insonation).

Remember that new occlusive clot can be anechoic particularly at depth and this needs to be excluded for a successful canalisation

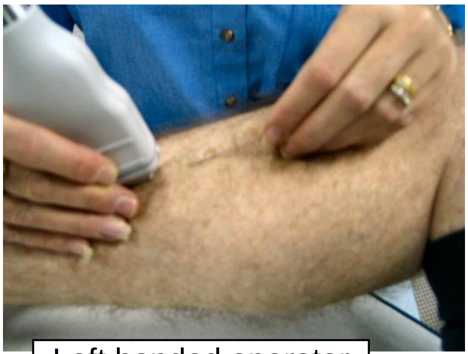
3. CAVITY

Ultrasound guidance for pleurocentesis, amniocentesis or paracentesis enables identification of the largest safe pocket of fluid and maximum depth for the insertion of drainage or aspiration equipment.

When scanning these cavities, make sure the probe remains at 90˚ to the skin surface for accurate depth calculations. The fluid for drainage may often contain blood, debris, or cells, which can result in small echogenic foci being present in the fluid when imaged, and while this is acceptable, echoes within the fluid must be differentiated from solid structures within the fluid like lung, bowel or fetal anatomy.

NEEDLE INSERTION

When using ultrasound for needle guidance, a survey scan should first be preformed. Local anatomy in the area of interest should be positively identified by methods described above.


Left handed operator

When choosing the site for needle placement, remember that the needle may be inserted a small distance away from the transducer in order to achieve the angle of approach required to visualise the needle.

Once the vessel or region of interest has been established, the entry site should be marked on the patient's skin with indelible pen. Be aware that scanning in ultrasound gel will remove the ink from many common brand marker pens. Be sure to remove all gel used for the survey scan before marking the skin. Gel on the nibs of the average marker pen will destroy the pen.

It is most important to always use the dominant hand for needle manipulation whilst using the other hand to hold the transducer.

The transducer hand should not move once in position, instead, manipulate the needle relative to the transducer, either inserting the needle along the plane of the transducer face (longitudinal not transverse plane with respect to the transducer face), or in some cases, inserting the needle in the centre of the transverse plane of the transducer.

The vessel or area of interest should be aligned with the needle tip. This is accomplished by carefully placing the imaged vessel in the centre of the monitor and, viewing the transducer from above, advance the needle tip whilst aligning it with the centre of the transducer thickness and along the plane of the beam.


Right handed operator

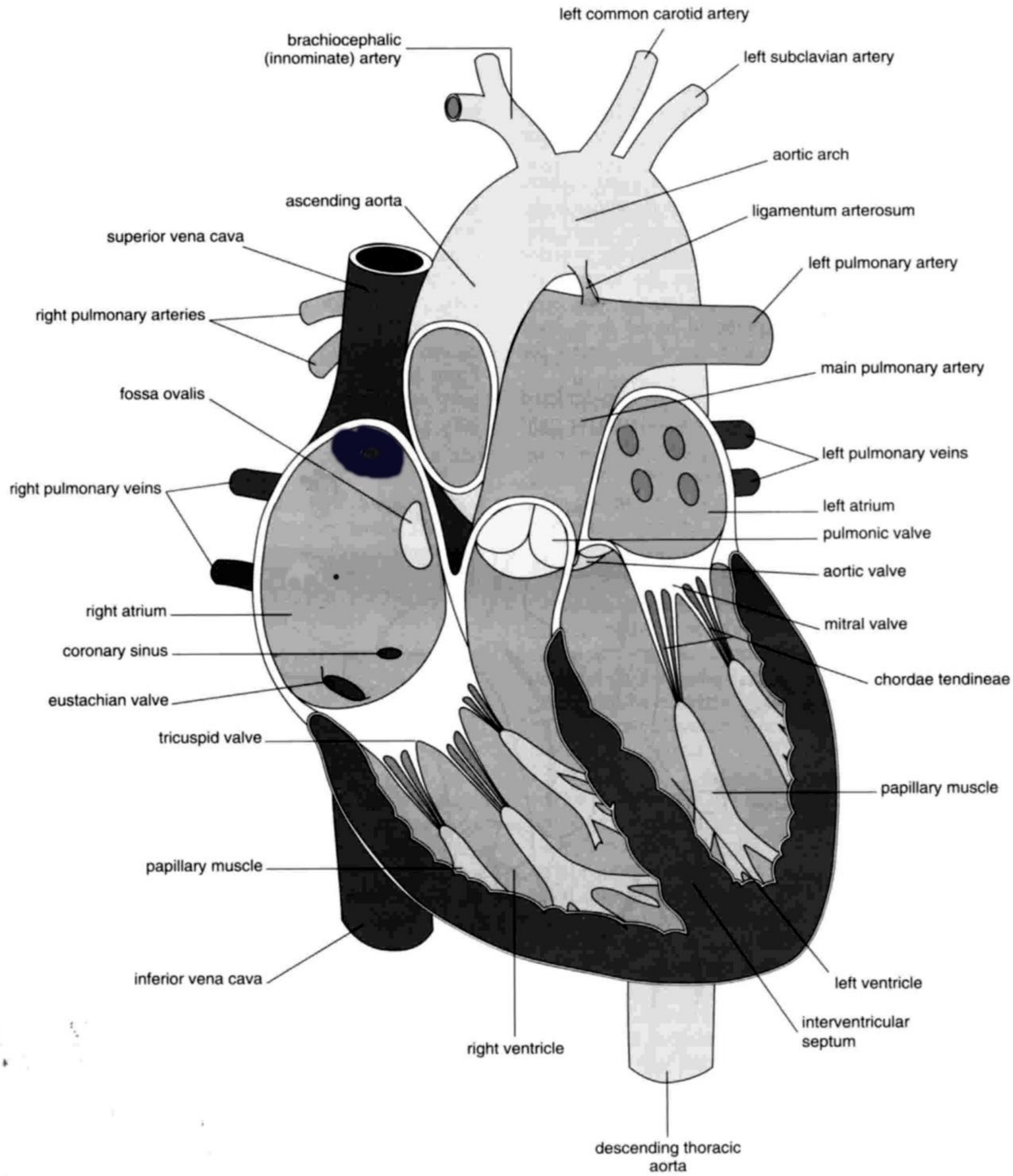
The tip of the needle appears as a hyperechoic dot and often the hyperechoic needle shaft can also be visualised, dependent on the angle of approach. The ultrasound beam and needle must be aligned accurately to enable visualisation. Bobbing the needle in and out slightly enhances visualisation during insertion

MOVE EITHER NEEDLE OR PROBE – NOT BOTH TOGETHER!!

CARDIAC EXAMINATION

ANATOMY

The cardiac anatomical knowledge needed for typical bedside examination is generally of a lower order than that of the fully trained cardiac sonographer. A full discussion of cardiac anatomy and cardiac sonography is beyond the scope of this course and we shall be limiting our learning to the basis necessary to answer the common clinical questions

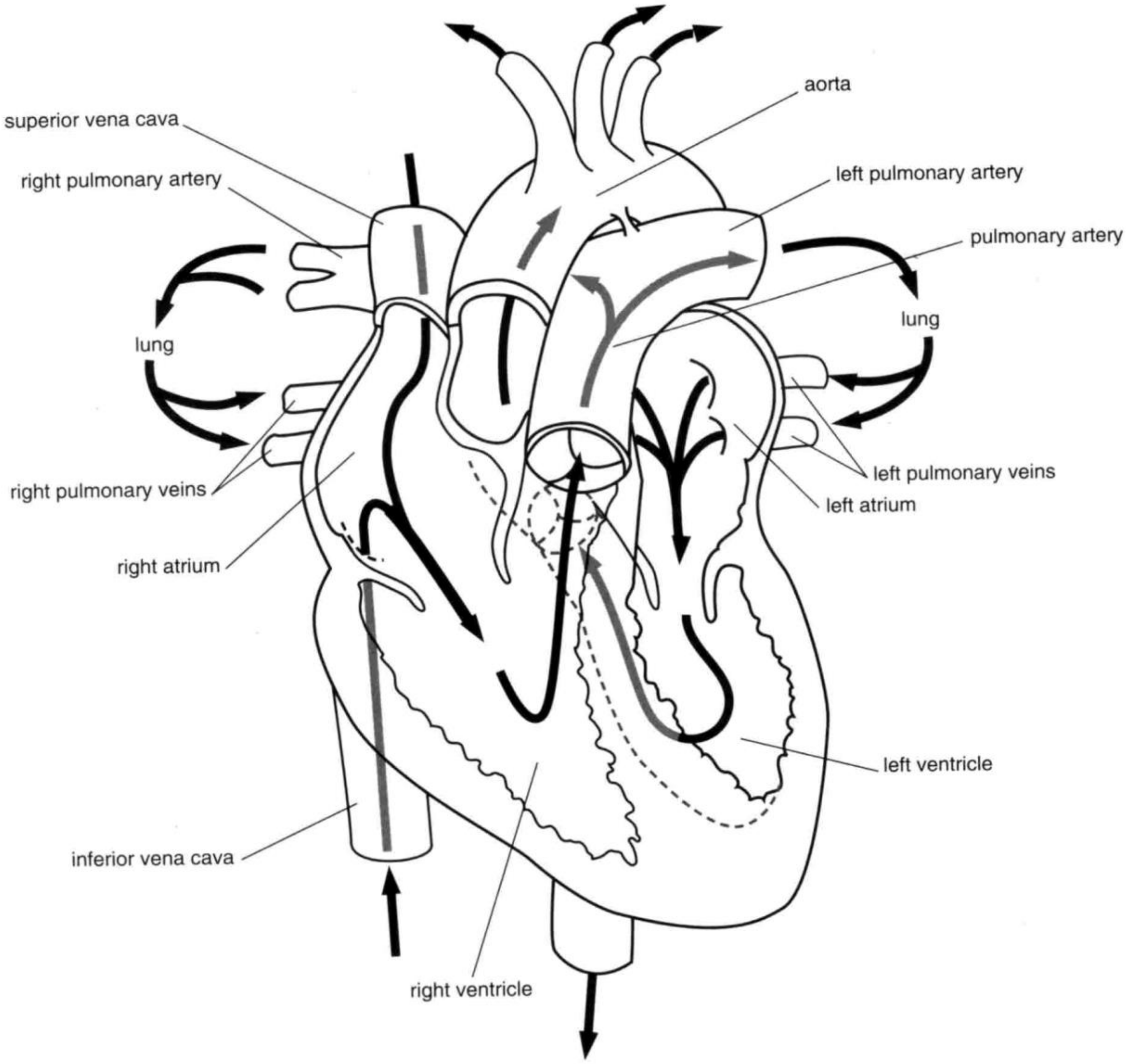


The internal structures of the heart are demonstrated in the diagram above.

The heart lies in the middle mediastinum at a 45° angle, between the third and fifth intercostal spaces. The pericardium surrounds the heart and is lubricated with up to 30ml of serous fluid in the normal individual.

CARDIAC CIRCULATION

The following diagram is representative of the blood circulation through the heart.



Deoxygenated blood enters the right atrium via:

- Lower body – IVC
- Upper body – SVC
- Heart muscle – coronary sinus

Blood then flows through the tricuspid valve, to the right ventricle. From the right ventricle, the blood passes through the pulmonary valve, into the main pulmonary artery. This then divides into the right & left pulmonary arteries, which carry blood to the lungs for oxygenation.

Freshly oxygenated blood returns to the heart through the four pulmonary veins and flows into the left atrium. The blood then passes from the left atrium, via the mitral valve, to the left ventricle. The left ventricle then pumps blood through the aortic valve into the ascending aorta and onwards around the body.

SYSTOLE & DIASTOLE

Diastole is the left ventricular relaxation and filling phase of the cardiac cycle. Diastole occurs from the end of the T wave until the beginning of the next QRS complex. During this portion of the cardiac cycle:

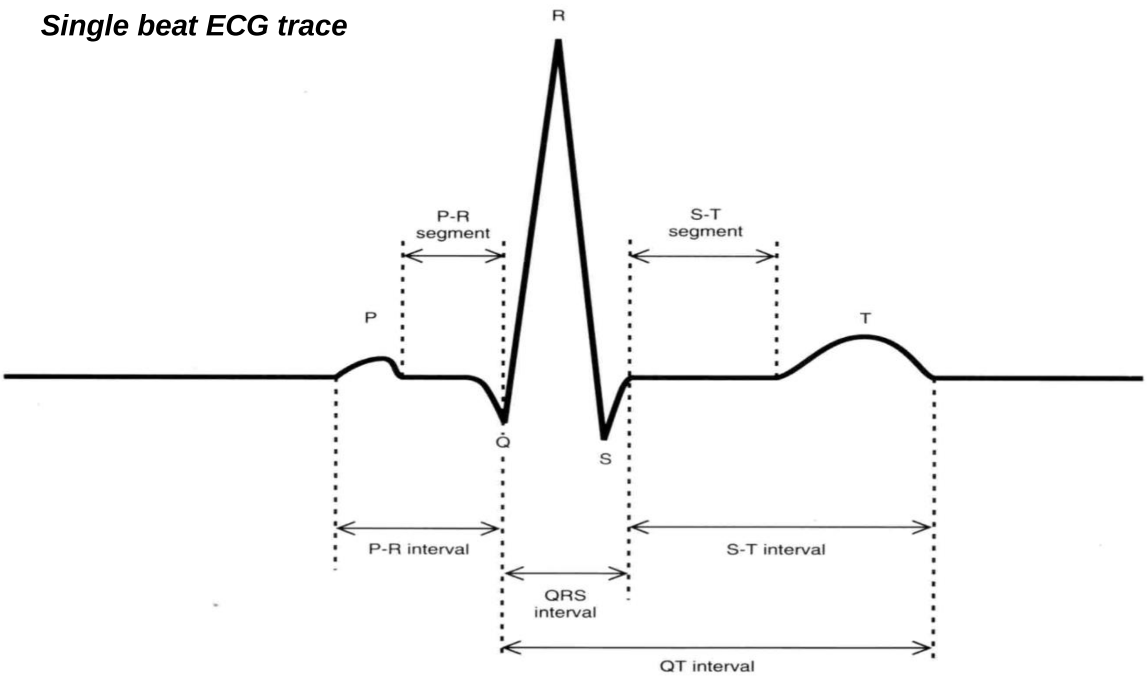
- the atria are filling with blood
- the AV valves are closed
- ventricular pressures are at or near 0mmHg

As the atrial pressure rises to above that of the ventricles, the AV valves open to eject the blood into the ventricles (rapid filling phase). At that point the ventricular myocardium is relaxed. As the ventricular pressure rises, the valves begin to close. Just prior to the ventricular systole, the atria contract (corresponds to P wave on trace) to eject their final volume of blood into the ventricles.

Systole is the ventricular ejection phase and occurs from the onset of the QRS complex to the end of the T wave.

- ventricular muscles contract
- increase in pressure causes the AV valves to close, preventing backflow of blood and the semilunar valves open.
- blood is ejected from the ventricles and forced into the outflow tracts
- as the blood is ejected, pressure falls in the ventricles and increases in the atria
- this sets the stage for the next cardiac cycle

Single beat ECG trace



This is a supremely simplified view of the cardiac anatomy and physiology and further reading should be completed to increase detailed knowledge.

NORMAL SONOGRAPHIC APPEARANCES

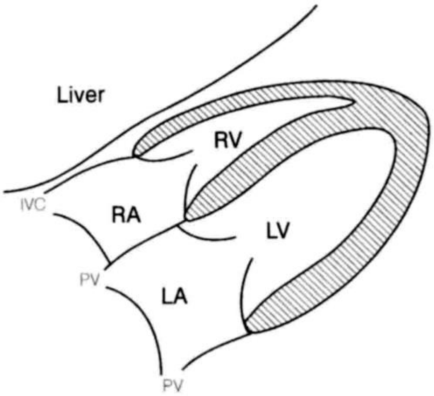
1. ***Pericardium:*** The most echogenic structure of the heart, often seen as bright or white in colour.
2. ***Blood or other fluids:*** Appear anechoic or black
3. ***Myocardium & papillary muscles:*** Appear homogeneous mid-grey level echoes
4. ***Mobile valve leaflets:*** Appear echogenic when compared to the myocardial echoes

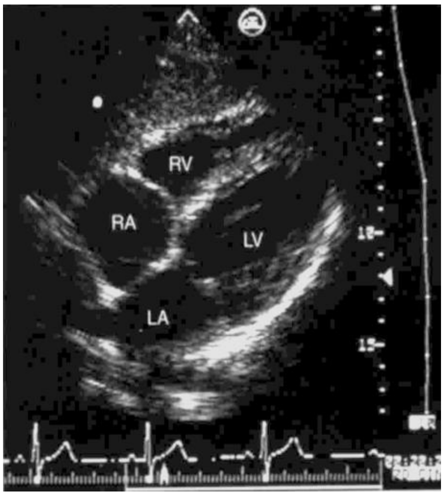
STANDARD WINDOWS FOR BESIDE CARDIAC EXAMINATION

Standard View	Probe Position/Direction	Advantages
Subcostal (SC)	Left intercostal margin at xiphoid Beam toward left shoulder	Readily accessible; screen for fluid, wall motion, and chamber size; supine position adequate
Left parasternal long axis (LPLA)	Left parasternal 2–4 inches Beam toward back	Easily interpreted; proximal aorta, left ventricle, left atrium well seen
Left parasternal short axis (LPSA)	Left parasternal 2–4 inches Beam varies with level (right shoulder to left hip)	Mitral and aortic valves well seen; global LV function visualized
Apical	Cardiac apex Beam toward right shoulder	Easily interpreted; all 4 chambers seen; contractility, size, and fluid visualized

*If the standard abdominal ultrasound machine "set up" is maintained, the marker dot points toward 4 o'clock for LPLA, 8 o'clock for LPSA and apical, and 8 to 9 o'clock for SC.

Subcostal Window



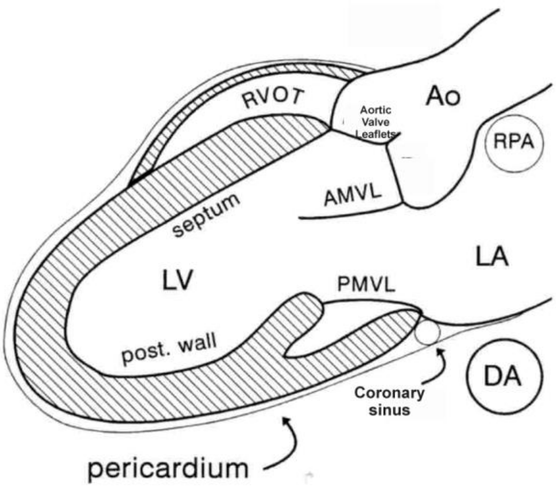


- With the patient supine and the legs bent at the knees to relax the abdominal wall musculature, subcostal images of the cardiac structure are obtained.
- A view of all four chambers shows the right ventricular free wall, the mid section of the interventricular septum, and the posterolateral left ventricular wall
- This window often provides the most significant information for a single view examination
- The anterior and posterior aspects of the pericardium appear as single, bright reflecting surfaces with no separation.
- A small amount of fluid is normal in the pericardial sac.
- The subcostal view has advantages as a starting point, it quickly screens for:
  - Mechanical activity
  - Pericardial fluid
  - Relative size of ventricles

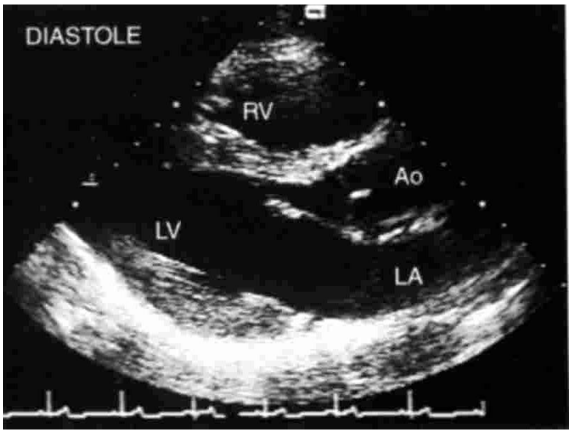
- Global wall motion

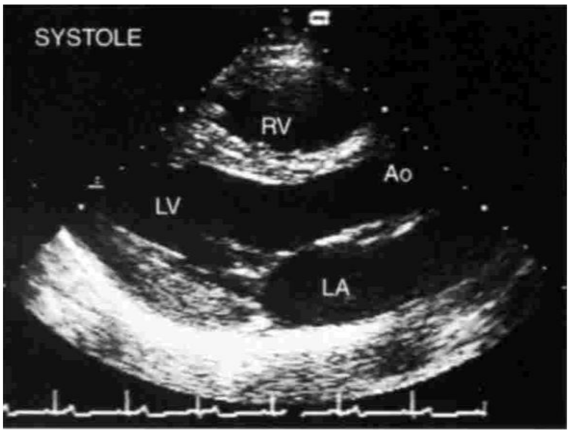
Left parasternal Views

Long Axis

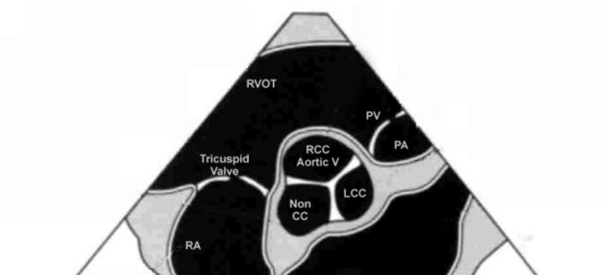


- Patient supine or lt. Lateral decubitus, place transducer in left parasternal position, between the 4th & 6th intercostal spaces
- The plane of the beam is parallel to a line drawn between the right shoulder and the left hip
- This view allows good visualisation of the aortic valve, proximal ascending aorta & left ventricular size
- Also allows assessment of synchronised wall motion
- May not be easy in non-compliant patient



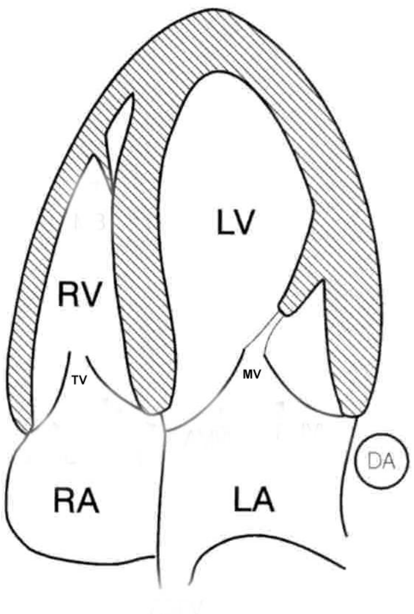


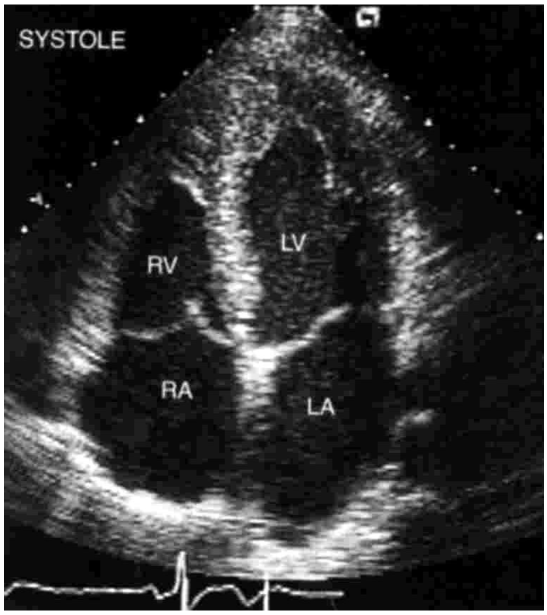
Short Axis – Aortic Valve Level



- From PSLA, rotate transducer 90° clockwise so that plane of beam is perpendicular to long axis of the heart
- Tilt transducer from apex, through the mitral valve level to the aortic valve
- Also difficult in non-compliant patient

Apical View





- Patient in left lateral decubitus position
- Feel for & place transducer over, the apical pulsation
- Point beam towards the right shoulder
- Tilt and rotate the transducer slightly, one motion at a time, to access required view
- Allows assessment of chamber size
- Allows for assessment of cardiac masses

These four views make up only a minimal portion of the full echocardiographic examination, but can answer most of the clinical concerns of the bedside sonographer.

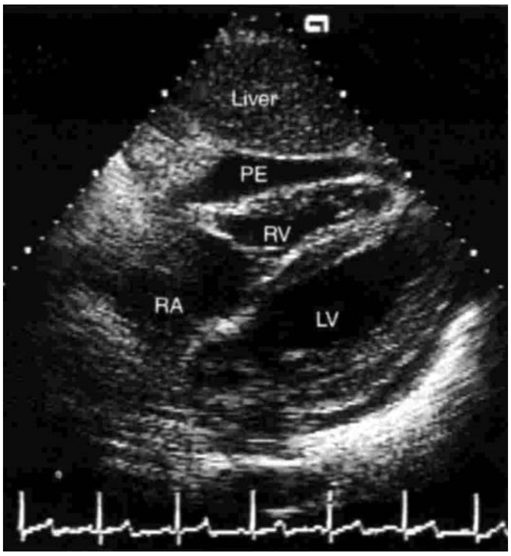
Please Note!!

All descriptions of transducer positioning and beam directions relate to Cardiac System orientation

CLINICAL QUESTIONS: CARDIAC

"Is pericardial effusion present?"

Using a subcostal window, patient supine with knees drawn up (see page 46) assess the pericardium for evidence of fluid collection.

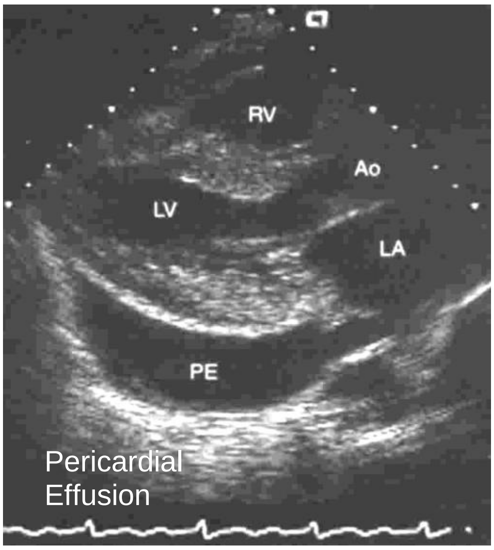


- Normal amount of pericardial fluid is usually not visible over the non-dependent aspect of the heart. Circumferential pericardial collections are easily seen in this view.
- Size of effusion, when the separation between the parietal and visceral pericardium is
  - <0.5cm = small
  - 0.5-2cm = moderate
  - >2cm = large

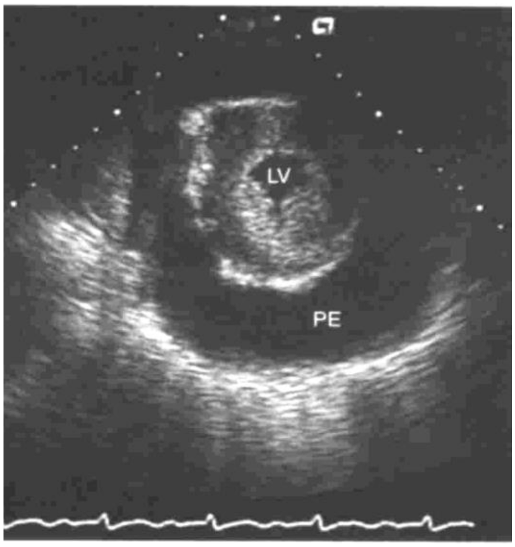
"Is cardiac tamponade present?"

Using the same subcostal approach as previously, assess the heart for – pericardial effusion & irregularity of movement. A parasternal long & short axis view or apical 4-chamber view will enable the sonographer to assess the heart for the presence of right atrial collapse in systole or right ventricular collapse in diastole. These latter views may or may not be necessary or possible, depending on patient cooperation.

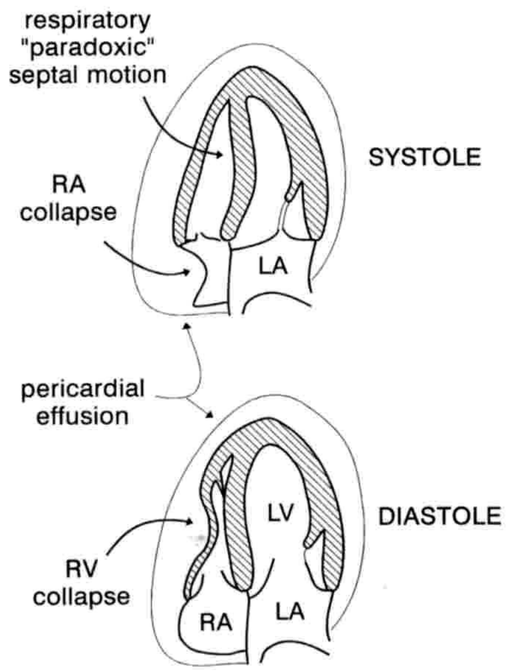
Parasternal view –Long Axis



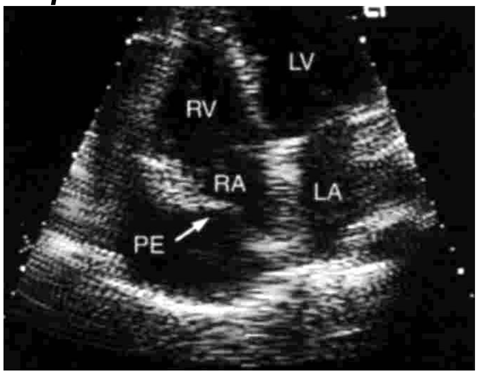
Short Axis



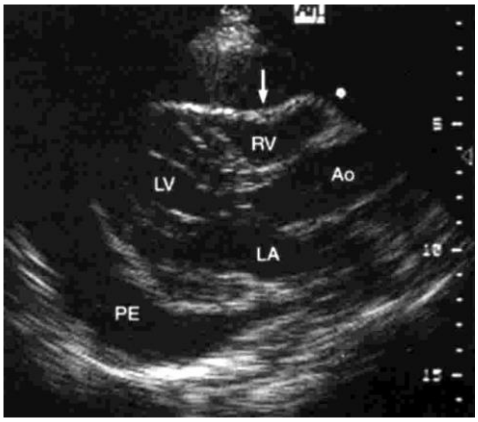
Schematic diagram of RA & RV collapse



Apical 4-chamber view



Parasternal long axis view



"Are ultrasound signs of shock present?"

There are three observations made during the bedside cardiac assessment which will assist in the recognition of shock.

First is that of the ultrasound signs of pericardial effusion that may be compressing the heart, leading to a mechanical cause of obstructive shock.

Second is left ventricular global contractility. Determination of the size and contractility status of the left ventricle will allow for those patients with a cardiogenic cause of shock to be rapidly identified.

Third is the relative size of the left ventricle to the right ventricle. If the right ventricle is substantially larger than the left, this will give rise to concerns that there are signs of acute right ventricular strain, possibly from a pulmonary embolus in the hypotensive patient.

RUSH – RAPID ULTRASOUND IN SHOCK

Ultrasound technology is ideal in the care of the critical patient presenting with symptoms of shock. Determination of the type of shock *and progress of therapy* can be assisted by the examining physician using the bedside ultrasound protocols described here.

Phillips Perera and colleagues have described the three step shock ultrasound protocol termed RUSH[1], which describes a simple method of assessing clinically, which classification of shock best fits the patient's current clinical status.

Step 1: The pump
Step 2: The tank
Step 3: The pipes

The three steps described are the assessment of the "the pump", "the tank" and "the pipes".

- Assessment of the pump (the heart), being a critical component of this study, is usually undertaken first.

- Second is usually assessment of the tank, which involves:

  - Critical appraisal of the size of the IVC. Looking at the respiratory dynamics of the IVC will provide an assessment of the patient's volume status to answer the clinical question, ''how full is the tank".
  - Critical appraisal of the internal jugular veins to view their size and changes in diameter with breathing to further assess volume
  - An assessment of the lung, pleural cavity, and abdominal cavities for pathology that could signal a compromised vascular volume.
    - Ultrasound appearances which in the hypotensive patient may represent a tension pneumothorax requiring immediate decompression. Tension pneumothorax presumably limits venous return into the heart due to increased pressure within the chest cavity
    - The lung can also be examined for ultrasonic B lines, a potential sign of volume overload and pulmonary edema.
    - The thoracic cavity can be examined for ultrasound evidence of pleural effusion, or haemothorax in the setting of trauma or instrumentation
    - FAST exam (Focused Assessment with Sonography in Trauma examination), to look for fluid in the abdomen, indicating a source for ''loss of fluid from the tank.''

- Thirdly, assessment of the pipes to answer the clinical question "are the pipes ruptured or obstructed", which involves:

  - Arterial assessment
    - Abdominal (and thoracic where possible) aorta for ultrasound signs of dissection or aneurysm
  - Venous assessment
    - The femoral and popliteal veins can be examined, looking for the presence of ultrasound signs of DVT. The presence of thrombus in the hypotensive patient may signal a large pulmonary thromboembolus.

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Rapid Ultrasound in SHock (RUSH) protocol: ultrasonographic findings seen with classic shock states				
RUSH Evaluation	**Hypovolemic Shock**	**Cardiogenic Shock**	**Obstructive Shock**	**Distributive Shock**
Pump	Hypercontractile heart Small chamber size	Hypocontractile heart Dilated heart	Hypercontractile heart Pericardial effusion Cardiac tamponade RV strain Cardiac thrombus	Hypercontractile heart (early sepsis) Hypocontractile heart (late sepsis)
Tank	Flat IVC Flat jugular veins Peritoneal fluid (fluid loss) Pleural fluid (fluid loss)	Distended IVC Distended jugular veins Lung rockets (pulmonary edema) Pleural fluid Peritoneal fluid (ascites)	Distended IVC Distended jugular veins Absent lung sliding (pneumothorax)	Normal or small IVC (early sepsis)* Peritoneal fluid (sepsis source) Pleural fluid (sepsis source) * or anaphylaxis
Pipes	Abdominal aneurysm Aortic dissection	Normal	DVT	Normal

Table 1 – The RUSH Exam – Perera et al

PRACTICAL PROTOCOLS

Practical protocols have been developed to assist in answering the clinical questions raised. All the practical point of care ultrasound protocols described have been designed to ensure a speedy, reliable, reproducible approach to confident decision making in the management of patients in shock.

1. THE PUMP

- **Probe**
  - A phased array cardiac transducer is preferred for the limited echocardiogram employed in bedside ultrasound, since the small footprint of these probes facilitates easier access to intercostal spaces. If this is not available, these views can be obtained to a diagnostic level in most patients employing a 3.5mHz curved array probe.
- **Approaches**

  These have been described in the cardiac section of the workbook (page 51), following is a brief review of diagnostic criteria published by Perera et al:
  - Subcostal – pericardial effusion -
    - Small effusions may be seen as a thin stripe inside the pericardial space whereas larger effusions tend to be circumferential
    - Small, isolated anterior anechoic areas may represent pericardial fat.
    - Tamponade – compression of the right side of the heart

- Parasternal long & short axis - ''Squeeze of the pump'': determination of global left ventricular function
  - Evaluation of motion of the left ventricular endocardial walls, assessment made by a visual calculation of the percentage change from diastole to systole, with the walls almost coming together and touching during systole
  - The anterior leaflet of the mitral valve will vigorously touch the wall of the septum during ventricular filling long-axis view.
  - grading of contractility strength:
    - good, with the walls of the ventricle contracting well during systole
    - poor, with the endocardial walls changing little in position from diastole to systole
    - intermediate, with the walls moving with a percentage change in between the previous 2 categories

- Apical 4-chamber - ''Squeeze of the pump'': determination of global left ventricular function and ''Strain of the pump'': assessment of right ventricular strain
  - Visual assessment of the relative sizes of the ventricles of the heart.
    - Normal ratio of the left to right ventricular size = 1:0.6. ∴ the right ventricle will be smaller than the left in the normal patient

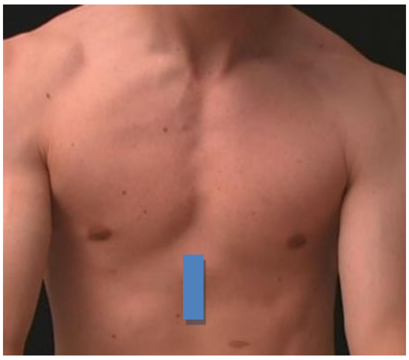
2. THE TANK

- Evaluation of the effective intravascular volume as well as to look for areas where the intravascular volume might be compromised

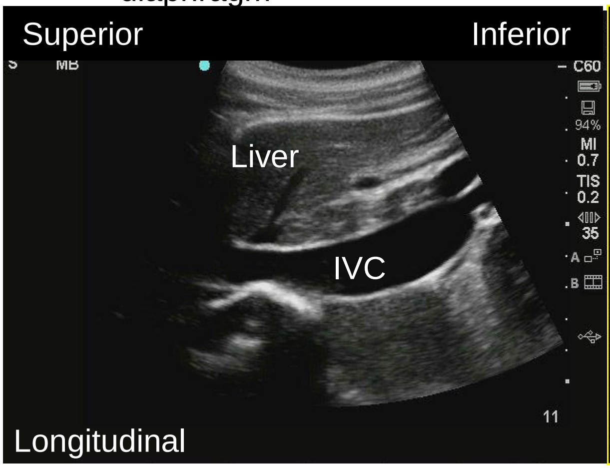
➡ The IVC

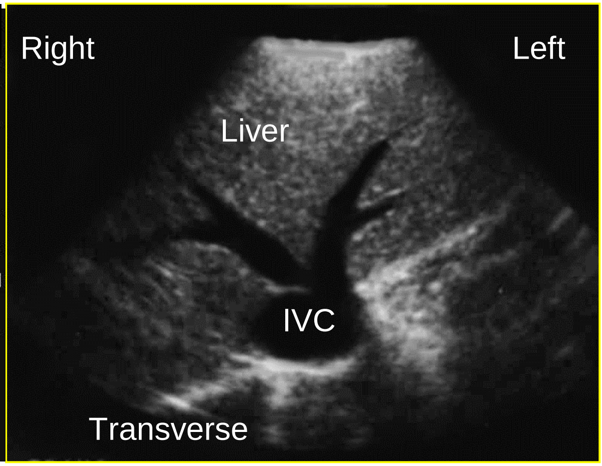
- Firstly by visualisation of the inferior cava for size and collapse with inspiration

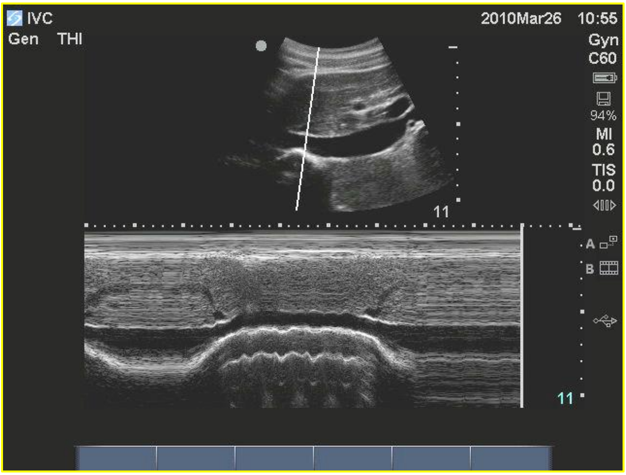
- **Patient**
  - Supine
- **Probe**
  - Either phased array sector cardiac probe or a 3.5mHz curved array abdominal probe
- **Preset**
  - Abdominal
- **Start Position**
  - Transducer in the longitudinal plane, marker end towards patient head, directly under the xiphisternum
  - Pressure on the non-marker end of the probe should be sufficient to direct the sound beam towards the diaphragm



- **Protocol**
  - Fan beam left to right to locate aorta
  - Fan beam from the aorta, towards the right of the patient
  - Visualise the IVC passing through the diaphragm and entering the right atrium of the heart and 3 to 4cm caudal.
  - Rotate the probe to the transverse plane and visualise the IVC at the diaphragm







- In both planes, evaluate the change in IVC calibre with normal respiration and with forced inspiration, valsalva or during a sharp "sniff".

- Apply an M-Mode cursor and activate the scrolling M-Mode to visualise the change in calibre for documentation

Clinical Concepts

- A smaller calibre IVC (<2 cm diameter) with an inspiratory collapse greater than 50% roughly correlates to a CVP of less than 10 cm of water. This phenomenon may be observed in hypovolemic and distributive shock states.
- A larger sized IVC (>2 cm diameter) that collapses less than 50% with inspiration correlates to a CVP of more than 10 cm of water. This phenomenon may be seen in cardiogenic and obstructive shock states.
- Evidence suggests that the bedside ultrasound estimate of CVP is most accurate when the IVC is small and inspiratory collapse is high. However, rather than relying on a single measurement of the IVC, it is better to determine the effective vascular volume by following changes in size and respiratory dynamics over time with fluid challenges. Observing a change in IVC size from small, with a high inspiratory collapse, to a larger IVC with little inspiratory collapse, suggests that the CVP is increasing and "the tank" is more full. (Perera et al)

Mechanically Ventilated Patients

- *If the patient is receiving positive pressure ventilation, the respiratory cycle of the IVC collapse reverses and maximum diameter may be more accurate. Raising the legs and observing the effect on the IVC size can mimic the potential effect of a small fluid load.*
- Many studies have evaluated IVC diameter changes as a measurement of response to fluid loading. Unfortunately, these studies calculated their cut-off points using different formulae. The simpler formula is ((Insp size - Exp Size)/Exp size). The result is expressed as a percentage; using this formula the cut-off is 18% change. Values greater than this predict an increase in cardiac output to a fluid challenge. (Barbier et al *Intensive Care Med.* 2004;30:1740-1746)

Internal Jugular Vein (IJV) assessment

- Secondly, the IJV can be visualised (see page 38 for scan protocol) and examined to further evaluate the intravascular volume.

Clinical Concepts

- The location of the superior closing meniscus is determined by the point at which the walls of the vein touch each other. Similar to the IVC, the jugular veins can also be examined during respiratory phases to view inspiratory collapse. Veins that are distended, with a closing meniscus level that is high in the course of the neck, suggest a higher CVP.16 Coupling this data with the evaluation of the IVC may give a better overall assessment of the effective intravascular volume. (Perera et al)

‘‘Leakiness of the tank’’: FAST exam and pleural fluid assessment

- Once a patient’s intravascular volume status has been determined, the next step in assessing the tank is to look for ‘‘abnormal leakiness of the tank.’’
  - Internal blood loss – traumatic haemoperitoneum or haemothorax
  - Pleural effusion and ascites – non-traumatic fluid overload
  - Intra-abdominal abscess – sepsis
- NB: Remembering that many patients who have depletion of the vascular volume may still have intra-abdominal or intra-thoracic fluid collections, it will be apparent that assessment of IVC and IJV in conjunction with FAST and pleural assessment can be very helpful in the diagnostic process.

FAST & Extended FAST Protocol

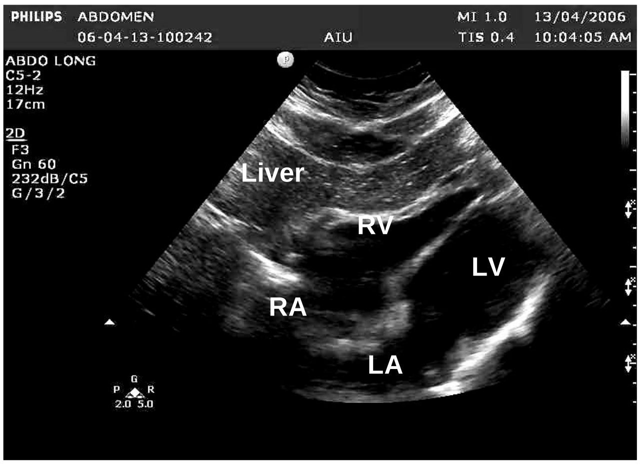
- The four areas of the abdominal cavity assessed in the FAST exam are:
  - Subcostal cardiac
  - Morrison’s Pouch
  - Spleno-renal angle
  - Pelvis
- As an extension of this, the pleural cavities can be viewed, looking for fluid or collections in the pleural spaces

Subcostal Cardiac Protocol

- This has already been discussed in detail earlier in the workbook, this section will give an overview of the subcostal protocol in pictorial form.

Hand over probe – start position transverse at xiphisternum
Apply **DOWNWARD** pressure

Keeping pressure on – angle beam steeply towards patient head Fan beam anterior/posterior



THINGS TO REMEMBER

- FOCUS ON PROBE PLACEMENT BEFORE LOOKING AT IMAGE

1. Probe ON xiphisternum is start position
    a. Bend knees to relax abdominal wall
2. Probe grip is IMPORTANT to control
    a. DOWNWARD pressure towards bed
3. Maintain pressure while angling beam
    a. Scoop beam under xiphisternum
    b. Don't allow probe face to slide away from xiphisternum
4. Optimise image
    a. DEPTH, FOCUS, TGC

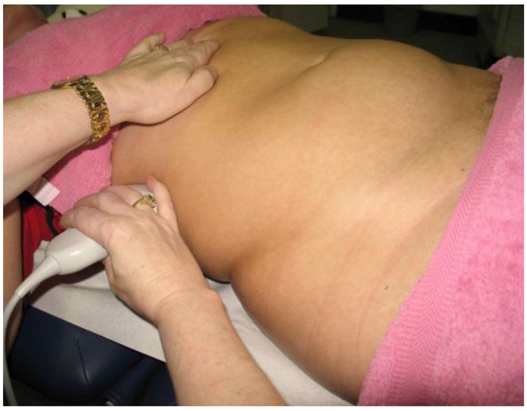
What to do if you don't see the heart

1. Look at patient & check beam direction
2. Ask the patient for deep inspiration
3. Check DEPTH again – increase
4. Sweep beam superior / inferior looking for heart movement
5. Sweep beam SLIGHTLY LEFT TO RIGHT

Morrison's Pouch Protocol

- Freeze the monitor before placing the probe at the start position. Imagine the beam and visualise its course through the body, illuminating the target area.

Palpate xiphisternum, lay forearm parallel to bed

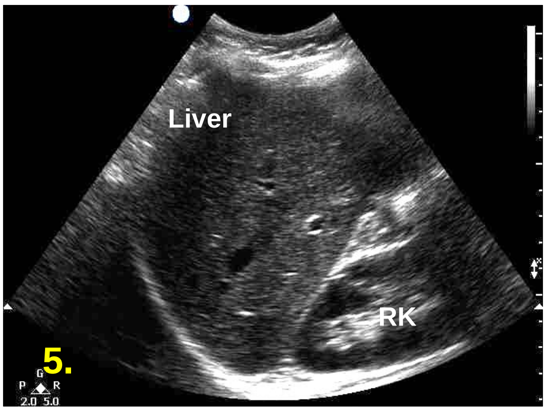


Place probe ½ way between forearm & bed

NOTE PROBE GRIP – IMPORTANT FOR CONTROL OF BEAM DIRECTION

Rotate probe to plane of kidney

Tilt beam posteriorly towards retroperitoneum



THINGS TO REMEMBER

1. Optimise image
   a. DEPTH, FOCUS, TGC

- What to do if you don't see the correct anatomy

1. Look at image – what do you see?
2. Think about relational anatomy
3. Look at patient & check probe position & beam direction
4. Tilt beam posteriorly
5. Ask the patient for deep inspiration
6. Slide probe to head / to feet into rib spaces
7. Sweep beam anteriorly / posteriorly

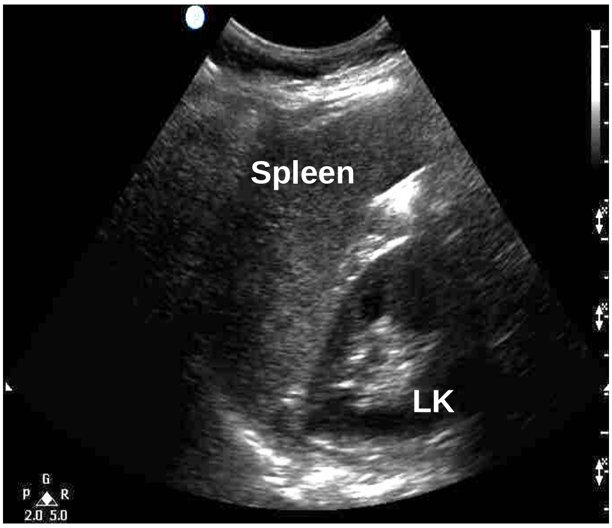
Spleno-Renal Angle Protocol

- Freeze the monitor before placing the probe at the start position. Imagine the beam and visualise its course through the body, illuminating the target area.

1. Palpate xiphisternum, lay forearm parallel to bed
Place probe at level of small finger, ¾ distance between fingers & bed

2. Rotate probe to plane of kidney (align with rib space)

3. Tilt beam posteriorly
Note: Probe grip is important for control of beam direction



THINGS TO REMEMBER

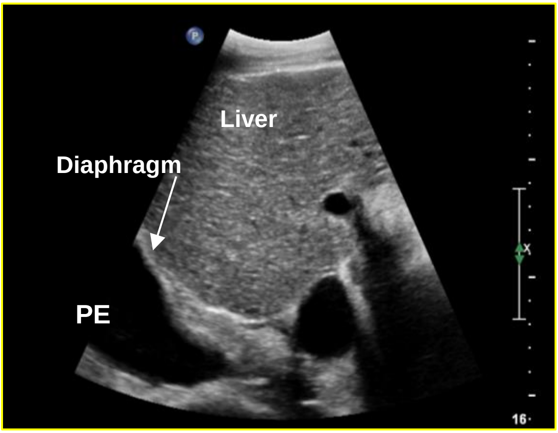
- **FOCUS ON PROBE PLACEMENT BEFORE LOOKING AT IMAGE**

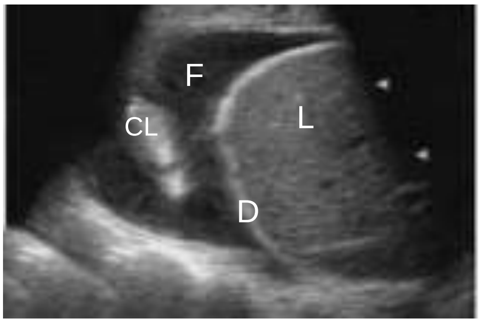
5. Left kidney is usually higher than you think
6. Probe face aligned with rib space for good window
7. Left kidney is usually more posterior – slide probe towards bed (½ - ¾ of AP distance)
8. Optimise image
    a. DEPTH, FOCUS, TGC

- What to do if you don't see the correct anatomy
    1. Look at image – what do you see?
    2. Think about relational anatomy
    3. If you see stomach gas, slide probe posteriorly
    4. Look at patient & check probe position & beam direction
    5. Ask the patient for deep inspiration
    6. Slide probe to head / to feet into rib spaces
    7. Sweep beam anteriorly / posteriorly

Pleural Effusions Protocol

- This protocol relates to both left and right thorax and the views are best undertaken after completing the Morrison's Pouch view and the Spleno-renal angle view.
- Slide the probe cephalad until it rests between ribs in an intercostal space.
- Fan anterior and posterior
- Use probe curvature to point the beam superior and inferior
- The diaphragms should appear as a bright line directly superior to the liver and spleen and the lung may appear as a bright "curtain" of reverberant echoes, seen moving in and out of the frame with respiration.
- In the presence of fluid or blood, these reverberant echoes will be replaced with an anechoic (dark) space.
- Fluid in a large effusion may compress the lung tissue, in which case it may appear a similar texture to liver and spleen – the base of the lung can sometimes be seen moving within the fluid with respiration
- Effusions can be classified as anechoic, complex, septated or non-septated – depending on the type of fluid within the space.
- Assessing the patient with the head slightly elevated may improve the sensitivity of this examination, as this will cause intrathoracic fluid to accumulate just above the diaphragms.





- Pleural effusion
  - Showing liver (L), diaphragm (D), fluid (F)& compressed lung tissue (CL)

Pelvis Protocol Longitudinal

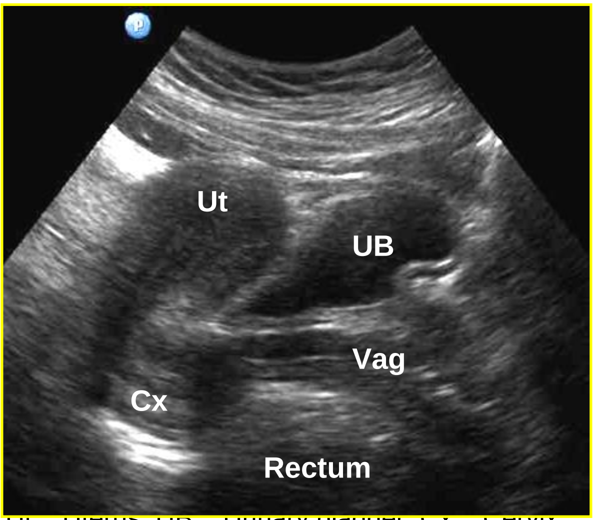
- The peritoneal potential spaces are slightly different between male & female patients. POD in the female extends deeper into the pelvis than the vesico-rectal space in the male.

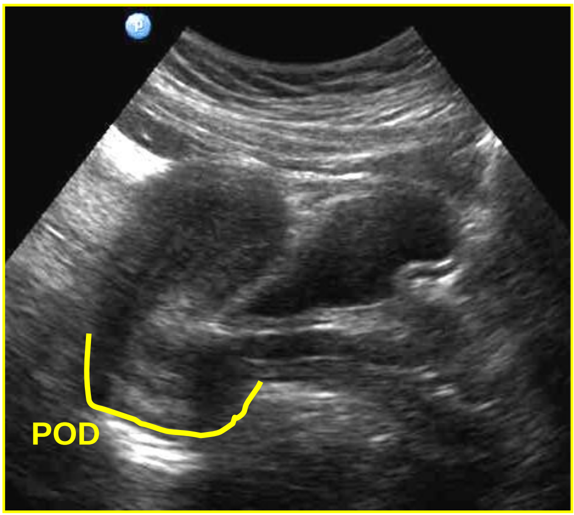
Palpate superior border of symphysis pubis

Base of probe resting on superior border
Longitudinal midline section
Beam directed posteriorly

Use probe curvature to angle beam into pelvis
NOTE: Probe grip is important

Use probe curvature to angle beam up out of pelvis



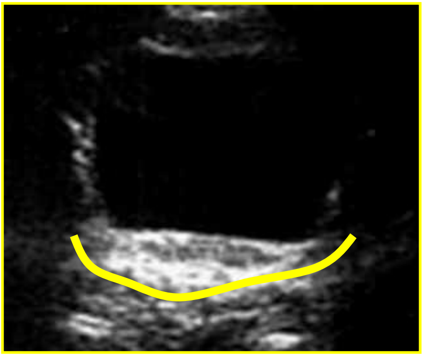


Ut = Uterus; UB = Urinary bladder; Cx = Cervix,
Vag = Vagina; POD = Pouch of Douglas

- Once the vagina has been located, optimise the image and fan left to right, examining the POD, which is located directly anterior to the rectum and directly posterior to the posterior vaginal wall.

Pelvis Protocol Transverse

- Rotate probe 90^0 to the transverse plane



THINGS TO REMEMBER

- **FOCUS ON PROBE PLACEMENT BEFORE LOOKING AT IMAGE**

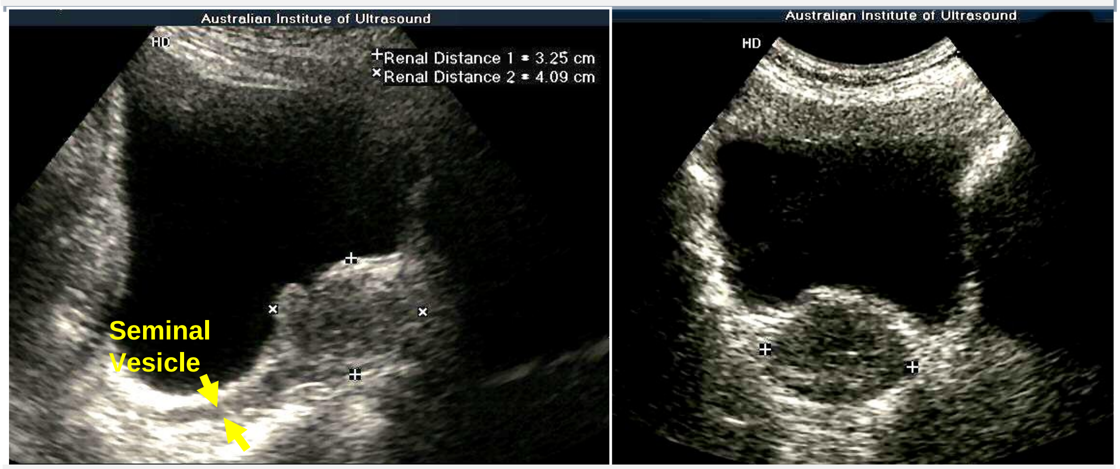
9. SUPERIOR border of symphysis pubis – NOT anterior border
10. Probe gripped with fingers low down to control face
11. Depress upper edge of probe face into abdomen
12. Depress lower edge of probe face into abdomen – use 2 hands
13. Use left hand to rotate probe, right hand to hold it in position
14. Optimise image
    a. DEPTH, FOCUS, TGC

THINGS TO REMEMBER

- What to do if you don't see the correct anatomy

1. Look at image – what do you see?
2. Think about relational anatomy
3. Use graded compression to move bowel gas
4. Sweep beam superiorly / inferiorly
5. Use probe curvature to look left / right

Male Pelvis - Prostate



LONG (Rotate probe 90^0 to transverse) TRANS

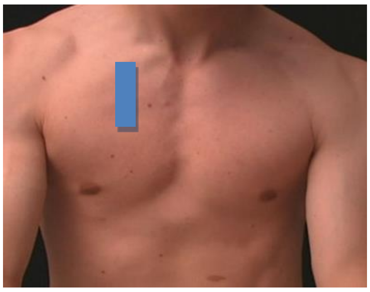
- Fluid most commonly seen lateral to the prostate and superior to the seminal vesicles and bladder wall.

Pneumothorax Protocol

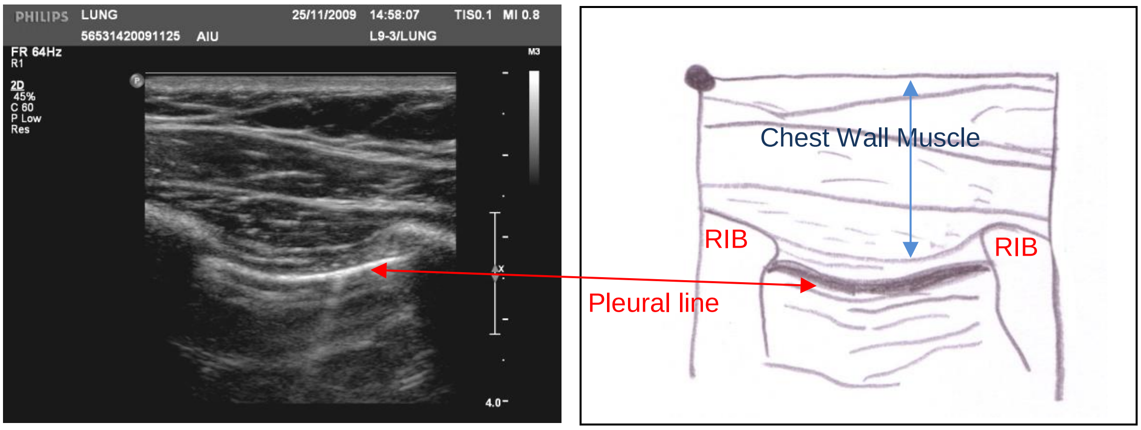
- Pneumothorax detection with ultrasound relies on the fact that free air (pneumothorax) is lighter than normal aerated lung tissue, and thus will accumulate in the nondependent areas of the thoracic cavity. Therefore, in a supine patient a pneumothorax will be found anteriorly, while in an upright patient a pneumothorax will be found superiorly at the lung apex.

- Patient supine approach is the preferred option ultrasonically

- **Start Position**
  - Transducer longitudinal, marker to patient's head
  - Placed at the mid clavicular line just below the clavicle
  - Identify the pleural line
  - Optimise the image
  - Slide probe over the non-dependent area of the anterior thorax (clavicle to nipple line / medial to lateral), accessing all intercostal spaces
  - Frequent stops along the scan line to allow motion to be demonstrated, using M-Mode to document findings.



- **Identify Pleural line**



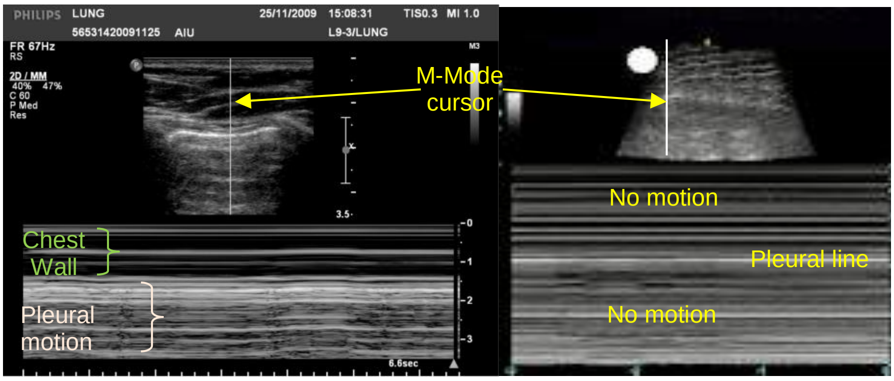
- Stop probe movement and watch monitor – there should be sliding movements of the pleural line as the visceral and parietal pleura move over each other. There may also be "comet-tail" artifacts seen moving from side to side, these are not mandatory for normal appearances.

- Apply M-Mode cursor over the pleural line and press update

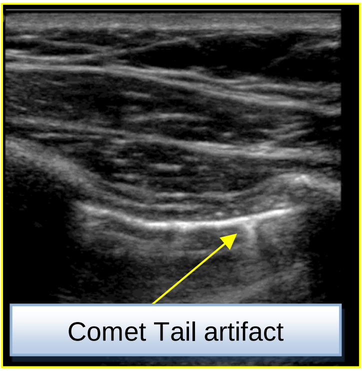
- Normal M-Mode appearances should be of the "seashore" variety
  - Chest wall – anterior – "waves" linear appearance – no motion
  - Sliding pleura – posterior – "beach" appearance – lung motion

- When a pneumothorax is present, air gathers between the parietal and visceral pleura, preventing the ultrasound beam from detecting lung sliding. In pneumothorax, the pleural line seen consists only of the parietal layer, seen as a stationary line. M-mode Doppler through the chest will show only repeating horizontal linear lines, demonstrating a lack of lung sliding or absence ofthe ‘‘beach’

- Abnormal M-Mode appearances should be of the “barcode” variety
  - Chest wall – anterior –linear appearance – no motion
  - Pleura – posterior – linear appearance – no lung motion



- Comet Tail Artifacts
  - A sonographic finding seen in normal lung, but absent in pneumothorax, is the comet tail artifact. Comet tail artifact is a form of reverberation echo that arises from irregularity of the lung surface. This phenomenon appears as a vertical echoic line originating from the pleural line and extending down into the lung tissue.

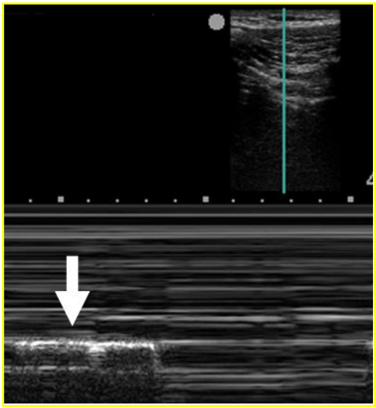


  - The presence of comet tail artifact rules out a pneumothorax. The combination of a lack of lung sliding and absent comet tail artifacts very strongly suggests pneumothorax.

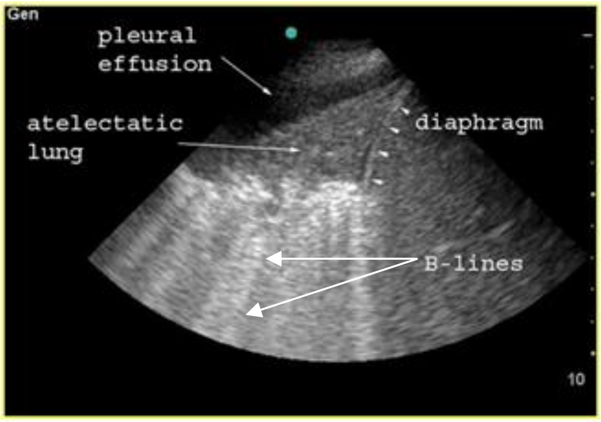
- Although the presence of lung sliding is sufficient to rule out pneumothorax, the absence of lung sliding may be seen in other conditions in addition to pneumothorax, such as a chronic obstructive pulmonary disease bleb, consolidated pneumonia, atelectasis, or mainstem intubation. Thus the absence of lung sliding, especially as defined in one intercostal space, is not by itself diagnostic of a pneumothorax. The operator can examine through several more intercostal spaces, moving the transducer more inferiorly and lateral, to increase the utility of the test.
- This maneuver may also help identify the lung point, or the area where an incomplete pneumothorax interfaces with the chest wall, as visualized by the presence of lung sliding on one side and the lack of lung sliding on the other

- Lung Point
    - The normal seashore sign (arrows) can be seen alternating with the stratosphere sign in time with respiration.

Gillman *et al. Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine* 2009 **17**:34



- B-Lines
    - B lines result from thickening of the interlobular septa, as extravascular water accumulates within the pulmonary interstitium
    - A small pleural effusion and atelectatic lung are shown in this image. The transition between atelectatic and aerated lung is clearly visible. Groups of B-lines originate from the transition zone and extend to the outer limit of the image



An Introduction to Pleural Ultrasonography for the Pulmonary and Critical Care Physician

PCCU Article | 05.15.09*By Paul H. Mayo, MD, FCCP; and Peter Doelken, MD, FCCP*

3. THE PIPES

- **Arterial**
    - The aorta from the diaphragm to the bifurcation can be imaged and examined easily, quickly & accurately using bedside ultrasound. With experience the operator can also examine portions of the thoracic aorta from a parasternal and suprasternal approach to look for dissection..

    - **Start Position**
        - Place the 3.5mHz curved array transducer in the transverse position, at the xiphisternum. Probe grip should be “hand over” and downward pressure on the probe should be exerted and held, whilst the beam is “scooped” up and under the xiphisternum and pointed towards the diaphragm (this is essentially the same start position as the subcostal pericardial view).
- **Protocol**
    - Follow the step by step protocol described below, the same way each time
    - Remember to optimise images

Palpate xiphisternum

Hand over probe – start position transverse
Apply **DOWNWARD** pressure

Keeping pressure on – angle beam steeply towards patient head

Maintain **DOWNWARD** pressure
Sweep beam inferiorly, looking for landmarks

CHANGE GRIP
Use left hand to hold probe steady

Maintain **DOWNWARD** pressure
Slide probe towards feet, staying in midline

CHANGE GRIP
Slide probe below umbilicus
Angle beam up towards bifurcation

Slide probe above umbilicus, midline
CHANGE GRIP
Angle beam posteriorly
Use left hand to rotate probe

Use probe curvature to look inferiorly & superiorly in the long aorta

Slide probe superiorly to proximal aorta

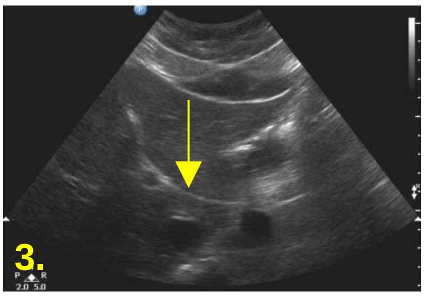
THINGS TO REMEMBER

- **FOCUS ON PROBE PLACEMENT BEFORE LOOKING AT IMAGE**
- Probe grip is important
- If bowel gas is obscuring landmarks – MOVE ON
- Perform a transverse survey sweep in a smooth motion focusing on the calibre of the aorta – is it getting wider?
- What to do if you don't see the correct anatomy
  1. Look at image – what do you see?
  2. Think about relational anatomy
  3. Look at patient & check probe position & beam direction
  4. Proximal - Ask the patient for deep inspiration
  5. Mid-Distal – use compression

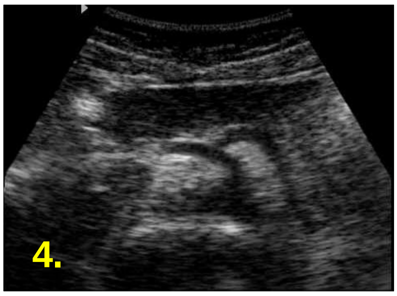
- **Ultrasound Appearances of upper abdominal landmarks**

Hepatic Veins

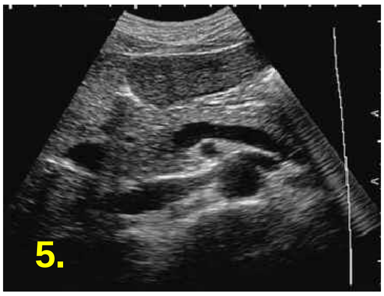
Portal Veins



Ligamentum Venosum at diaphragm leads eye to aortic entry site



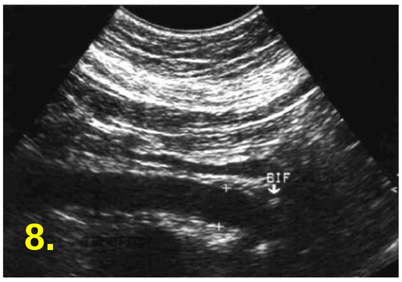
Celiac trunk



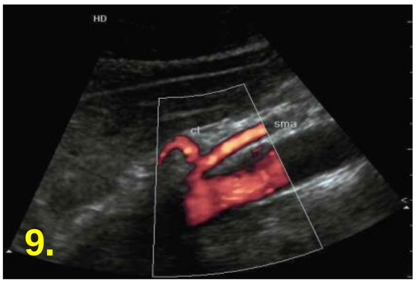
Splenic Vein, SMA, Pancreas

Mid – Distal Aorta , compression

Bifurcation – from below umbilicus, beam angled superiorly



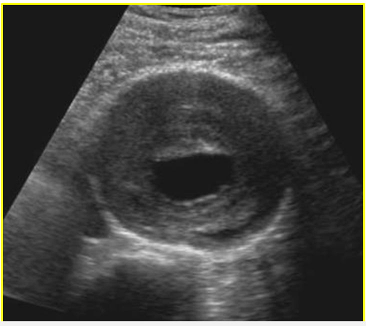
Long distal Aorta



Long proximal aorta – normal variant
SMA origin from Celiac trunk

AAA

- The clinical question here is "Is there a AAA present?"
- The criteria for positive diagnosis is
  - Does the black hole get narrower? – or - Does the lumen of the aorta narrow from proximal to distal?
- When there is a AAA present, ultrasound appearances are those of a widened aortic lumen with or without the presence of ehoes from intramural thrombus.

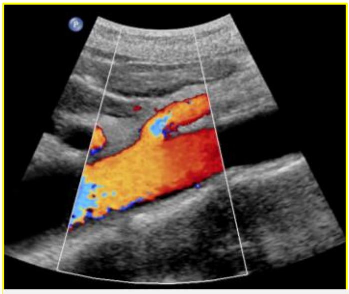


Transverse Aorta

- AAA with intramural thrombus

Longitudinal Aorta

- Measure 3cm distance from SMA origin, if the proximal edge of the AAA is within this distance, the AAA is considered supra-renal until proven otherwise.



Longitudinal Aorta
SMA Origin

Venous

- Bedside ultrasound for DVT In the patient in whom a thromboembolic event is suspected as a cause of shock, the EP should then move to an assessment of the venous side of ‘‘the pipes.’’ As the majority of pulmonary emboli originate from lower extremity DVT, the examination is concentrated on a limited compression evaluation of the leg veins.
- Simple compression ultrasonography, which uses a high frequency linear probe to apply direct pressure to the vein, has a good overall sensitivity for detection of DVT of the leg. An acute blood clot forms a mass in the lumen of the vein, and the pathognomonic finding of DVT will be incomplete compression of the anterior and posterior walls of the vein
- In contrast, a normal vein will completely collapse with simple compression. Most distal deep venous thromboses can be detected through. simple compression ultrasonography of the leg using standard B-mode imaging.
- Ultrasound may miss some clots that have formed in the calf veins, a difficult area to evaluate with sonography. However, most proximal DVTs can be detected by a limited compression examination of the leg that can be rapidly performed by focusing on 2 major areas.
- The proximal femoral vein just below the inguinal ligament is evaluated first, beginning at the common femoral vein, found below the inguinal ligament. Scanning should continue down the vein through the confluence with the saphenous vein to the bifurcation of the vessel into the profunda and femoral veins.
- The second area of evaluation is the popliteal fossa. The popliteal vein, the continuation of the femoral vein, can be examined from high in the popliteal fossa down to trifurcation into the calf veins.
- If an upper extremity thrombus is clinically suspected, the same compression techniques can be employed, following the arm veins up to the axillary vein and into the subclavian vein. Although a good initial test, the sensitivity of ultrasound for proximal upper extremity clots is lower than for lower extremity clots, as the subclavian vein cannot be fully compressed behind the clavicle.
- Although clinically less common, an internal jugular vein thrombosis that may form in a patient with a previous central line can also be well seen with ultrasound.
- Previous studies have shown that EPs can perform limited ultrasound compression for lower extremity venous clots with good sensitivity in patients with a high pretest probability for the disease. The examination can also be performed rapidly, and can be integrated into the overall RUSH protocol with a minimum of added time

Start Position

- Place flat linear transducer in the transverse position, at the groin crease.

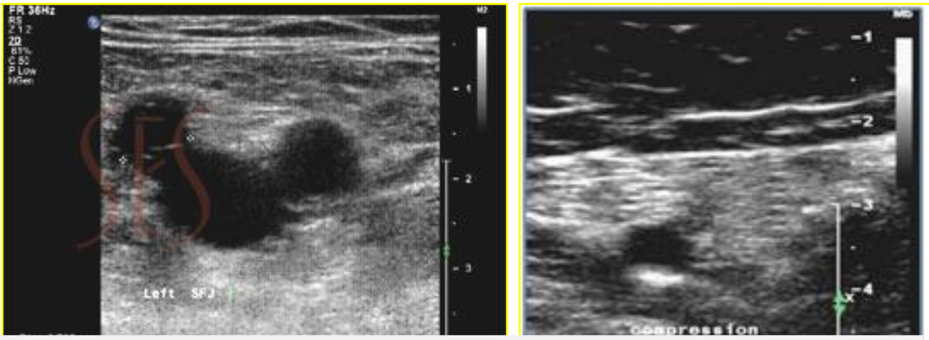
Protocol – Upper target area

- Complete apposition of vein walls is the required criteria to discount DVT under the probe. This protocol is a limited one, targeting 2 small areas of the lower limb veins.
- Locate femoral artery & vein

- Optimise image
- Compress to define vein
- With little or no pressure on the probe, it should be slid proximally to locate the sapheno-femoral junction (SFJ) (mickey mouse appearance)
- Slide cephalad 1-2cms beyond SFJ and begin compression run.
- Compress the vein every cm from start to just below the SFJ

Protocol – Popliteal target area

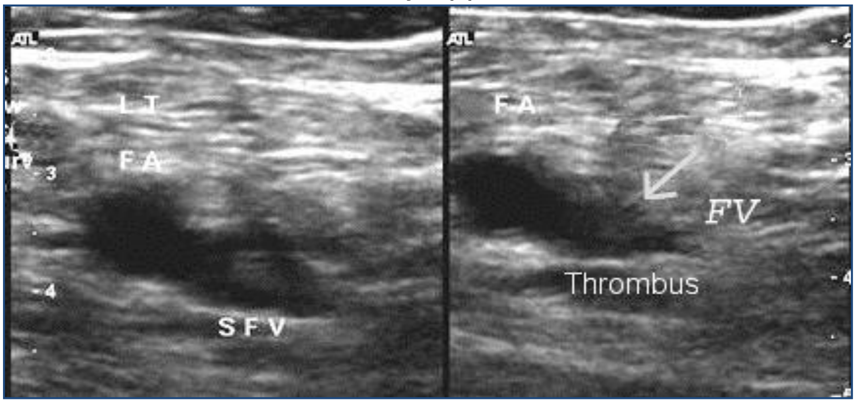
- Place probe transversley at the knee crease posterior;ly
- Locate popliteal artery & vein in the medial knee crease
- Optimise image
- Compress to define vein
- Compress every cm from proximal politeal to distal poplital

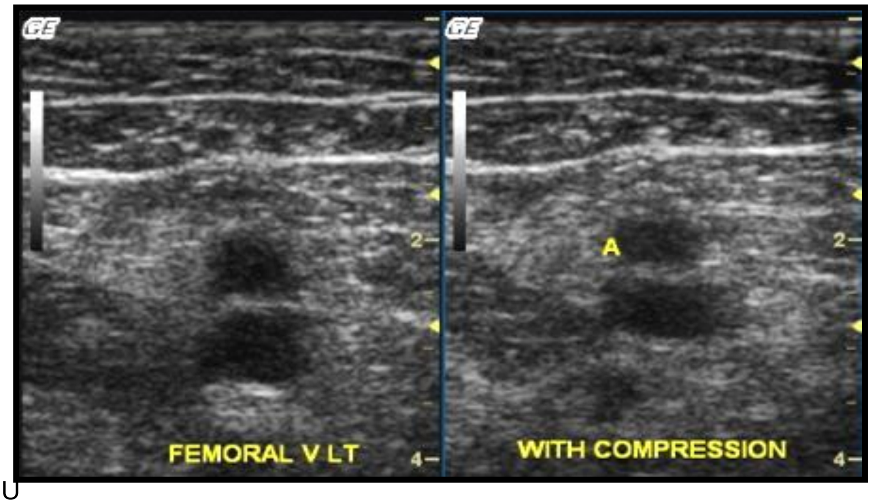


Transverse Groin - Compression

Abnormal Appearances

- Lack of apposition on compression
- Beware new thrombus may appear anechoic

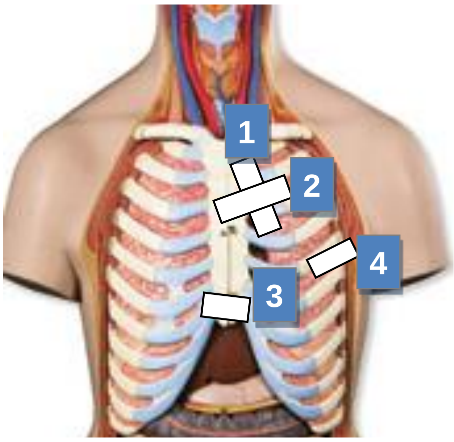


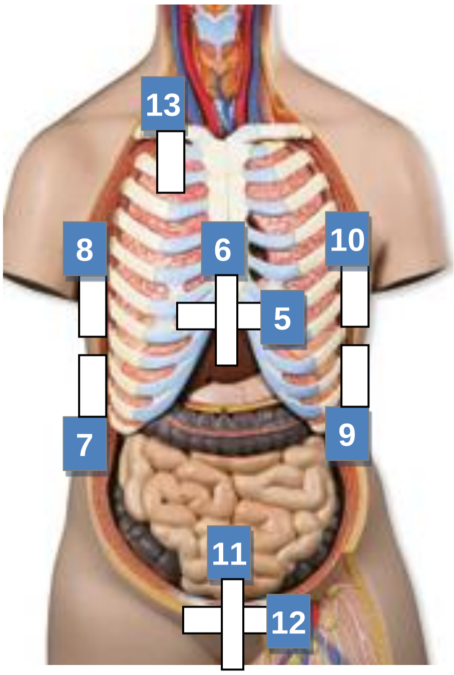


4. RUSH SUMMARY

The Pump

- Parasternal long axis
- Parasternal short axis
- Subcostal
- Apical 4 chamber



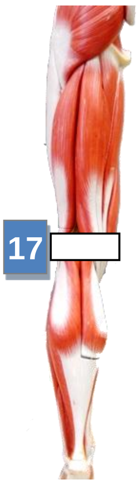


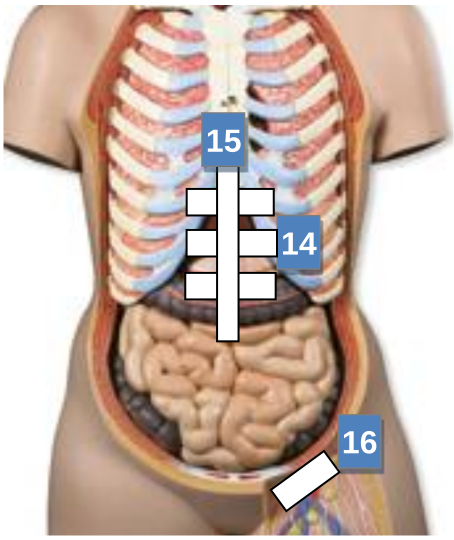
The Tank

5. Subcostal transverse – IVC
6. Subcostal longitudinal - IVC
7. FAST Morrison's Pouch
8. Rt pleural
9. FAST Spleno-renal angle
10. Lt pleural
11. FAST pelvis longitudinal
12. FAST pelvis transverse
13. Pneumothorax

The Pipes

14. Abdominal Aorta – transverse sweep
15. Abdominal Aorta – longitudinal sweep
16. Femoral vein proximal – DVT
17. Popliteal vein – DVT



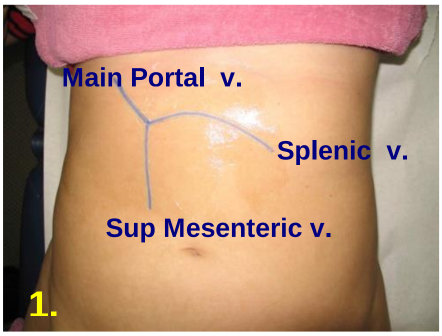


ULTRASOUND EXAMINATION OF THE GALL BLADDER

The examination of the gall bladder at the bedside is a simple, speedy procedure which, if executed in a regimented step by step protocol within a clinical question environment, is safe and accurate.

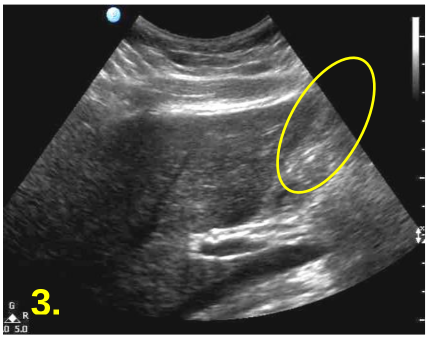
Start position

- The curved array transducer is placed in a longitudinal plane, in the mid clavicular line, at 90^0 to the costal margin. The marker end of the transducer should be ON the lowest rib with the beam directed toward the right shoulder.



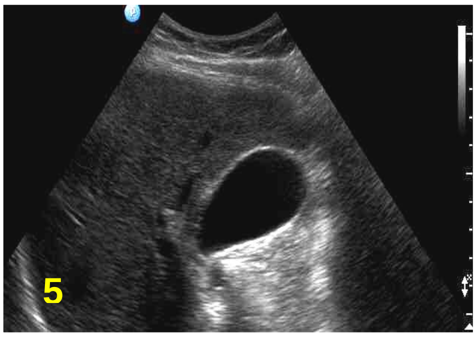
Remember vascular landmarks

Place probe on oblique line, 90^0 to costal margin– angle beam slightly towards patient Rt shoulder

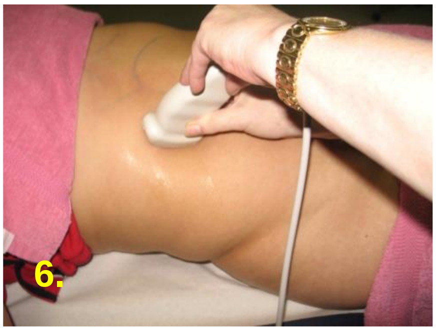


Adjust Depth until posterior MPV is at back of image. Focus eyes on liver edge (shaded area)

Slide probe along costal margin to the right

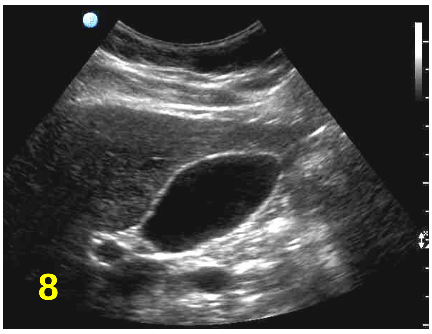


Look for “black hole” of the GB lumen in shaded area



Use left hand to rotate probe, right hand to hold in position

Continue rotating to elongate GB to its longest section



Sweep through GB lumen

Decubitus position with relaxed abdo muscles allows GB to fall forward – better window

THINGS TO REMEMBER

FOCUS ON PROBE PLACEMENT BEFORE LOOKING AT IMAGE

1. Remember to imagine landmarks in 3D
2. Use fingers to gauge best window for MPV
3. Probe grip is IMPORTANT to control
   a. Direct beam to right shoulder
4. Optimise image
   a. DEPTH, FOCUS, TGC
5. Focus eyes on lower edge of liver between ant abdominal wall & anterior wall MPV
6. Slide probe without rotating – one movement at a time, look for "black hole"

- What to do if you don't see the MPV
   a. Look at patient & check beam direction
   b. Ask the patient for deep inspiration
   c. Check DEPTH again
   d. Sweep beam SLIGHTLY LEFT TO RIGHT
   e. Roll patient to decubitus position
   f. Ask the patient to relax abdominal muscles – GB falls forward, better window

Clinical Questions: Gall Bladder

- "Does the gall bladder contain calculi?",
- "Are ultrasound signs of acute gallbladder disease present?"

The following protocol will allow visualisation of the entire gall bladder and determination of the presence or absence of gall stones, along with their size, position and mobility and also the presence or absence of wall thickening – leading to the diagnosis of gallbladder disease

Transducer (Curved Linear)	Slight patient - 4-6MHz Mid - Large Pt - 5-2MHz
Patient Positioning	Supine / Left lateral oblique / Left lateral decubitus
Initial Approach	Oblique section, Transducer positioned directly below, and at 90° to the costal margin in the mid clavicular line, tilted toward the right shoulder
Respiratory Manoeuvre	Deep inspiration ± protrusion of anterior abdominal wall
Scanning Procedure	1. Spread out gel with transducer face 2. With patient in quiet respiration, survey the area 3. Go to initial scanning position 4. Initiate respiratory manoeuvre 5. Move transducer smoothly along the costal margin, watching monitor, looking for the portal vein & GB 6. If necessary, change respiratory manoeuvre 7. Identify position of neck & fundus of GB 8. Rotate transducer to join the two points 9. Scan through the entire GB 10. Assess presence or absence of calculi, wall thickening, biliary sludge

Image	Neck, body & fundus in long section
Measure	1. GB wall thickness (AP diam) if abnormal 2. Any calculi present
Second approach	Transverse section 1. Observe angle of transducer with respect to costal margin 2. Rotate transducer through 90°, maintaining angulation
Scanning Procedure	1. Scan using sweeping angulation, through the GB from neck to fundus
Image	Two transverse sections showing: 1. Neck 2. Fundus
Third Approach	Intercostal View Transducer positioned along appropriate intercostal space
Scanning Procedure	1. Using right lobe of liver as a sonographic window, tilt the transducer up and down under the rib. 2. Locate neck and fundus of gall bladder as before and use differing respiratory manoeuvres to position gall bladder under window 3. Assess presence or absence of calculi, wall thickening & sludge
Fourth Approach	1. Gallbladder should ALWAYS be examined in 2 patient positions, move the patient into the left lateral decubitus or left posterior oblique position. 2. Review all approaches with patient repositioned 3. Palpate GB fundus with transducer to elicit positive Ultrasound Murphy's sign
Scanning Procedure	1. Assess movement of sludge and/or calculi
Image	Any redistribution of calculi or sludge to document mobility

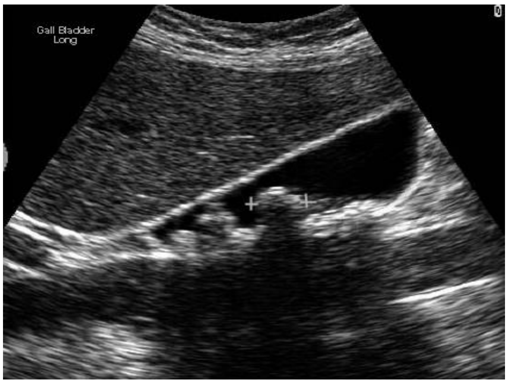
Problem Solving

1. Can't see gall bladder from any approach
   - Has the patient undergone cholecystectomy?
   - Has the patient eaten a fatty meal recently?
   - If possible, examine patient erect
   - Look for calculi filled, contracted GB
2. Bowel gas constantly obscuring fundus
   - Roll patient to three quarters prone position and scan through left lobe of liver from anterior approach, with beam directed to patient's right shoulder
   - Roll patient to right posterior oblique position and scan through right lobe of liver subcostally or intercostally

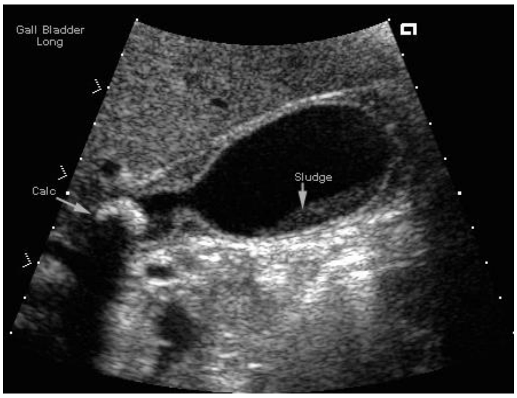
Typical appearances of normal gall bladder & some GB pathologies

1. ***Normal Gall Bladder***

2. ***Cholelithiasis***

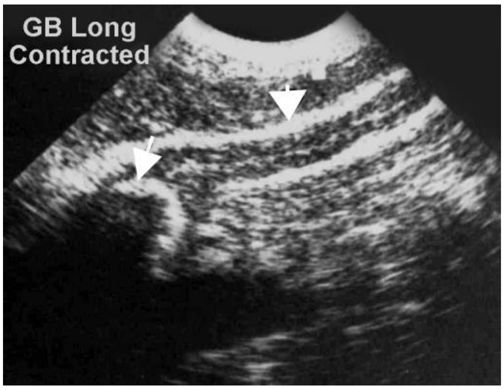


3. ***Sludge***

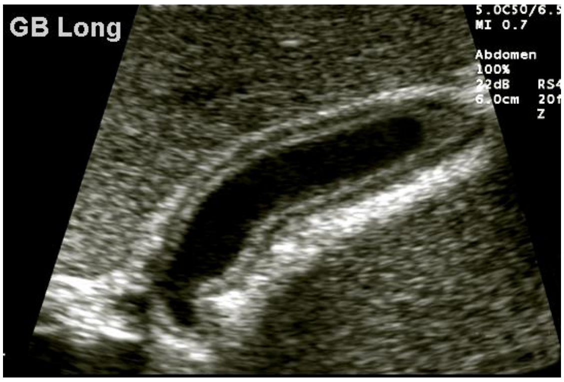


Sludgeball

4. ***Contracted GB with stone in neck***

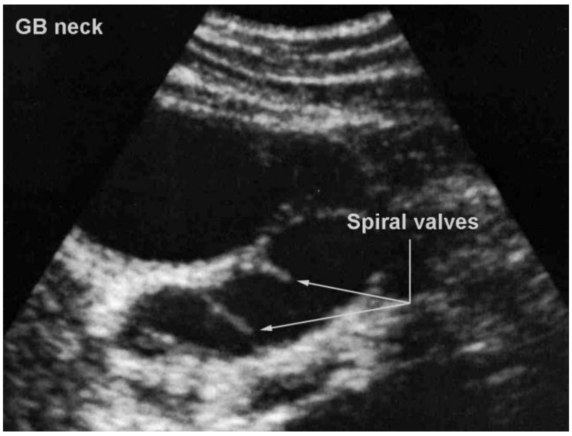


Thickened GB wall



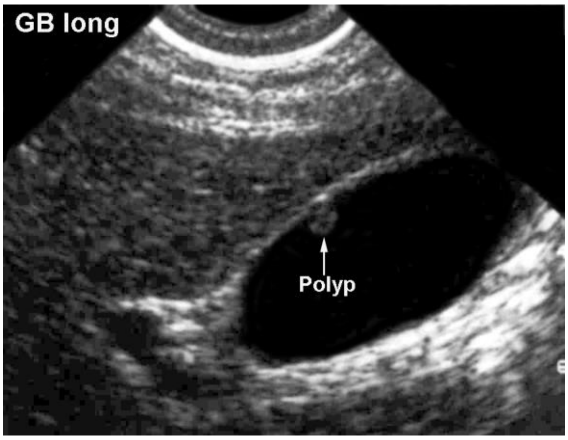
Two other common appearances in the gall bladder are those of spiral valves in the neck and polyps. These can often be misinterpreted unless recognised as such.

Spiral valves in GB neck



Spiral valves can appear highly echogenic, but on careful examination – do not exhibit any posterior shadowing.

Gall Bladder Polyp



Polyps do not exhibit posterior shadowing, nor do they move away From their respective wall – scanning with the patient in differing positions whilst watching the polyp, will ascertain its' attachment to the wall.

It should be remembered that scanning is a dynamic, interactive process and one or several different manoeuvres may be necessary for any given examination. Since there are no hard and fast rules that work for every patient, the sonographer should be creative and learn to improvise. Refinements in technique and an intuitive sense of what will be successful in which situation will come with experience.

A meticulous scanning technique is crucial to correct diagnosis

RENAL TRACT TECHNIQUES

Anatomy

The upper urinary tract consists of the:

- Right & left kidneys (anatomy described in abdominal notes)
- Right and left ureters

Ureters

Long, narrow tubular structures arising from the renal hilum and descending to expel urine into the posterior urinary bladder. Diameter decreases from proximal to distal extent. They are composed of three layers:

- Inner - mucosal
- Mid - muscular
- Outer - Fibrous

Regular peristaltic motion along the ureters moves urine at intervals varying between seconds and minutes (depending upon the hydration level of the body) from the renal pelvis to the urinary bladder. Ureters enter urinary bladder posteriorly, at the trigone.

Blood supply from branches of the renal, internal spermatic, hypogastric and inferior vesicular arteries.

Lower Urinary Tract

Consists of:

- The urinary bladder
- Urethra.

The urinary bladder is a symmetrical, hollow, muscular organ composed of four layers:

- Inner - mucosal
- Submucosal
- Muscular
- Outer - Serosal

The inner mucosal layer lies in folds when the bladder is empty and gradually distends to become smooth as the bladder fills with urine.

Relations

- Inferior portion is composed of posterior base (trigone) and neck, which leads to urethra.
- Inferolateral surfaces in contact with pelvis floor muscles
- Anterior portion lies behind symphysis pubis
- Superior portion covered by extension of peritoneum

Urethra

Membranous, hollow canal conveying urine from bladder to outside the body.

Length:
- Male – 20cm
- Female – 3-4cm

Sonographic Appearances

Ureters
- Not normally seen unless pathological
- Ureteric “jets” (urine being expelled into the bladder) can be seen with colour

Bladder
- Cavity is not visible until filled with urine, when it appears anechoic
- Walls appear as a smooth, echogenic line (in the distended bladder)
- Shape is variable with amount of distension and in the transverse view, appears somewhat squared
- Female – posterior wall may be indented by the uterus
- Male – posterior wall may be indented by the prostate

TYPICAL MEASUREMENTS

Kidneys
- Length - 9-12cm bipolar diameter

Ureters
- Length - 25-35cm
- Width - ~6mms (decreasing distally)

Distended bladder wall
- AP diameter 3-6mms (depending on extent of distension)

Urethra
- Length - male, 20cm; female, 3-4cm

TYPICAL IMAGING PROTOCOL

Urinary Bladder

Bladder should be imaged both before and after micturition

- Longitudinal Lateral, medial, mid
- Transverse Inferior, mid, superior

Female

Representative images of pelvic organs as required such as:

- Long & trans uterus & cervix
- Long & trans both ovaries

Male

Representative images of the prostate as required, such as:

- Long, right, left & mid
- Trans, inferior, mid & superior

Kidneys

- Long Lateral, medial, mid
- Trans Upper, mid, lower
-

Measurements

- Bipolar length, both kidneys
- Bladder volume, pre & post void
- AP diameter bladder wall (where necessary)
- Prostate volume in males

NB:

- As in all ultrasound examinations, all organs viewed should be scanned thoroughly throughout their full extent and note taken of shape, size, contour, internal texture and architecture.
- A general survey of the entire abdomen should be carried out
- Any unusual appearances noted should be documented

Clinical Questions: Urinary Tract

Ultrasound examination in the urinary tract is not as sensitive as IVP in the diagnosis of small urinary tract calculi, but can, very quickly, demonstrate the results of an obstructing stone; i.e. hydronephrosis and/or proximal or distal hydroureter. Therefore, the sonographer should be meticulous in answering clinical questions and completing a full and careful review of all renal tissue.

"Is renal pathology present?"

The following protocol will allow visualisation of both kidneys and proximal ureters.

Transducer (Curved Linear)	Slight patient - 4-6 MHz Mid - Large Pt - 5-2 MHz
Patient Positioning	Supine / Left lateral oblique / Left lateral decubitus/ Right lateral oblique / Right lateral decubitus
Initial Approach – Rt kidney	Long section – patient supine Transducer positioned directly below the costal margin in the mid clavicular line, beam pointing slightly cephalad
Respiratory Manoeuvre	Deep inspiration ± protrusion of anterior abdominal wall
Scanning Procedure	1. Spread out gel with transducer face 2. With patient in quiet respiration, survey the area 3. Go to initial scanning position 4. Initiate respiratory manoeuvre 5. Move transducer smoothly along the costal margin, angling slightly towards the lateral edge of the liver. 6. If necessary, change respiratory manoeuvre or patient position (Oblique or decubitus) 7. Locate upper pole of kidney – STOP –LOOK – locate lower pole of kidney – STOP – LOOK 8. Rotate transducer to join the upper and lower poles. 9. Move the transducer cephalad or caudad to position the kidney in the center of the display 10. Angle beam slightly from side to side, sweeping through the long section of the kidney 11. Repeat 10. two or three times, focusing on central collecting system
Image	Long section
Measure	Bipolar distance
Second approach	Transverse section 1. Assess angulation & position of transducer in long section 2. Rotate transducer 90°, maintaining angulation
Scanning Procedure	1. Sweep cephalad and caudad to assess central collecting system
Image	Transverse section @ mid portion of kidney

Patient Positioning	Supine / Left lateral oblique / Left lateral decubitus/ Right lateral oblique / Right lateral decubitus
Initial Approach – Lt. kidney	Long section – patient supine Transducer positioned intercostally, from a coronal approach on the let side
Respiratory Manoeuvre	Deep inspiration ± protrusion of anterior abdominal wall
Scanning Procedure	1. Spread out gel with transducer face 2. With patient in quiet respiration, survey the area 3. Go to initial scanning position 4. Initiate respiratory manoeuvre 5. Angle transducer slowly under the rib and move along rib space to assess window 6. If necessary, change respiratory manoeuvre or patient position 7. Locate upper pole of kidney – STOP –LOOK – locate lower pole of kidney – STOP – LOOK 8. Rotate transducer to join the upper and lower poles. 9. Move the transducer cephalad or caudad to position the kidney in the center of the display 10. Angle beam slightly from side to side, sweeping through the long section of the kidney 11. Repeat 10. two or three times, focusing on central collecting system
Image	Long section
Measure	Bipolar distance
Second approach	1. Transverse section 2. Assess angulation & position of transducer in long section 3. Rotate transducer 90°, maintaining angulation
Scanning Procedure	1. Sweep cephalad and caudad to assess central collecting system
Image	Transverse section @ mid portion of kidney

Problem Solving – Right Kidney

- Air in right hepatic flexure of the colon obscures kidney
  - Change respiratory manoeuvre and watch renal movement
  - Change patient position (use gravity to pull bowel loops anteriorly and move kidney out from under the ribs)
  - Position transducer above iliac crest and employ a coronal approach
- Kidney not visible using either approach
  - Try intercostal approach, using right lobe of liver as a window

Problem Solving – Left Kidney

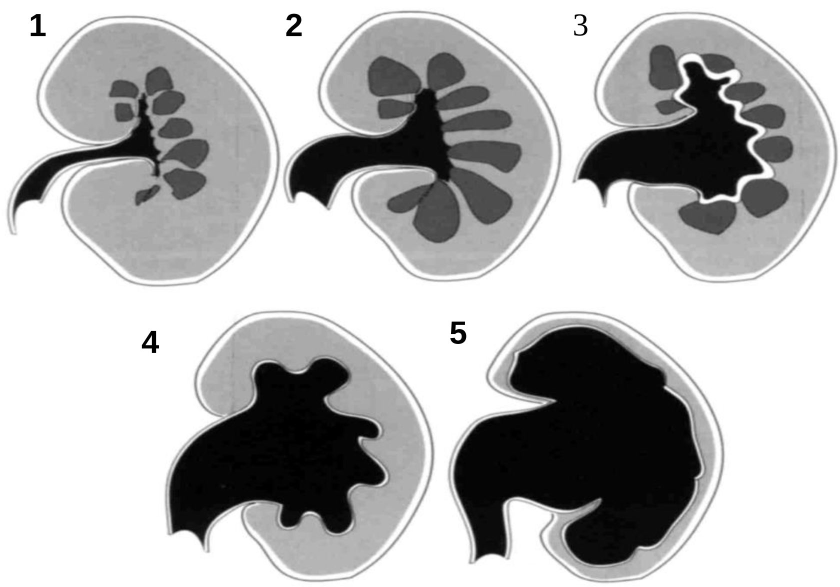
- Air in left hepatic flexure obscures kidney
  - Move transducer to a more posterior approach
  - Change respiratory maneuver

- Change patient position to decubitus or oblique (gravity pulls kidney forward)
- Position transducer at iliac crest, move anteriorly and angle back slightly

Remember

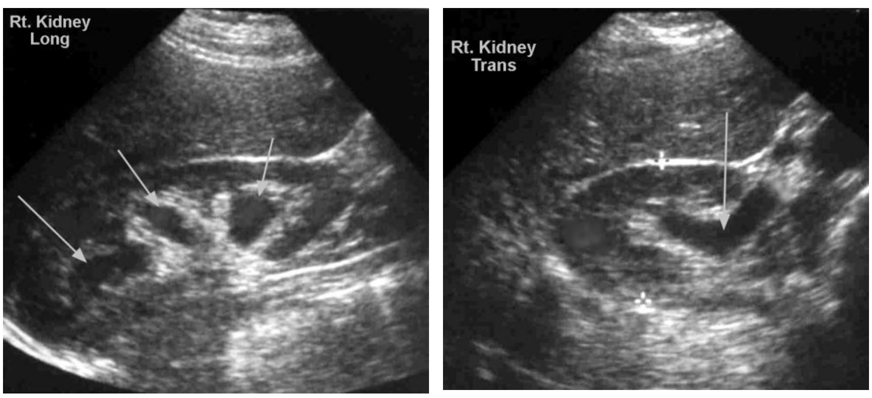
1. to imagine the position of the kidney before beginning
2. to position transducer so that the imaginary beam illuminates the kidney
3. to change respiratory manoeuvres and patient position where necessary
4. to understand that the kidneys are very mobile organs in most patients
5. not to mistake medullary pyramids for cysts
6. not to mistake an extrarenal pelvis for hydronephrosis
7. to follow the ureter inferiorly in the case of hydroureter
8. to look for obstructing stones in the vesico-ureteric junctions if the bladder is filled
9. that other pathologies may be noted in the kidneys – document any cysts, solid lesions, extrarenal fluid etc.

Diagrammatic representation of the progression of hydronephrosis from minimal to severe.



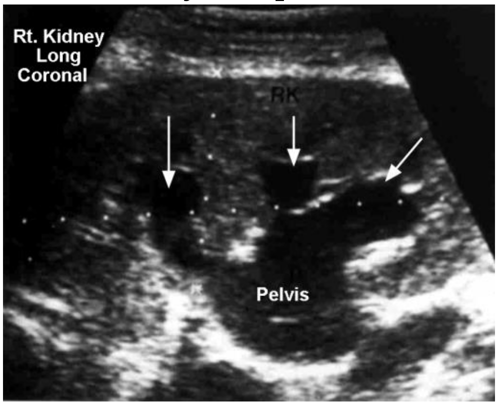
Typical sonographic appearances of common renal pathologies

1. Mild hydronephrosis



1. Arrows indicate mildly dilated renal pelvi-calyceal system

2. Moderate hydronephrosis

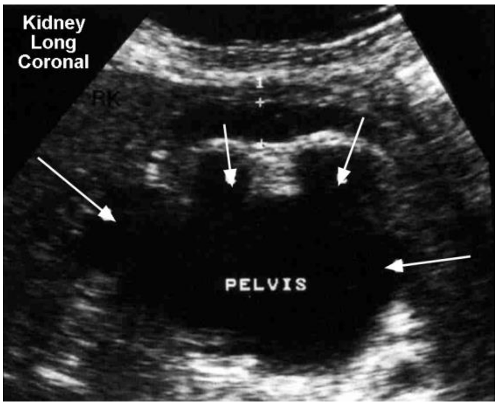


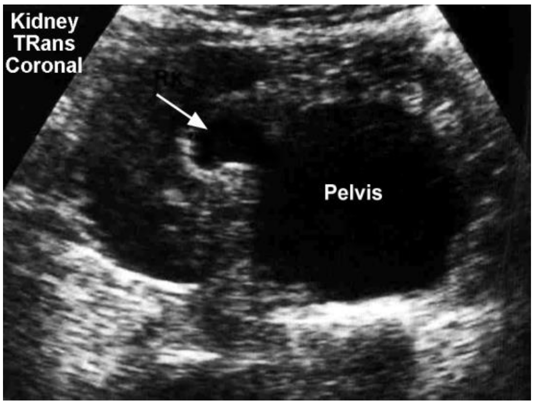
2. The coronal plane is excellent for diagnosis of calyceal dilatation, since the dilated calyces can be seen to be emptying into the renal pelvis.

(Multiple small cortical cysts would not have any connection with the renal pelvis)

3. Note the thinning of the renal cortex in gross hydronephrosis

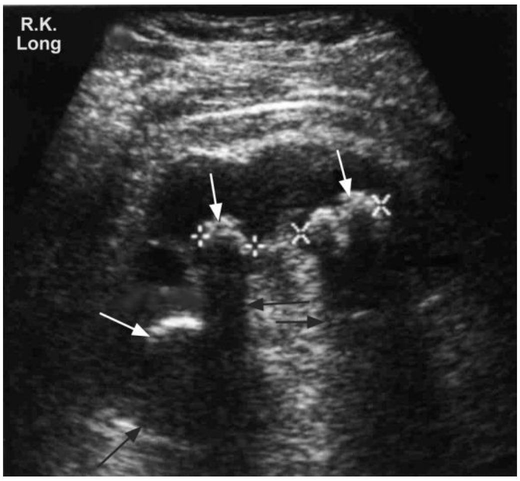
3. Gross hydronephrosis

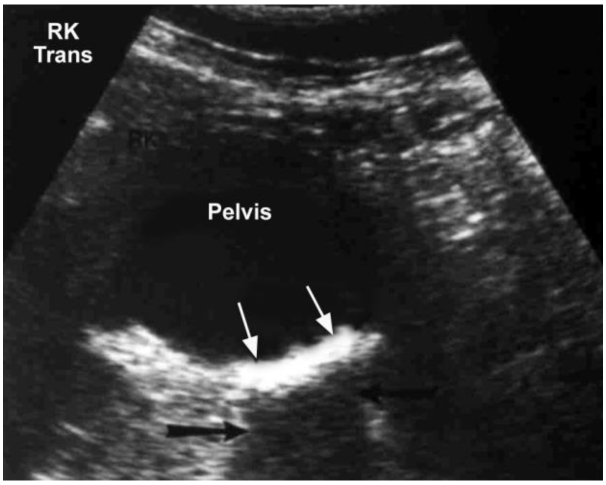




4. Staghorn calculi with hydronephrosis

This patient is an elderly woman presenting with severe flank pain. Staghorn calculi were detected (white arrows) exhibiting posterior shadowing (dark arrows). The transverse view shows gross hydronephrosis with multiple calculi (white arrows) in the dilated renal pelvis.





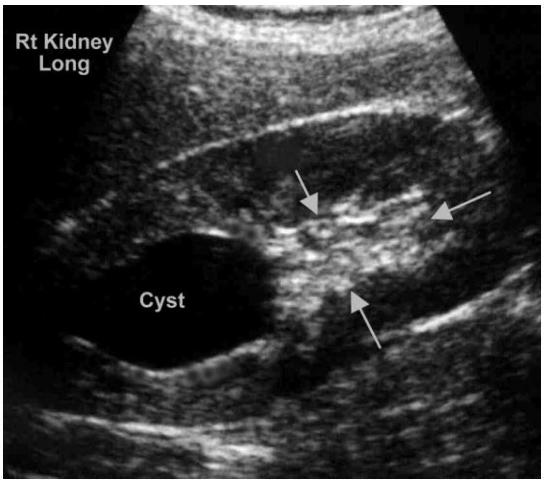
5. Single renal calculus

Slight dilatation of calyces with single calculus (white arrow), exhibiting marked posterior shadowing (dark arrow)

6. Renal Cysts

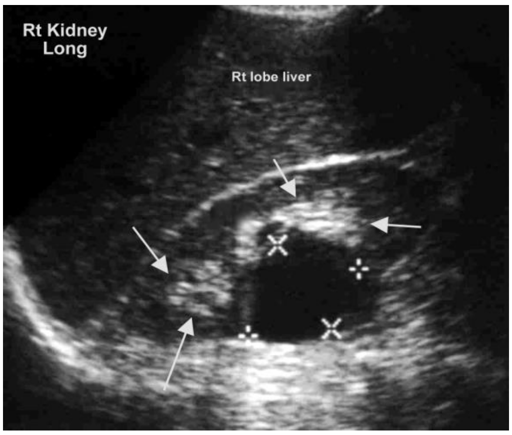
There are many types of renal cyst and discussion of all those seen on ultrasound examination is beyond the scope of this course. In the emergency department you will regularly see simple cysts, which are usually an incidental finding and rarely contribute to symptoms unless they are very large or multiple. Para-pelvic cysts are seen quite commonly and are important mainly in that they must not be confused with hydronephrosis. Examples of both of these types of cyst are seen below.

Simple Cyst

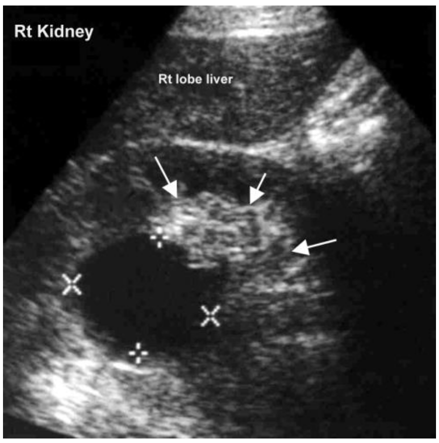


- *Note: In both cases the renal sinus echoes (arrows) appear normal*

Para-pelvic Cyst – long



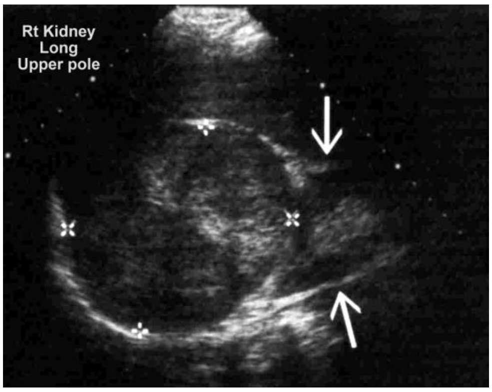
Trans



7. Solid Renal Masses

Once again, there are a multitude of pathologies, which produce either solid or complex renal masses, and it is certainly outside the boundaries of this course to look into them in any detail.

Renal Cell Carcinoma



- *Renal cell carcinoma arising from the upper pole of the right kidney (calipers). Lower pole cortex and collecting system exhibit normal sonographic appearances (arrows).*

ASSESSING THE DIAPHRAGM

From the Beginning – the background to the problem

The diaphragm is the principal muscle of respiration. In concert with the other accessory muscles of respiration it enlarges the chest cavity on inspiration, allowing the lung to passively inflate owing to the negative intra-thoracic pressure.

When the diaphragm relaxes, the intrathoracic pressure rises, and air is forced out of the chest. If one or both of the hemi-diaphragms is paralyzed, the negative pressure created at inspiration by the other muscles of respiration causes the diaphragm to passively move cranially, as opposed to its normal active caudal movement.

Methods of evaluation of the suspected paralyzed diaphragm focus on either observing the direction of movement or measuring the pressure in the chest.

Paralysis of the diaphragm can lead to dyspnea and can affect ventilatory function. Diaphragmatic paralysis can be unilateral or bilateral.

The clinical symptoms are more prominent in bilateral diaphragm paralysis. Ventilatory failure and cor pulmonale are usually seen in severe cases. Although an uncommon cause of dyspnea, it still remains an underdiagnosed condition.

Different studies show different results relating to the correlation between diaphragmatic movement (excursion) and inspired lung volumes. Diaphragmatic motion contributes about ¾ of inspiratory volume the other ¼ coming from thoracic expansion.

To date there have been limited studies into the qualitative assessment of diaphragmatic function and its use in a clinical care setting.

Dysfunction of the diaphragm has been shown to be a cause of failure to wean a patient from mechanical ventilation. If function can be accurately assessed then, it may be possible to predict the timing for successful extubation from mechanical ventilation. There may also be a function to help assess mechanical ventilation strategies to strengthen the diaphragm and applications around diaphragmatic pacing.

Severe diaphragmatic dysfunction comes into question with prolonged ventilated patients in whom the normal causes for failure to wean have been excluded or treated. These causes are pneumonia and volume overload, diagnosing such severe dysfunction is crucial because it has been shown to carry a high risk of subsequent complications such as pneumonia, sudden respiratory arrest, and prolonged mechanical ventilation.

Difficulties in discontinuing ventilatory support are encountered in 20–25% of mechanically ventilated patients, with a staggering 40% of time spent in the intensive care unit being devoted to weaning. The respiratory muscles play a pivotal role in determining the weaning outcome.

The diaphragm plays a major role in respiratory muscle endurance. Where fatigue occurs, velocity of movement slows and amplitude of movement decreases. Studies suggest that ‘diaphragmatic movement is a result of diaphragmatic strength and intrathoracic and intra-abdominal pressures’ and that there are several causes of extubation failure and that **POOR ENDURANCE** is one of the hardest to predict. Ultrasound may then be useful for evaluation of endurance of the patient.

X-ray, fluoroscopy, phrenic nerve stimulation studies and trans-diaphragmatic pressure are all used in the assessment of diaphragmatic function. They have all been shown to be incomplete in their assessment in some way.

Ultrasound provides a non-invasive method to assess diaphragmatic function and can complement current methods.

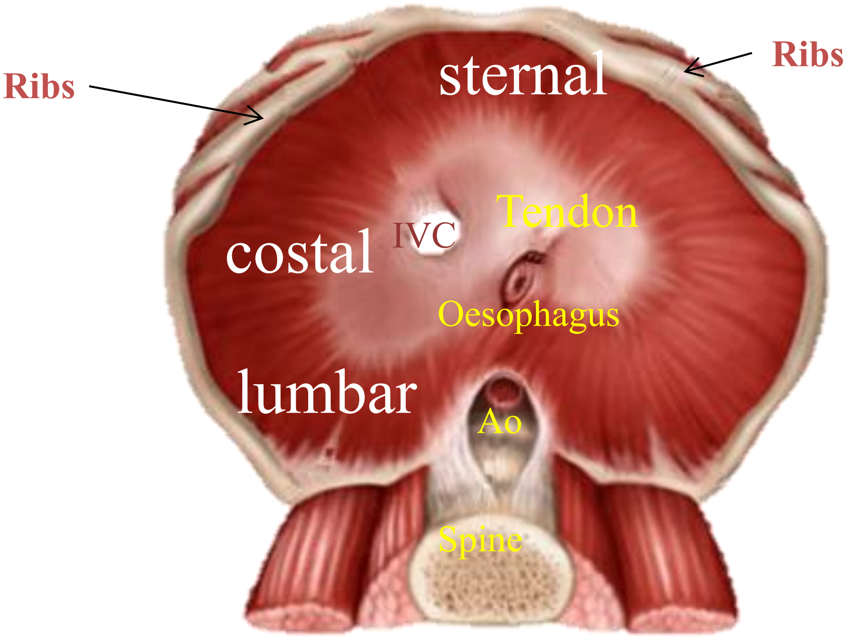
A rapidly accumulating body of evidence suggests that mechanical ventilation, with its attendant diaphragm muscle inactivity and unloading, is an important cause of diaphragmatic dysfunction.

Ultrasound of the diaphragm may be useful in ED in assessing: possible diaphragmatic paralysis in cases of:

- Raised hemi-diaphragm on CXR
- Spinal injury
- Dyspnea
- Orthopnea

Anatomical Considerations

Basic structures

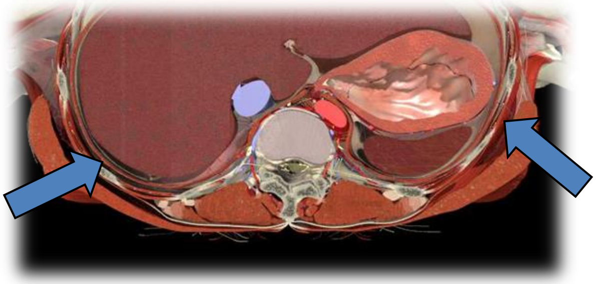


The diaphragm is a sheet of internal muscle and fascia, separating thoracic and abdominal cavities.
In a relaxed state it is shaped like a dome

There are 3 muscular portions around the rim that lead to a central tendinous area – the sternal, costal & lumbar areas on diagram to the left.

Covered on both sides by a fascial layer. Transversalis fascia on the abdominal side and endothoracic fascia on the thoracic side.
Phrenic nerves (one on each side) control diaphragmatic movement

Where is the best approach?



The lumbar section of the diaphragm has been shown to be the best approach to scanning. This arises from the lumbo-costal arches and the vertebrae and provides the most reproducible site which luckily is the area of maximum excursion.

Scanning Technique

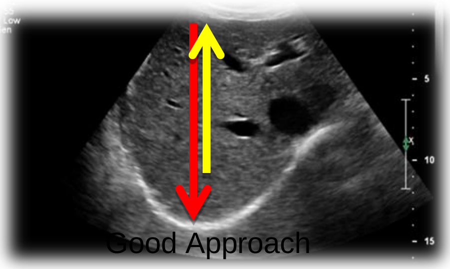
There are two scanning approaches to the right hemi-diaphragm, those are Subcostal & Intercostal. Scanning the left hemi-diaphragm has to be done from the intercostal approach due to obscuring stomach gasses.

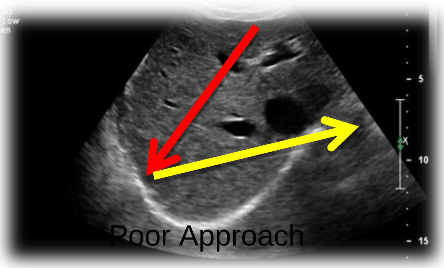
M-Mode Measurement Technique

M-Mode (Motion Mode) measures motion against time along a particular line of sight.
In this application we are interested in measuring the movement range or "excursion" of the leaflets of the diaphragm.

There are two very important things to remember here:

1. The lumbar (posterior) part of the diaphragm moves further in excursion distance than any other part of the diaphragm so this is the best place to measure
2. Remembering the physics is most important here as an incorrect angle of approach will result in highly inaccurate measurements.
    a. Poor B-Mode image
    b. The m-mode cursor line should be at 90^0 to the plane of movement, resulting in a reproducible measurement.

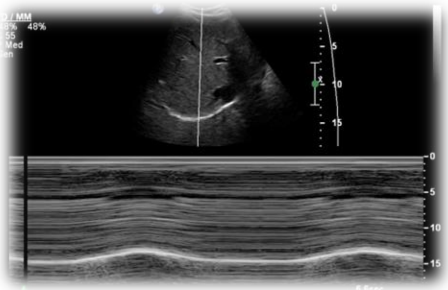




Protocol, Right Hemi-Diaphragm - Subcostal

- Start with the probe in a transverse plane, a the level of the xiphisternum
    - Overhand probe grip
    - Beam directed posteriorly
    - Apply downward pressure on the probe
    - Scoop the beam up, pointing towards the patient's head (remember to keep the pressure on)
    - Fan until the lumbar area of the hemi-diaphragm is visualised
    - **STOP**
    - Watch the excursion with normal respiration

- Measurement of the excursion distance is done in M-Mode



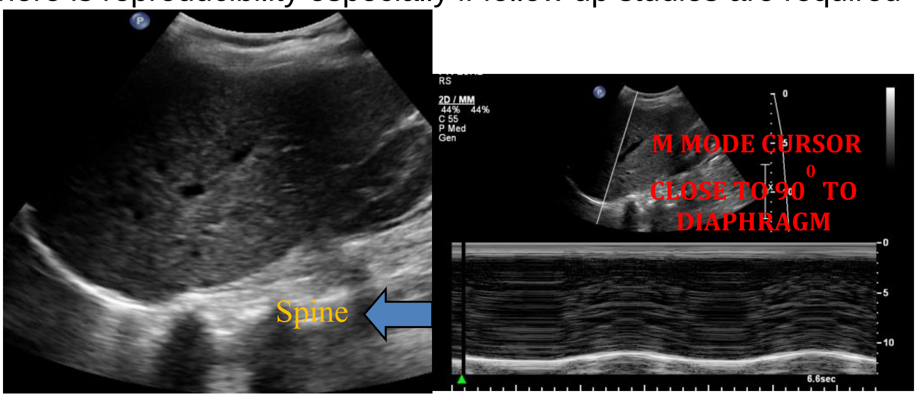
Place M Mode line in a reproducible position - approximately 5cm to the right of the right lateral border of the IVC

Placing the M mode line at a set distance from the edge of the IVC will decrease the subjectivity of subsequent studies.

Protocol, Right Hemi-Diaphragm – Coronal, intercostal

- Middle finger on xiphisternum, forearm extended
- Probe half way between arm and bed surface, parallel to the bed.
- Use the liver as a window
- Angle beam posteriorly until the diaphragm is seen inserting into the vertebral bodies.

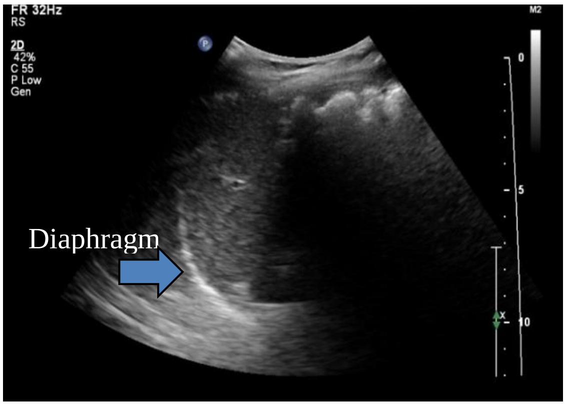
We use the spine as a landmark as it is non variable with respiration. The key here is reproducibility especially if follow up studies are required

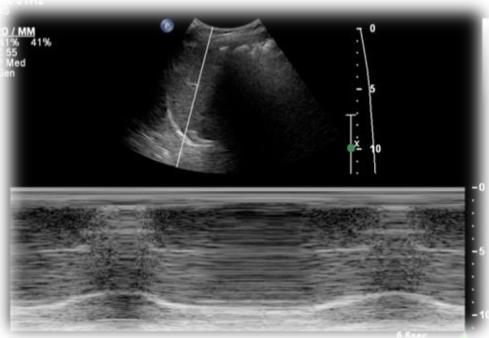


Protocol, Left Hemi-Diaphragm – Coronal, intercostal

- Middle finger on xiphisternum
  - Place probe two thirds of the way between your hand and the bed, probe parallel to the bed.
  - Use the spleen as a window.
  - Angle posteriorly until the diaphragm is seen clearly.
  - If necessary, adjust the probe position - Lt diaphragm is more difficult to visualise than the right.

Left hemi-diaphragm



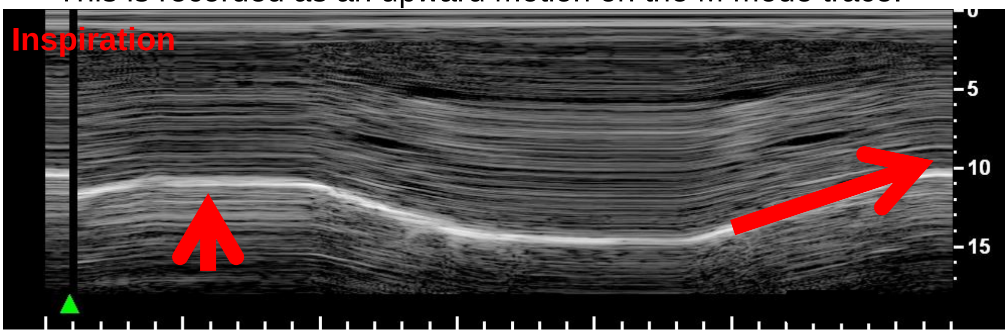


M-Mode trace – quiet respiration

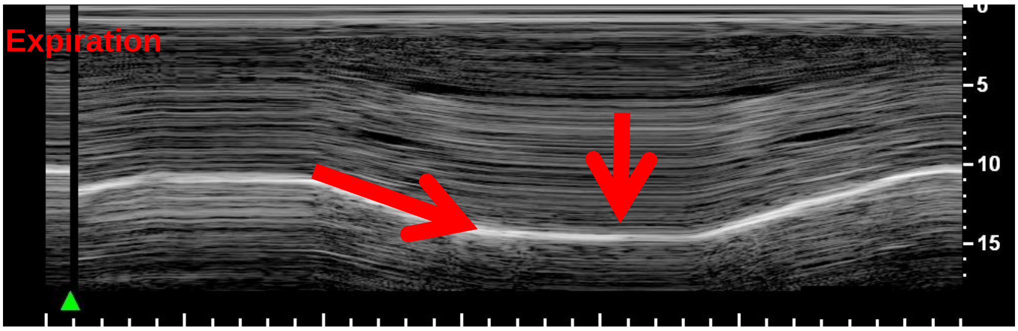
- During heavy breathing the left hemi diaphragm is often obscured by the descending lung.
- This results in the M Mode trace being obscured
- Diagnosis may prove very difficult in these instances

Interpreting the M-Mode

- During inspiration the normal diaphragm contracts and moves caudally *towards* the M-Mode line
- This is recorded as an upward motion on the M mode trace.



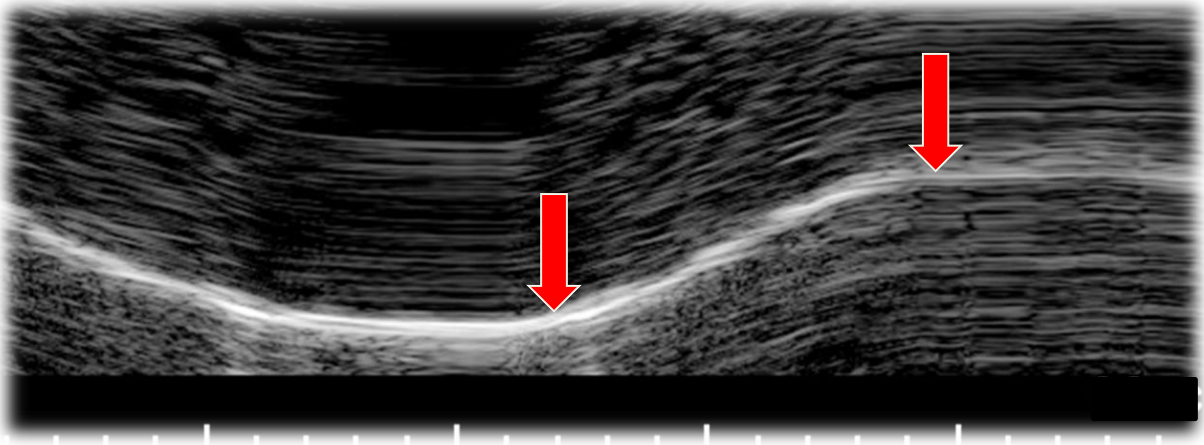
- In expiration the diaphragm moves cranially away from the M-Mode line and is recorded as a downward motion on the trace
- We measure direction of motion and amplitude of excursion



NB: SLOW sweep speed is necessary to capture more than one respiratory cycle, especially in patients with slow respiratory movements

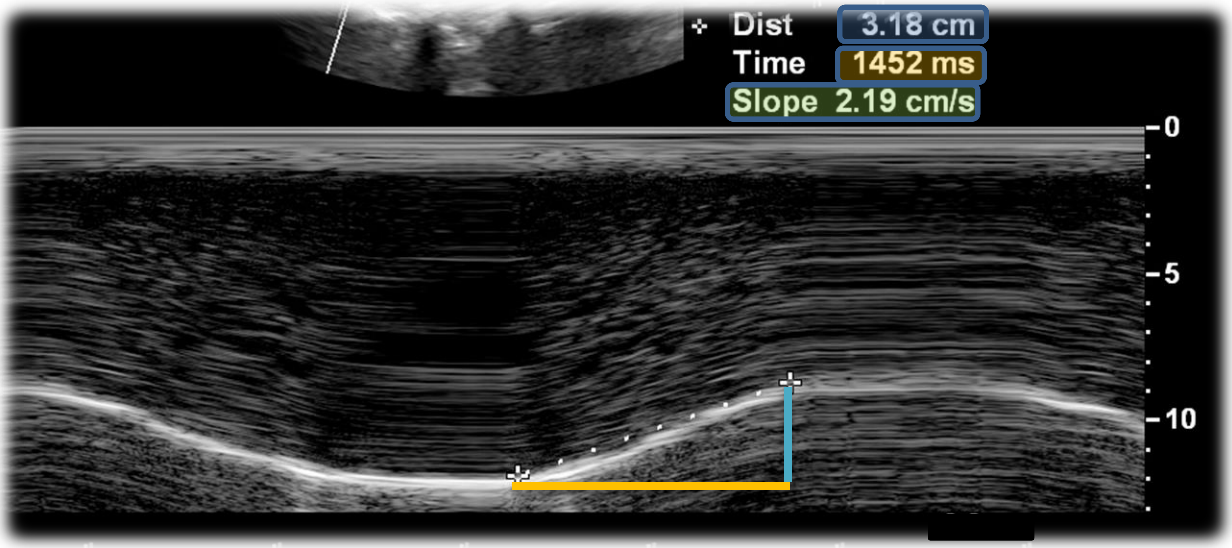
Measuring Excursion

- It is important to measure accurately.
- From the end of expiration (as the trace begins to rise)
- To the peak of inspiration



Most machines can be set up to show:

- The distance travelled by the diaphragm (seen in blue on the diagram below)
- The time of inspiration or expiration (seen in yellow on the diagram below)
- The mean velocity of the slope in cm/s (seen in green on the diagram below) (also known as the inspiratory mean velocity)



- The "inspiratory mean velocity" (IMV) is a quantitative measurement.
  - Often measurements are taken over three cycles and averaged out for accuracy.
- Measurements can be made for inspiration or expiration

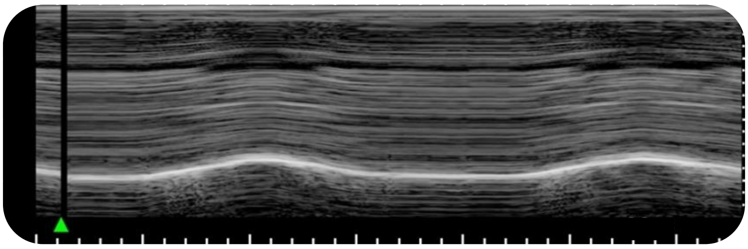
The IMV is calculated by dividing :

$$\frac{\text{distance of diaphragmatic movement (cm)}}{\text{time of inspiration or expiration (sec)}}$$

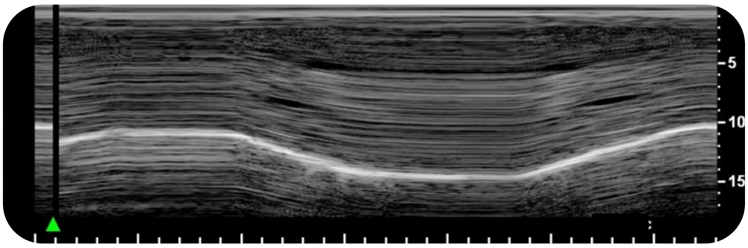
Most machines can be set up to show this value as part of an automatic calculation.

Expressed in cm/sec

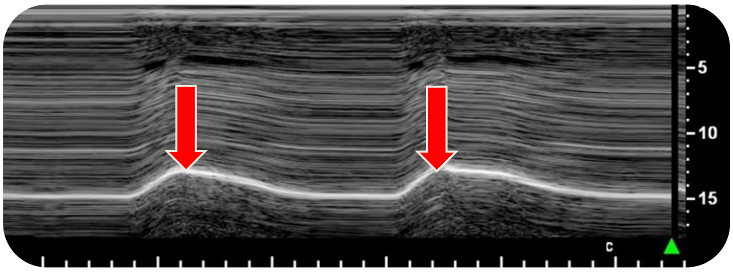
Some typical M-Mode breathing patterns are seen below:



Quiet breathing

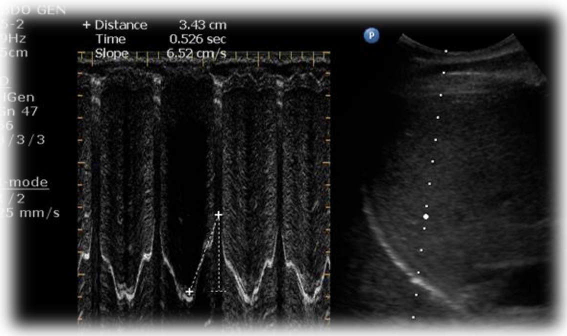


Heavier breathing



Sharp “SNIFF:

In comparison - the M-Mode trace below is from a cyclist at Vo2 Max



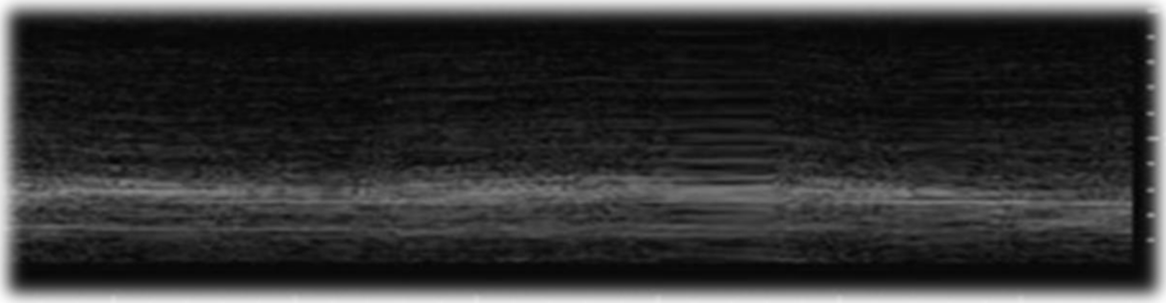
- Movement of the diaphragm can be described as normal, decreased, absent or paradoxical (reversed).
- Different studies quote a range of ‘normal values’.
  These vary with patient age, gender, position and clinical conditions

REFERENCE VALUES FOR M MODE DIAPHRAGMATIC MOVEMENT (lower limits)		
Quiet breathing	Men 1.0cm	Women 0.9cm
Sniff	Men 1.8cm	Women 1.6cm
Heavy Breathing	Men 4.7cm	Women 3.7cm
Diaphragmatic motion studied by M-mode ultrasonography. Boussuges MD, Gole Y, Blanc P. CHEST February 2009 vol. 135 no. 2 391-400		

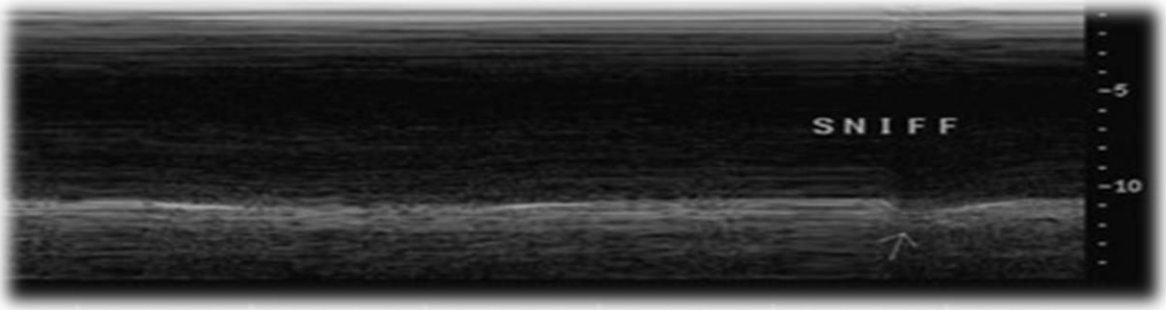
This was a very comprehensive study that sought to set values for an erect patient with no diaphragmatic pathology.
There is a large range of normal values and these must be used as a guide only.

Abnormal Appearances on M-Mode

- The M mode trace of a paralysed hemi diaphragm shows no active caudal movement of the diaphragm with inspiration

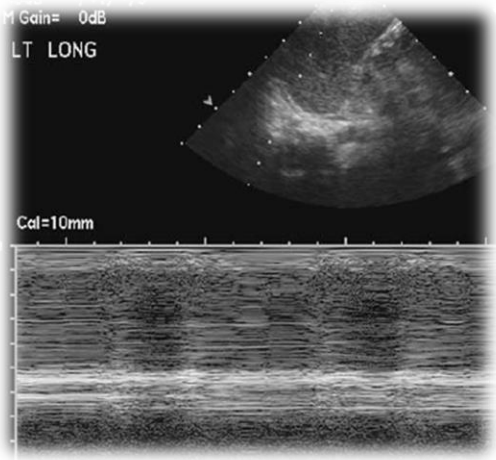


Abnormal paradoxical movement (i.e. cranial movement on inspiration) particularly with the sniff test

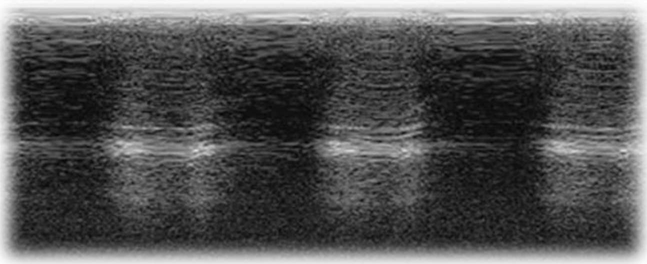


(Diaphragmatic paralysis: the use of m mode ultrasound for diagnosis in adults. Lloytd T, Tang YM, Benson MD, King S. Spinal Cord (2006) 44 505-508.)

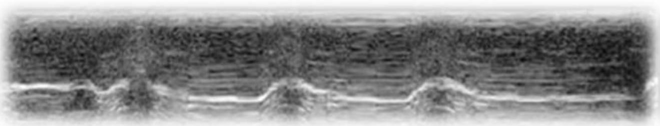
Example



Infant with left hemi-diaphragm paralysis



Some recovery after 3 days treatment



Complete recovery after 3 months

What conclusions can we draw?

1. The use of ultrasound at the bedside is constantly evolving

2. Its uses in diagnosis of diaphragmatic conditions and as a adjunct to current weaning parameters are in its infancy

3. **Published studies are limited but show promising results**

One such study has shown that u/s shows a greater prediction rate for extubation success than traditional weaning parameters.
The mean distance of travel for the diaphragm or associated organs was greater in patients in whom extubation was successful that for those in whom it was unsuccessful.

- The distance of diaphragmatic movement necessary for extubation:
  - Success => 1.1cm.
  - Unsuccessful < 1.1cm
- Tests Sensitivity, % Specificity, % Area
  - Pimax ≤ − 20 cm H_2O 93.1 50.1 0.74
  - Vtspon ≥ 5 mL/kg body weight 71.9 65.2 0.73
  - RSBI ≤ 105 81.3 56.5 0.81
  - MD ≥ 1.1 cm 84.4 82.6 0.84

Conclusions:

1. The cutoff value for predicting successful extubation was M.D (mean distance movement of diaphragm) 1.1 cm.

2. Using this cutoff value, the sensitivity and specificity to predict successful extubation were 84.4% and 82.6%, respectively

3. The sensitivity and specificity for successful extubation by MD ≥ 1.1 cm are better than by traditional weaning parameters, including the Pimax, Vtspon, and RSBI

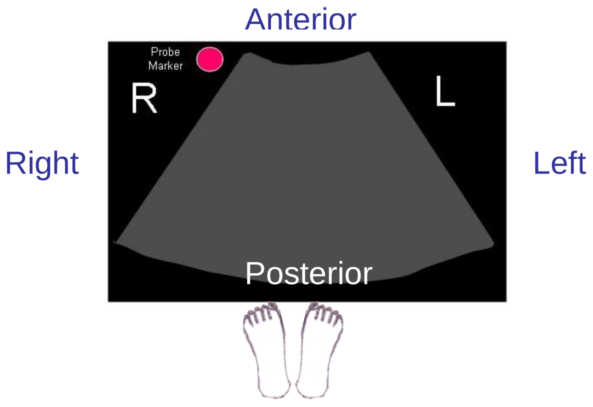
(Ultrasonographic Evaluation of Liver/Spleen Movements and Extubation Outcome Chest July 1, 2004 126:179-185)

Our Conclusion

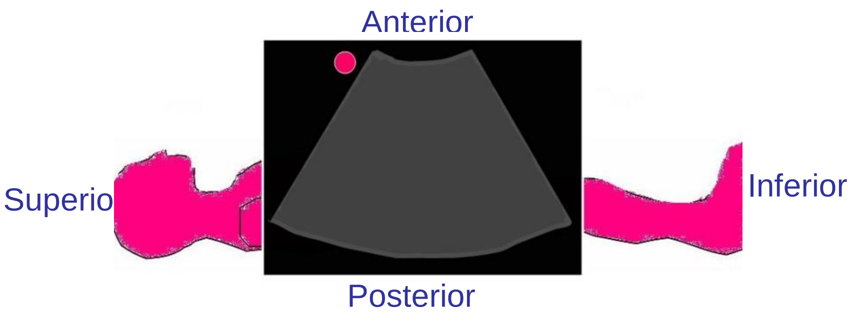
There is a lot of research work needed in this area to come to firm conclusions and specific values for the various measurements required before management decisions can be made confidently using just mean distance parameters alone.

In the mean-time – if you don't wish to be part of the research then use this application of ultrasound wisely in conjunction with all your other clinical resources.

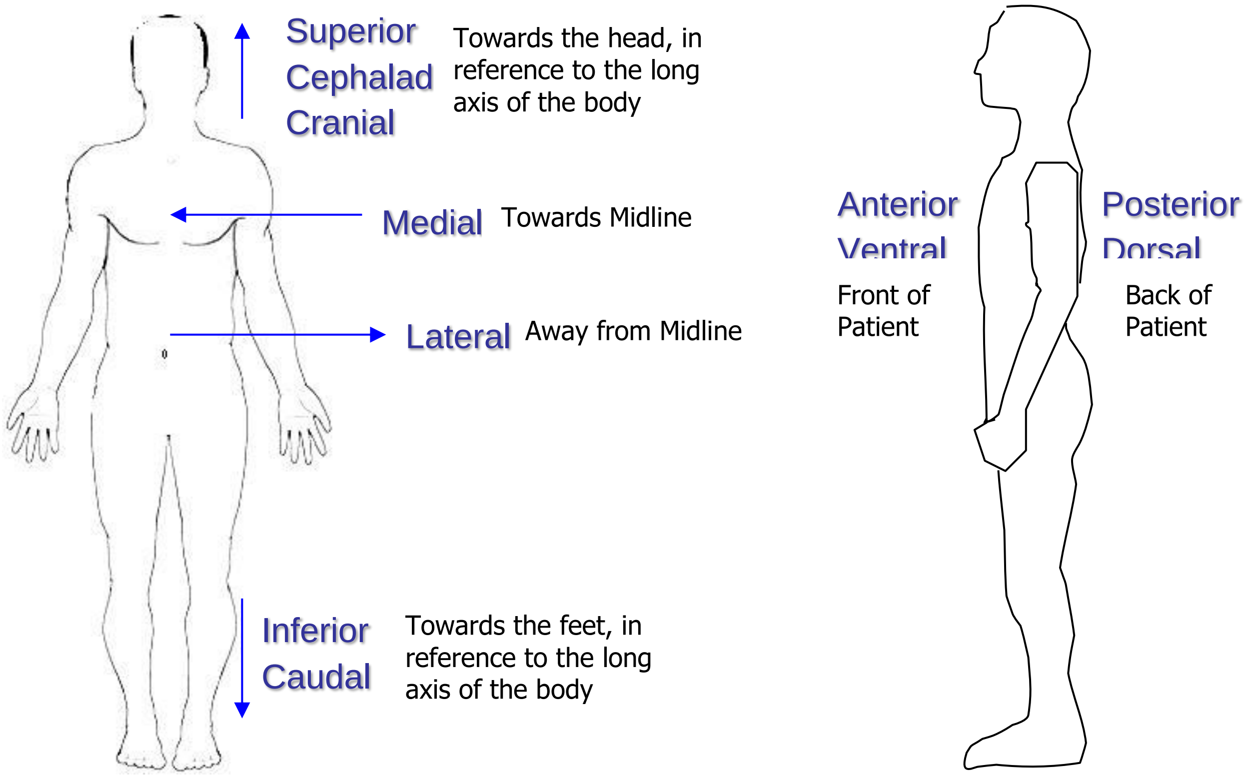
IMAGE ORIENTATION



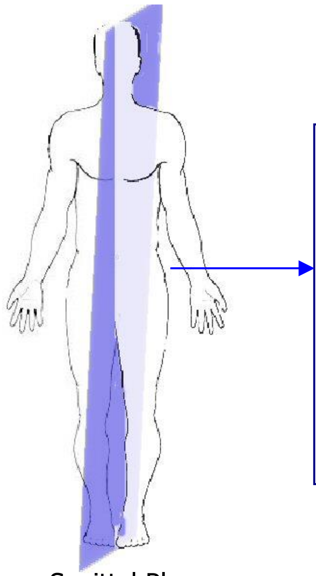
- When viewed in Transverse, the image is always viewed as if you are looking at the patient from the feet. The Patient's Right side is always on the left of the screen



- When viewed in Longitudinal, the image is always viewed with the cranial aspect on the left side of the image

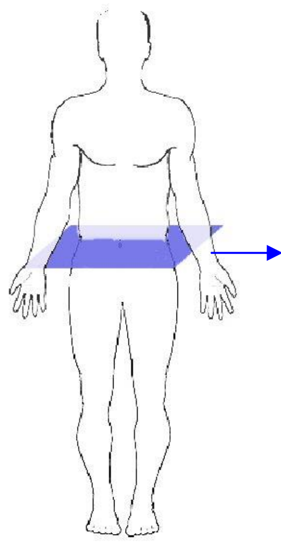


- Superficial or Deep are used to describe organs with respect to the surface of the body
- Ventral (especially related to Chest) is sometimes used for anterior
- Volar (especially related to hand or wrist) is sometimes used for anterior
- Rostral is used in the head to describe the position of a structure with respect to the nose (the front of the head)
- Dorsal is another word for posterior
- Ipsilateral on the same side of the body
- Contralateral on the opposite side of the body



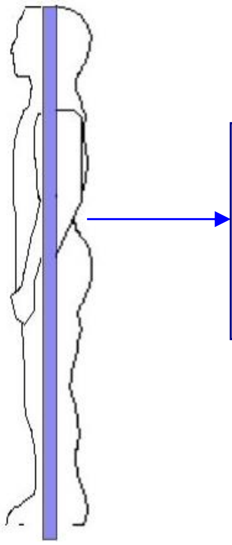
- Longitudinal is the plane along the vertical (long) axis of the body, also called Sagittal or Parasagittal
- Median Sagittal Plane is the midline of the body

Sagittal Plane
Longitudinal Plane Median Sagittal Plane (Midline)



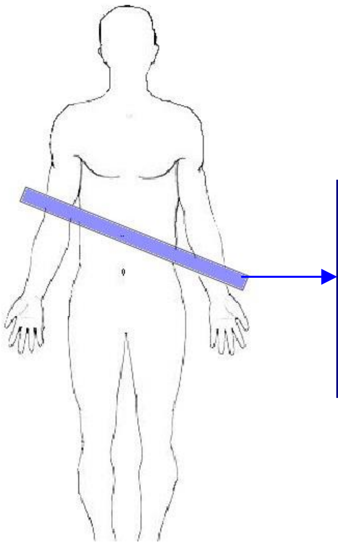
- Transverse Plane is the plane along the horizontal or short axis of the body, may also be called the axial plane

Transverse Plane
Horizontal or Axial Plane



- Coronal plane divides the body into anterior and posterior

Coronal Plane



- Oblique plane is at an angle to both the horizontal and vertical planes

Oblique Plane

Scan Planes are always noted on images in relation to the organ being scanned

Examples include:

- a scan plane which is longitudinal to the kidney would be an oblique plane to the body
- a transverse or oblique plane of the body would show the longitudinal axis of the pancreas
- a longitudinal view of the Subclavian Artery would be transverse to the body

Glossary of Terms

Absorption	transfer of some of the beam energy to the tissue through which it is traveling, this transfer of energy causes some tissue heating to occur
Acoustic Enhancement	through transmission - structures distal to a fluid filled structure appear brighter than neighbouring similar tissue
Acoustic Impedance	density of tissue times the speed of sound in tissue
Aliasing	if the sampling frequency is not at least twice the Doppler shift being measured, the spectral display will not be an accurate representation of the shift – the signal will 'wrap around' the display and be written in an incorrect location
Amplitude	strength of the sound wave, measured in Decibels
Anechoic	no internal echoes
Angle of Incidence	angle at which the ultrasound beam strikes a structure
Anterior	Structure lying toward the front of the body (Ventral)
Attenuation	progressive weakening of the sound beam as it travels through body tissue – caused by absorption, reflection, refraction, and scattering of the ultrasound beam.
Axial resolution	resolution along the vertical axis of the ultrasound beam
Baseline	represents zero Doppler shift on the Spectral display
B-colour	colorizes the grayscale image
Beam	the shape of the volume in which the sound energy exists
Beam Profile	name given to the shape of the ultrasound beam – varying transducers and frequencies give a variation in beam shape and resolution,
Beam Width	the dimension of the ultrasound beam in the plane through which it is moving – ultrasound beams are similar to light beams, in that they do not have clearly defined edges – the intensity of the sound decreases from the centre of the beam outwards.
Beam width artifacts	are caused by the assumption that all echoes detected by the transducer have arisen from the centre of the beam.
B-Mode	brightness modulation – method of displaying the intensity of an echo by varying the brightness of a pixel to correspond to echo strength
Calipers	electronic measurement tool
Caudal	towards the feet
Cephalad	towards the head

Cineloop	system memory stores the most recent sequence of image frames, can be reviewed in freeze mode
Colour Doppler Imaging	an area of the B-Mode field of view is assessed for evidence of Doppler shifts and colour coded over those regions where a shift is detected – the colour display is superimposed on the B-mode Image. The colour is coded either red or blue as flow towards or away from the transducer.
Colour Power, Power Angio, Colour Power Angio	amplitude mapping - similar to colour Doppler imaging, but with a single colour displayed, more sensitive to low flow, no directional information is conveyed.
Comet tail artifacts	a form of reverberation artifact – focal artifacts consisting of high amplitude echoes, tapering and reducing in brightness with depth
Complex lesion	a structure that has both hyperechoic and hypoechoic echoes from structures within it
Continuous Wave Doppler	uses a continuous wave ultrasound beam. A continuous wave transducer must have two crystal elements, one for emission and the other for reception of echoes – the elements are mounted at an angle to each other so that their fields of sensitivity overlap
Contralateral	On the opposite side of the body
Contrast resolution	the capability of the system to show tissues with different echo characteristics as areas of noticeably different echogenicity on the image
Coronal	midline plane dividing the body into anterior and posterior
Critical Angle	as the angle of incidence increases, the angle of refraction increases – this continues until at a certain angle of incidence, known as the critical angle, the beam is completely reflected, with no sound transmitted, and no echo from that area reaches the transducer to form an image
Critical Stenosis	haemodynamically significant – lesion which narrows the lumen of the vessel and results in a drop in pressure and flow
Crystal	active part of the transducer which converts electrical energy to sound waves and vice versa
Curved Linear Transducer	curved Array – Linear array transducer with a curved scan head
Cycle	frequency per second at which the ultrasound crystal vibrates.
Damping Material	material attached to the back of the transducer crystal to decrease the ring-time
Decibel (dB)	unit of intensity of amplitude of sound waves
Decubitus	Plane when patient lying on the side – left side up is right decubitus position
Depth control	varies the depth to which the echoes are displayed

Distal	away from the body (heart)
Doppler Spectral Display	a graph of the frequency of the Doppler shift (vertical axis) against time (Horizontal axis)
Dorsal	structure lying toward the back (spine) of the patient, posterior
Duplex Doppler	commonly used to refer to a combination of real-time B-Mode imaging with a Pulsed Doppler Display
Dynamic Focusing	ability to select focal zones at different depths throughout the image – as the number of focal zones increases, the frame rate decreases.
Dynamic Range	range of intensity from largest to smallest echo the system can process, the greater the dynamic range the more shades of grey are displayed, the lower the dynamic range the fewer shades of grey shown
Echogenic	increased brightness of echoes from a structure
Echogenicity	the intensity of the echoes returning from a structure – may be increased (brighter) – hyperechoic, or decreased (darker) - hypoechoic
Echolucent	no internal echoes, similar to anechoic
Echopenic	only a few echoes within a structure
Echotexture	the echo pattern returned from within an organ (smooth and even – homogenous, or irregular – heterogeneous)
Field of View	area of patient displayed as an ultrasound image
Focal Zone	depth of sound beam where resolution is highest
Focusing	act of narrowing a portion of the beam – this increases resolution within the narrowed region.
Footprint	size of the portion of the transducer which is in contact with the patient
Frame Rate (Image Rate)	Rate at which the image is refreshed in a real-time system display (usually set at around 30 frames per second for a flicker free image)
Frauhofer Zone	far field – area of divergence of the beam
Freeze	control that stops the moving real-time image for measurement or evaluation
Frequency	number of wavelengths per second, measured in Hertz
Fresnel Zone	near field – area of beam closest to the transducer
Gain	regulates the degree of amplification of all echoes within the image (brightness of the image)
Grating artifact	curvilinear artifact seen with linear arrays, on one or other side of a strong interface
Grey scale	number of shades of grey visible on the ultrasound image
Hertz	standard unit of frequency

Heterogeneous	the echo pattern from a structure of uneven composition of tissue types
Homogenous	the echo pattern from a structure of even and uniform composition (describes a smooth even shade of grey throughout an organ such as the liver)
Hyperechoic	strong echoes (bright white on display)
Hypoechoic	low level or reduced echoes (darker grey on display)
Insonate	to expose to ultrasound waves
Interface	border between two tissues of different acoustic impedance (more pronounced echo when the sound beam impacts it at 90°)
Ipsilateral	same side of the body
Isoechoic	having the same echogenicity as a neighbouring area, but not necessarily the same tissue structure
Lateral	away from the midline
Lateral Resolution	resolution perpendicular to the ultrasound beam
Linear Array	transducer with many small electronically co-ordinated elements – producing a rectangular image
Longitudinal	plane along the long axis of the body (Sagittal)
Main Bang Artifact	high level echoes at the skin surface
Matching Layer	minimizes the difference in acoustic impedance between the transducer crystal and the skin
Mechanical Array	physical movement of the element within the transducer housing
Medial	towards the midline
Mirror image artifacts	these artifacts result in a mirror image of a structure in the ultrasound display – the structure is displayed twice with one image being a mirror image of the other – caused when where is a high impedance mismatch curved specular reflector
Misregistration	incorrect placement of an echo within an image
M-Mode	Motion Mode – used in cardiac imaging to trace movements of the tissue
Multipath artifacts	are the result of the machine assumption that the echoes return directly to the transducer after reflection
Noise	artifactual echoes resulting from too much gain
Parasagittal	median sagittal plane
Persistence	duration of time that the image persists on the screen. This is the control that allows the accumulation of echo information over a longer period of time (almost like a blending of the image)

Phased Array	electronically steered system – to produce a focused wave front
Piezoelectric Effect	effect caused by crystals changing shape when a voltage is applied, which can generate a sound wave, and vice versa
Prone	lying on the stomach
Proximal	closer to the body (heart)
Post processing	image functions which may be changed after image acquisition
Power (Acoustic)	quantity of energy generated by the transducer – expressed in Watts.
Preprocessing	functions used prior to image acquisition – cannot be altered after freezing
Probe	Ultrasound Transducer - used interchangeably
Pulse Repetition Frequency	the number of Pulses emitted by the transducer each second (Doppler application)
Pulsed Wave Doppler	pulses of ultrasound are sent into the tissue and a measurement of the Doppler shift of moving echoes within the vessels is acquired and displayed as a spectral waveform
Range Ambiguity	if a large Doppler sample volume is used a wide range of signals from within that volume will be received, common in continuous wave Doppler applications
Read-Zoom	zoom function allows for magnification of the image by increasing the pixel size – this degrades the resolution of the image
Reflection artifacts	caused by deviation of the beam from a straight path – the echoes are written incorrectly within the image
Refraction artifacts	occur when the ultrasound beam strikes a reflector at an angle other than 90° - the transmitted component of the beam deviates from the original path
Resolution	ability of the ultrasound machine to distinguish between two adjacent anatomical structures and display them as being separate
Reverberation	artifact which results from a strong echo retuning from a large acoustic interface to the transducer, the echo is reflected back into the tissues, causing additional echoes parallel to the first, reducing in intensity
Ring-Down artifact	extreme form of reverberation artifact, occurs when a long series of echoes caused by a very strong acoustic interface are seen
Ring-Time	length of time that a transducer crystal vibrates after it has been activated
Rostral	is used in the head to describe the position of a structure with respect to the nose

Sample Volume	(range gate) this controls the length of time the receive gate remains open when acquiring a spectral Doppler trace, this is represented on the image as a small box along the Doppler line of sight
Sector Scanner	transducer with a small head, produces a wedge shaped image
Shadowing	failure of the sound beam to pass through an object – no echoes are returned from structures deep to the object
Scattering	occurs at interfaces throughout the beam path- the pattern of scattering relies on the size of the interface relative to the wavelength
Side Lobe artifacts	the energy radiated from an ultrasound transducer is not confined to a single lobe, some of the sound radiates at various angles to the transducer face as off-axis energy known as side lobes, just as the main lobe is three dimensional, so are the side lobes, echoes are generated by side lobes in a similar fashion to the echoes which are generated by the main beam, the ultrasound machine interprets these echoes as being within the main beam
Slice thickness	width of the ultrasound beam at 90° to the scan plane
Slice thickness artifacts	are very similar to beamwidth artifacts as they occur due to the finite dimensions of the beam – these artifacts are the equivalent of the partial volume effects that occur in CT scanning
Slide Pots	the TGC controls can be adjusted in small increments with the use of the slide pots on the ultrasound machine console. The top slide pot corresponds to the top portion of the image; the bottom slide pot corresponds to the deep portion of the image, regardless of depth of field of view used.
Sonographer	a health professional who is qualified and accredited to perform ultrasound examinations
Sonolucent	without echoes – similar to echolucent, or echopenic
Spectral Invert	the Doppler display is configured to show flow towards the transducer colour coded as red, and place the spectral trace above the horizontal line in the display, and flow away from the transducer colour coded as blue, with the spectral trace below the line: this can be inverted by the operator, so that all arterial signals are red, and the trace displayed above the baseline.
Specular Reflector	reflection from a smooth surface at 90° to the ultrasound beam – strong reflection because of the angle of incidence of the ultrasound beam.
Superficial	close to surface of the body
Supine	lying on the back
Temporal resolution	ability to accurately show changes in the image over time

TGC – Time Gain Compensation	control which compensates for the attenuation of the sound beam as it passes through tissue
Transducer (Probe)	used to refer to the crystal and the surrounding housing – device which converts energy from one form to another
Transverse	plane across the short axis of the body
Velocity	speed of the wave, with direction specified
Ventral	structure lying toward the front (sternum) of the patient
Volar	sometimes used for anterior (esp in respect to the hand)
Wall Filter	a variable frequency threshold which determines the slowest flow (lowest Doppler shift) which will be displayed.
Wavelength	distance the sound wave travels in a single cycle (the higher the frequency, the shorter the wavelength)
Write Zoom	high Resolution Zoom function – a box is placed on the screen and the area within can be expanded to fill the screen, the number of scan lines remains the same and the lines of sight are reallocated so that the image is a true magnification of the area without loss of resolution
Zoom	zoom function allows for magnification of the image – can be either Read-Zoom, or Write Zoom

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- Gent, R 1997, Applied Physics and Technology of Diagnostic Ultrasound
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