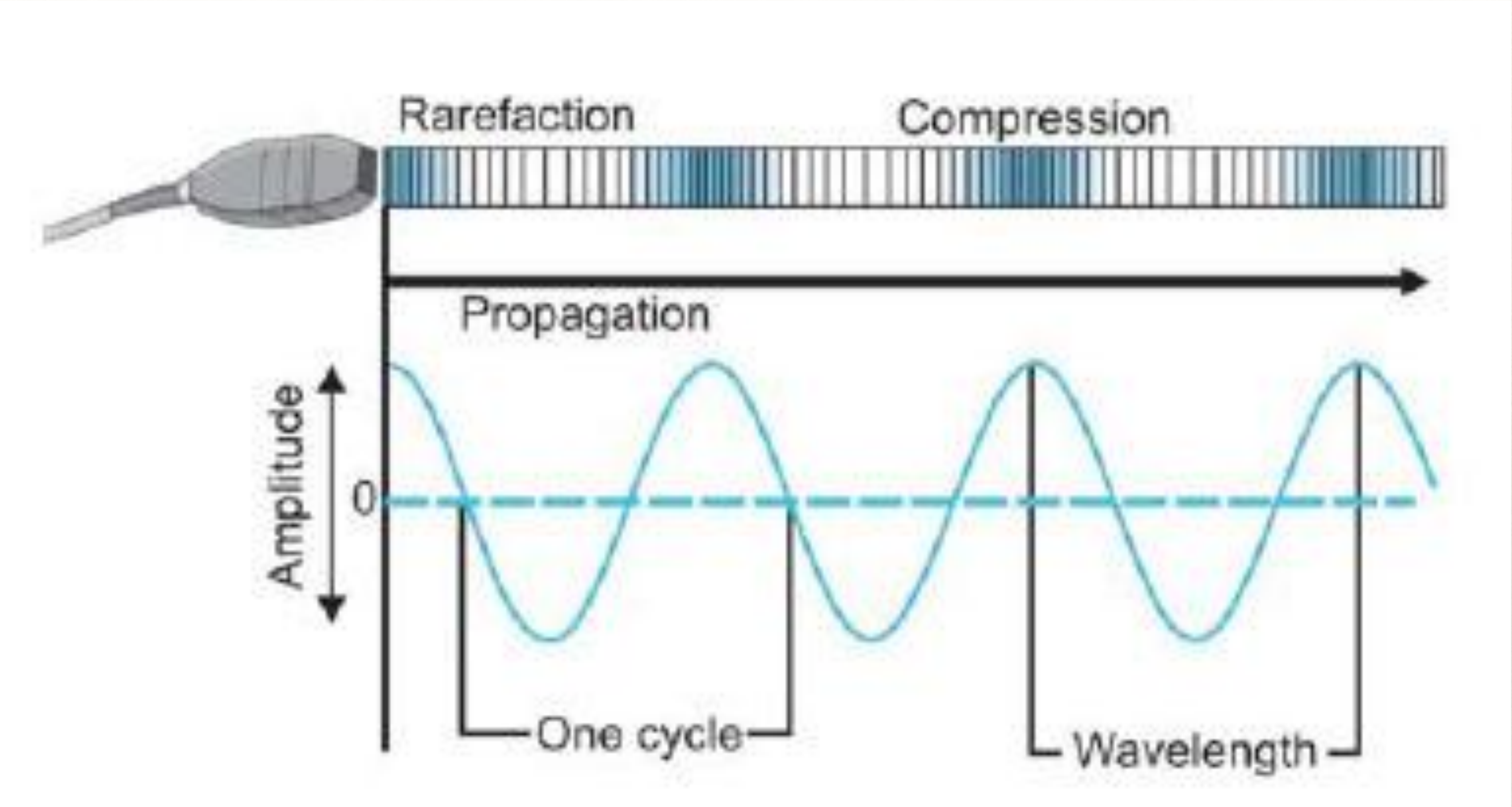
Ultrasound Physics in Echo

Echocardiography.

Anthony Ryan
Chief Cardiac Physiologist
Sligo University Hospital

Basic Physics of Ultrasound

- US is a form of *mechanical energy* transmitted by pressure waves through a medium-solid/liquid/gas.
- It occurs as a result of mechanical vibrations of molecules (*rarefaction* compression waves) as they are propagated through the medium, disturbing it from it from its steady-state equilibrium.
- Sound waves arising from vibrating objects (piezo-electrical crystals) are composed of areas of *compression* and *rarefaction* that propagate through a medium.


Rarefaction
Compression
Propagation
Amplitude
0
One cycle
Wavelength

Basic acoustic parameters

- Cycle duration measured in microseconds
- Wavelength, measured in millimetres (mm)
- Frequency, measured in mega Hertz (MHz)
- Propagation velocity, measured in metres/second.
- Amplitude, measured in decibels (dB)
- Power, measured in Watts
- Intensity, measured in Watts/centimetere squared

Basic Physics

- A cycle is the time taken for completion of a peak to peak (or trough to trough) movement of the sound wave.
- The distance the sound travels in one wavelength (mm)
- Frequency (Hz) is the number of cycles per second, and is the reciprocal of the cycle (period).
- Ultrasound has frequencies > 20KHz, and is inaudible to the human ear.
- The velocity of sound through soft tissue is 1540 m/s

Amplitude

- The amplitude relates to the ability of ultrasound to transmit energy, where power / intensity is proportional to the amplitude squared.
- US waves are described in terms of their *frequency, wavelength,* propagation velocity and *amplitude* are important to optimise US images.
- Equation: **velocity = frequency x wavelength.**
- Higher frequencies will result in *shorter* wavelengths.
- The wavelength determines both the *spatial resolution* of images
- and the *penetration* of US beams (depth)

wavelength

- Shorter wavelengths allow for an image with a higher resolution, but the penetration is poor.
- Longer wavelengths (abdominal US) will penetrate further but less detail.
- Echo frequencies are between 1.5 and 7.5 MHz, usually 3.5 MHz in adults.

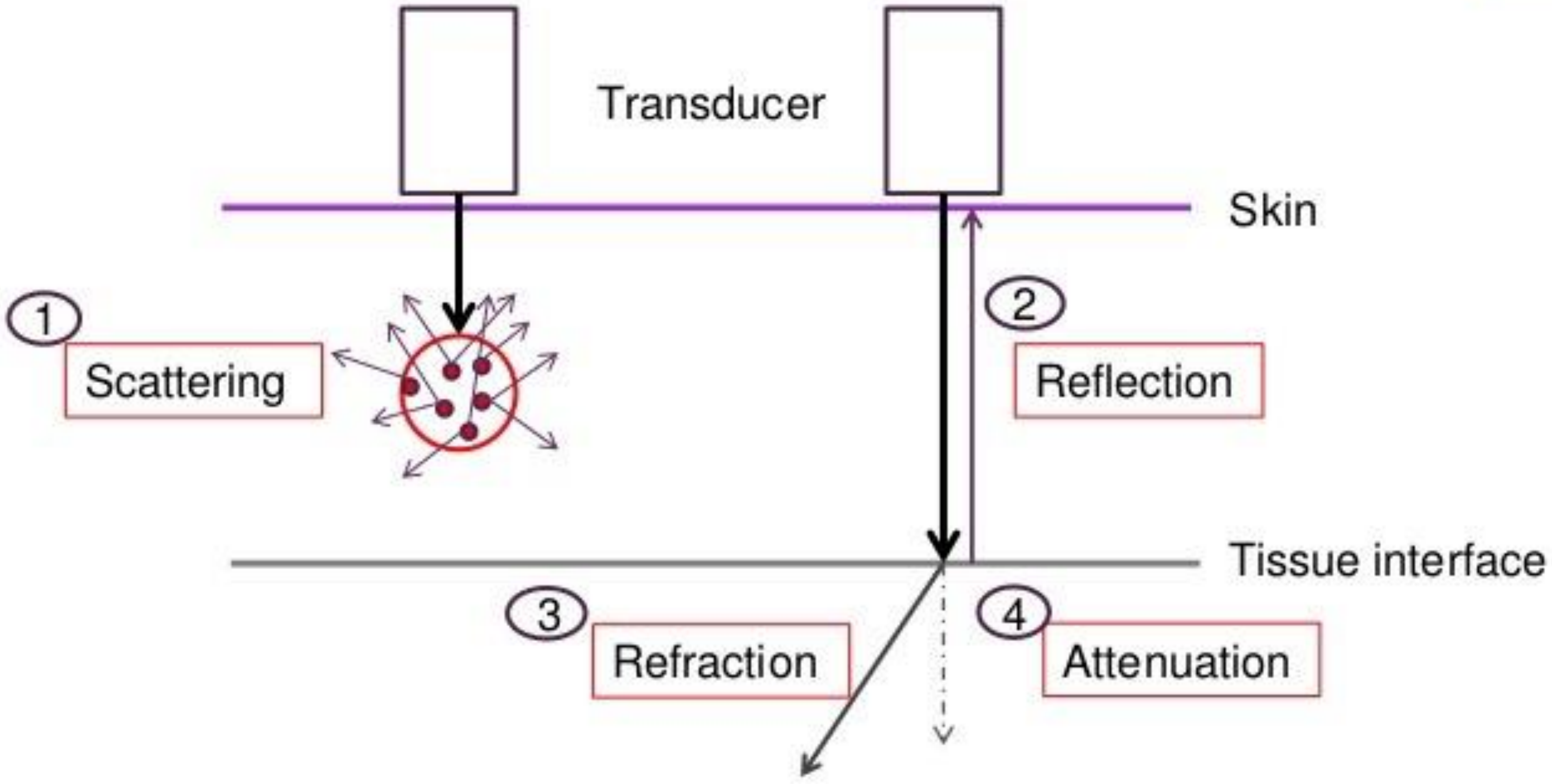
Attenuation (dB)

- As US propagates through a medium it releases some of its energy in the form of heat and tissue vibration, resulting in a progressive *reduction in amplitude.*
- The higher the frequency of the wave, the more energy will be released, *resulting in a higher attenuation* coefficient (decrease in amplitude / cm of propagation.

Reflection

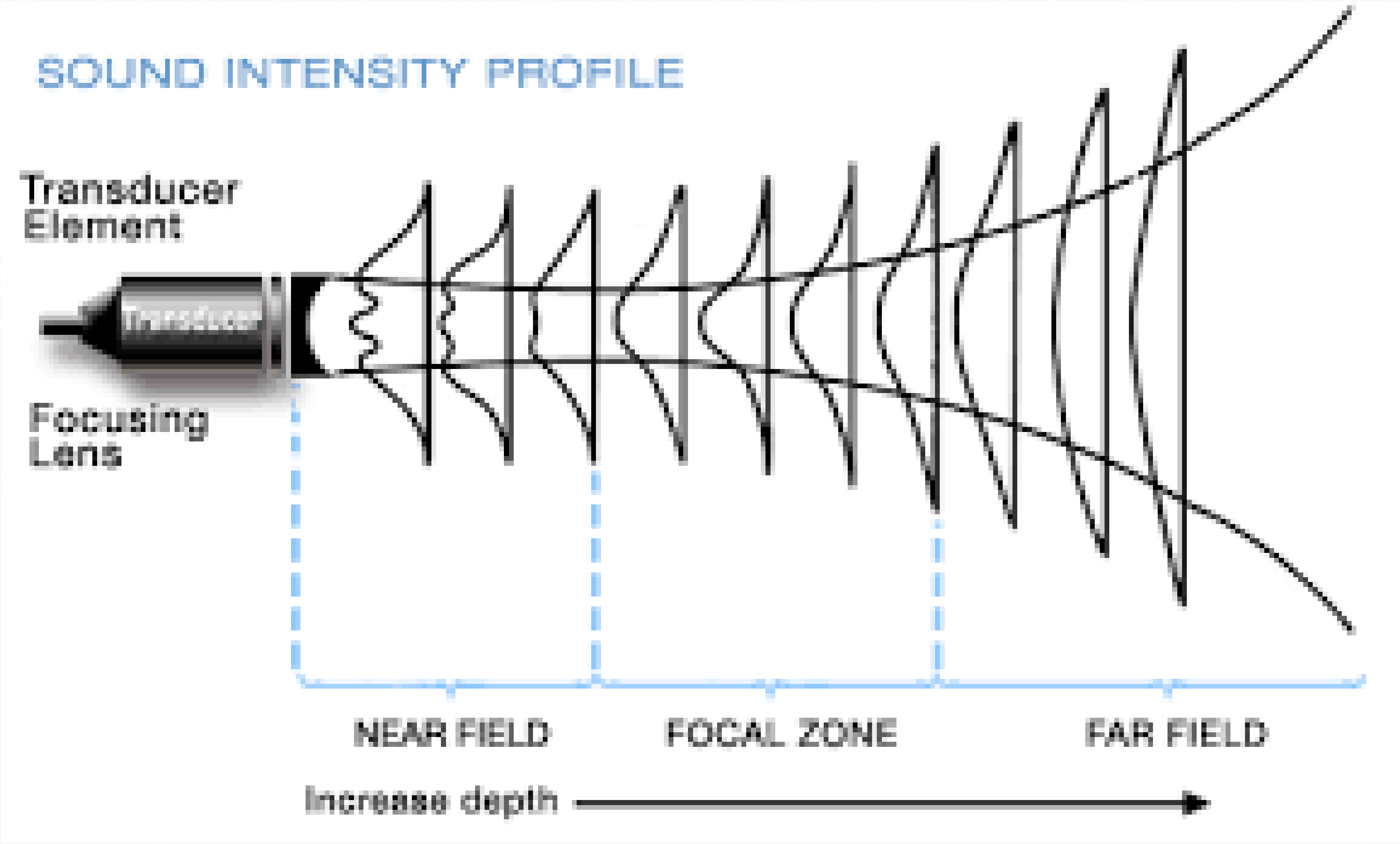
- When US passes through a uniform medium it maintains its initial direction and is progressively absorbed or scattered. Thus attenuation of the beam with distance travelled. when it arrives at a boundary with a different medium (air/fluid/ tissue) some of the wave is reflected back to the US transducer, results in image formation. The amount of reflection depends on the *reflectivity* of the tissue boundary (acoustic impedance). Minimum distances between boundaries is known as *axial resolution*, usually 0.5mm which can not be > 2 wavelengths .

Ultrasound/tissue interaction



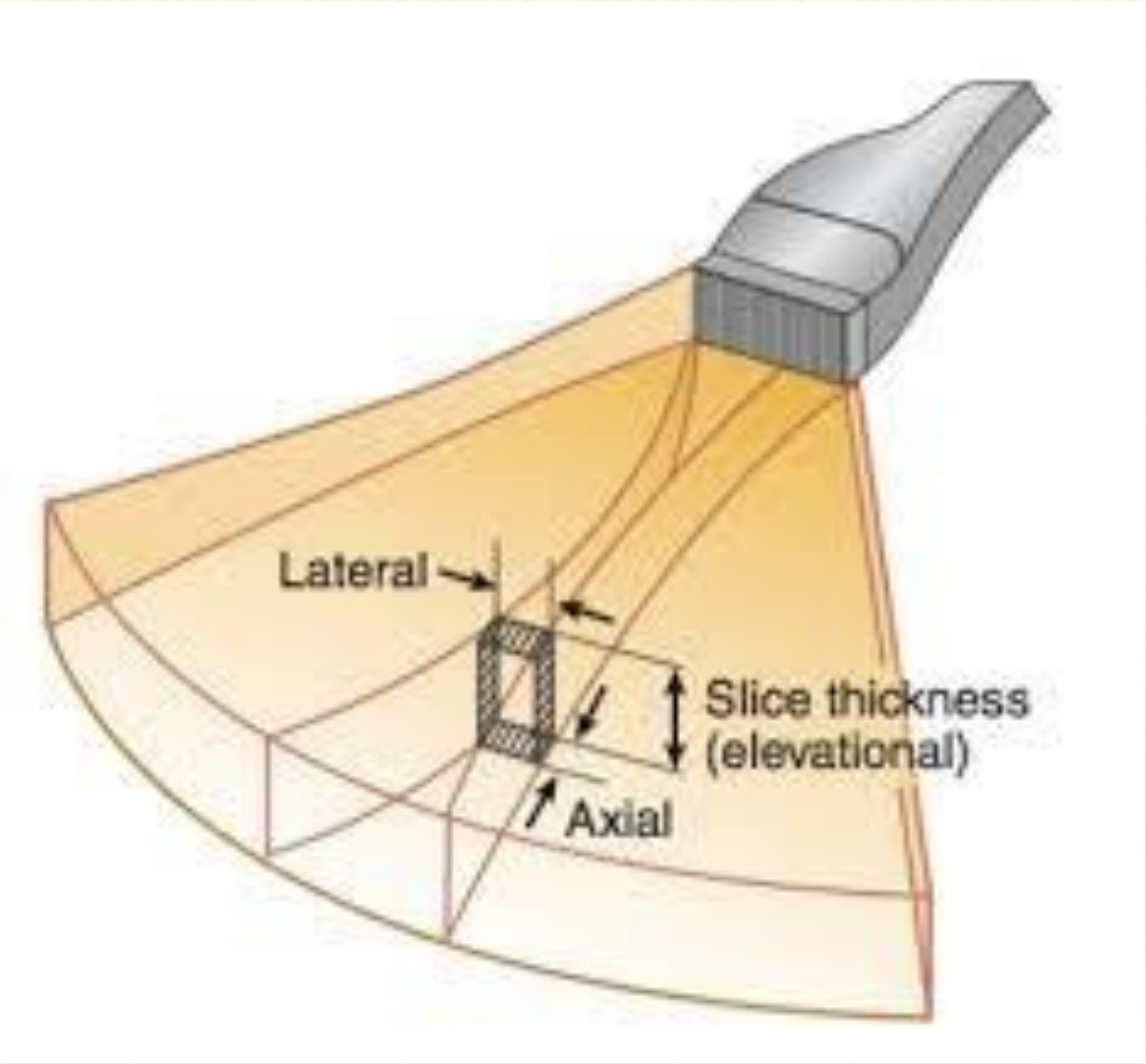
Refraction

- When US reaches a tissue boundary at an oblique incident angle, transmission with a change in direction occurs (*refraction*). This is similar to light waves bending when passing from air to water.
- Focus: US can be focused and directed in manner similar to light, providing US beam with a typical hourglass appearance, and the narrowest point being known as the focal point. This enables discrimination between two side by side boundaries (*lateral resolution*)

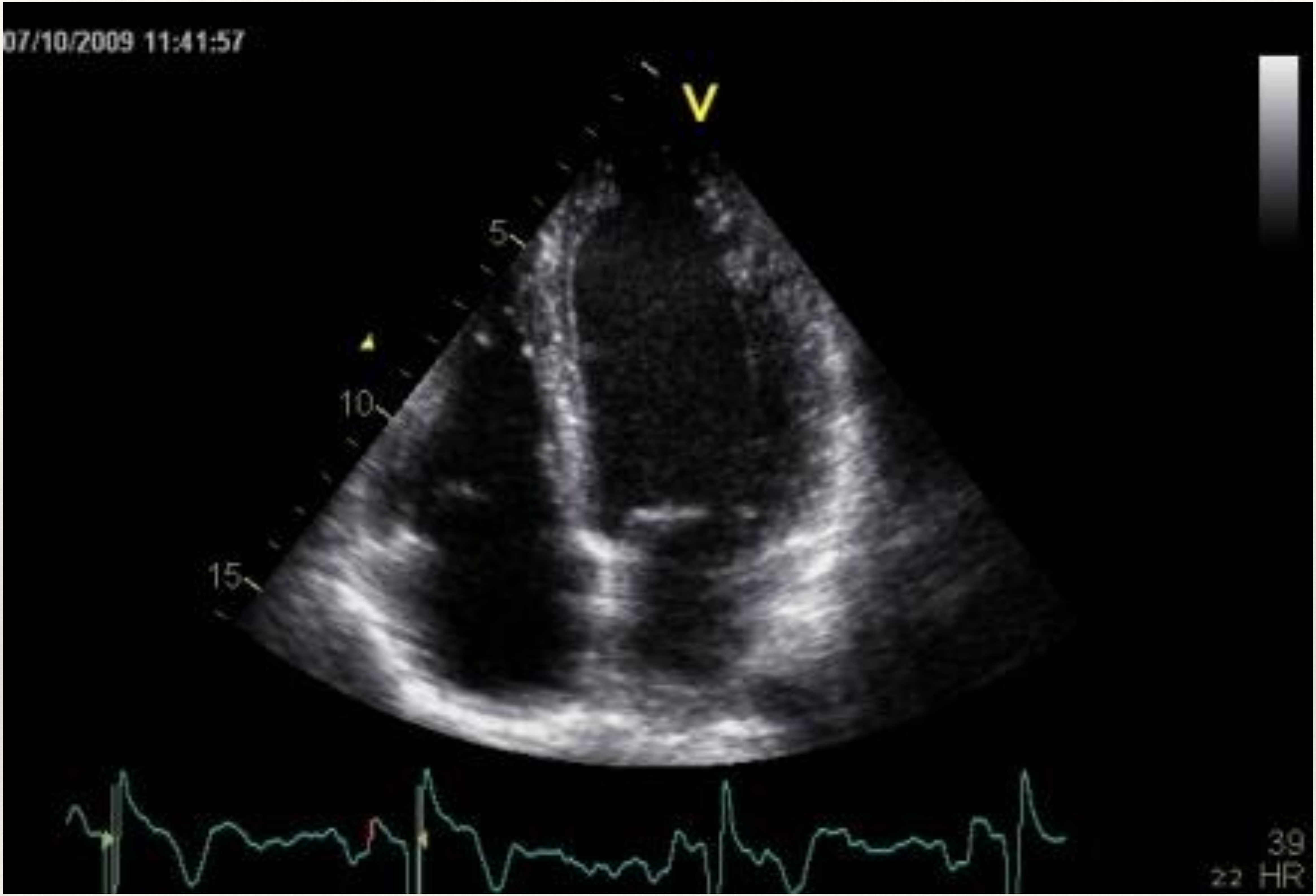

SOUND INTENSITY PROFILE
Transducer Element
Transducer
Focusing Lens
NEAR FIELD
FOCAL ZONE
FAR FIELD
Increase depth

Formation of images using US

- US is generated by piezoelectric crystals that vibrate when compressed and decompressed and decompressed by an alternating current applied across the crystals. The same crystals act as receivers of returning, reflected US, where the vibrations induced by the returning US are processed by specialised software within the US machine and displayed as images on the screen.



Lateral
Slice thickness
(elevational)
Axial


07/10/2009 11:41:57
V
5
10
15
39
HR

Spatial,Lateral, Axial Resolution.

- Spatial and temporal resolution determine the image resolution. Axial resolution is limited by *wavelength*, and thus determined by US frequency.
- Lateral resolution is determined by the US *focus width.*
- Temporal resolution is determined by the *frame rate* and, in return by the number of scan lines per sector and the sector depth and width.
- US is defined by its acoustic properties and its interaction with different media. Basic principles of US are important to understand the images acquired and how to optimise for interpretation.

Echocardiography

Ultrasound modes and controls

Anthony Ryan
Cardiac Physiologist
Sligo University Hospital

Knobology

- How to manipulate basic US controls to optimise image quality .
- understand how two-dimensional and images are formed

Basic Settings

- to obtain optimal images, the sonographer must select the correct probe, adjust the settings, and alter key controls on the echo machine.
- machine preset
- probe selection
- depth
- sector width
- focus
- gain

machine preset

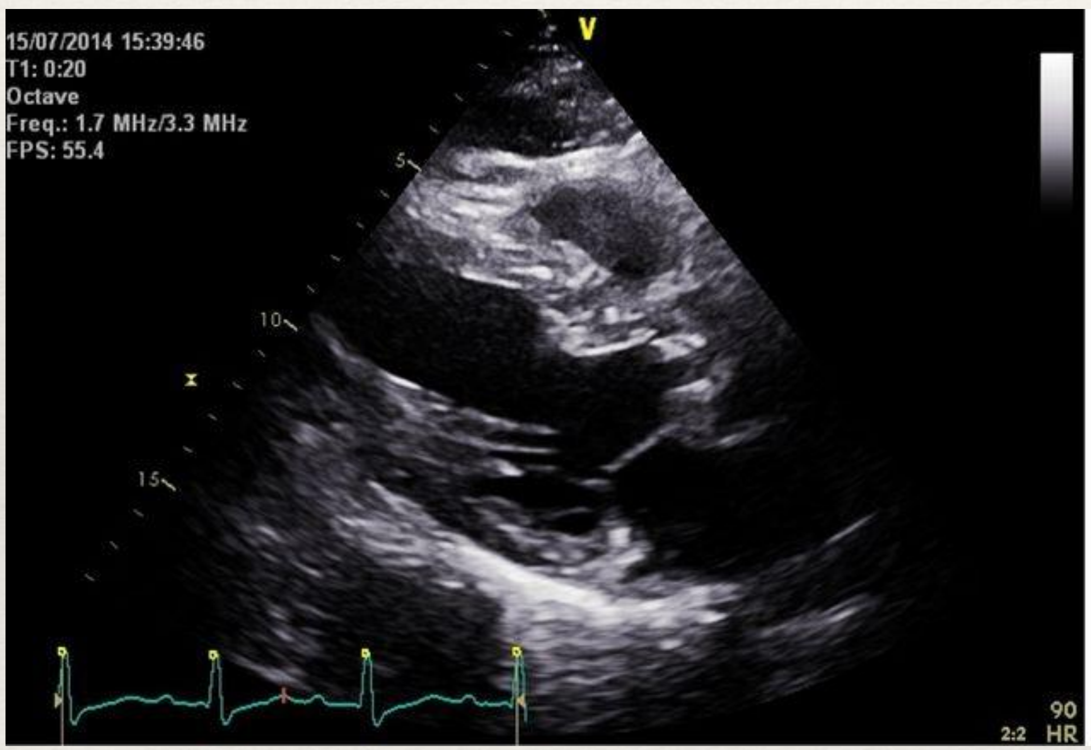
- most US machines used in ED/ICU are used by a number of people and for a range of imaging.
- prior to cardiac scanning select the cardiac preset, this will set the machine for scanning the heart of the average adult patient, with appropriate depth selection and screen orientation. It is important to check that the screen orientation marker is to the right of the display otherwise images will be reversed.

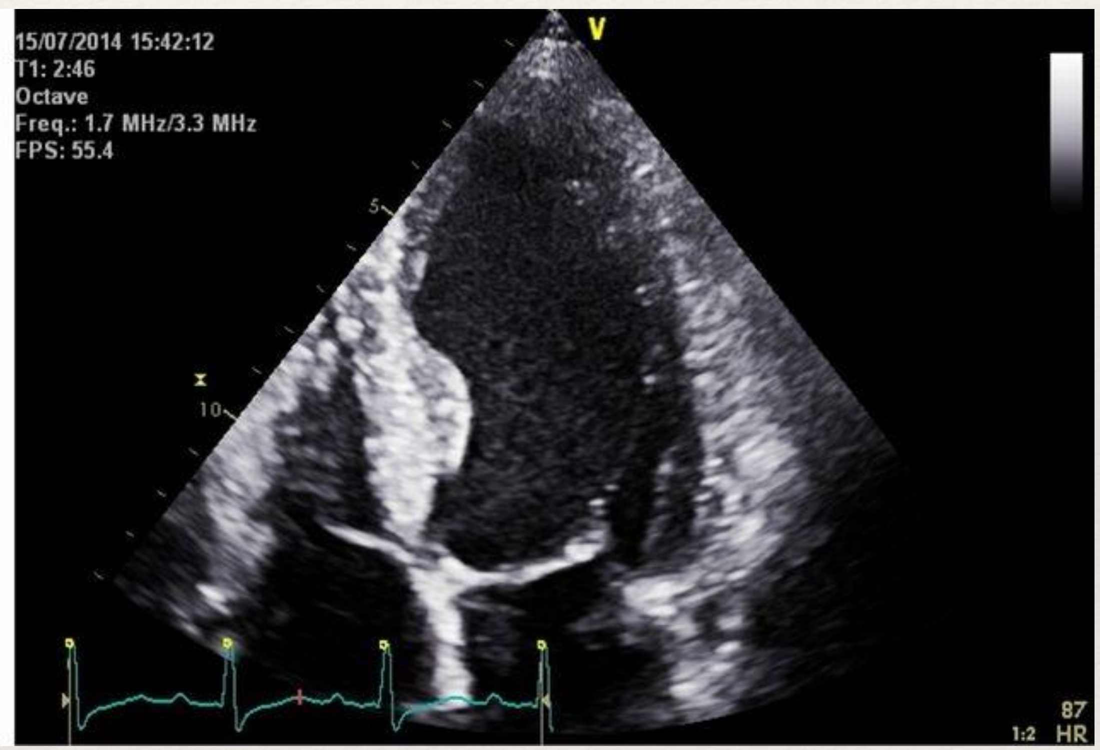
probe selection

- select the highest frequency cardiac probe that will provide imaging of the heart with adequate resolution, given the depth required (3.5MHz). If a probe of too high a frequency is selected, although the axial resolution, and proximal resolution will be high, there will be limited imaging of deeper structures due to poor penetration.

depth

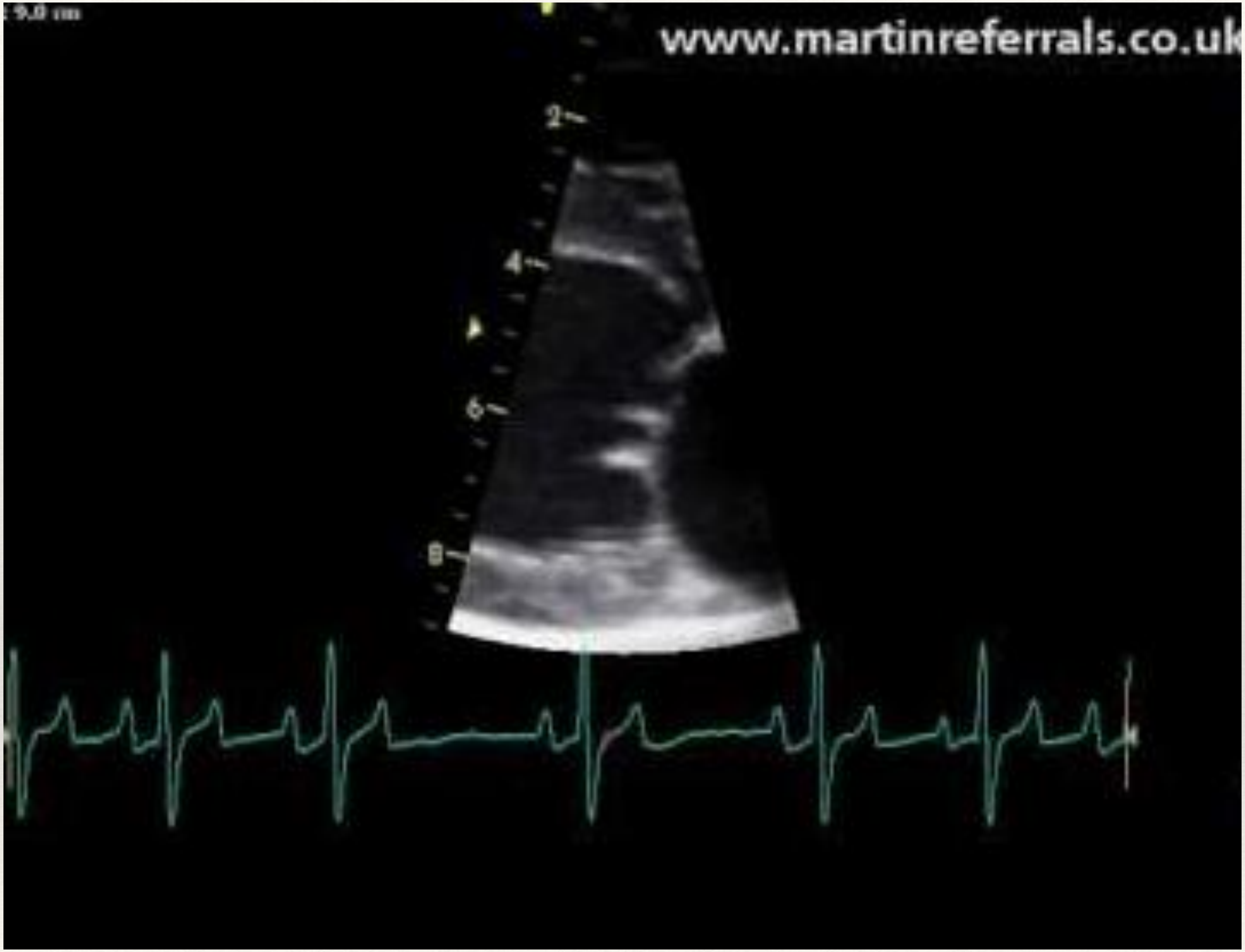
- the depth should be set according to what needs to be imaged. The depth is displayed on the side of the echo screen display. A common error when imaging subcostal images in a large patient to to underestimate the distance of the heart. Setting the excessive depth will reduce the temporal resolution.
- Imaging at the least depth possible will give the best resolution. A good starting depth is 18-20cm for subcostal views.


15/07/2014 15:39:46
T1: 0:20
Octave
Freq.: 1.7 MHz/3.3 MHz
FPS: 55.4
V
5
10
15
90
2:2
HR


15/07/2014 15:42:12
T1: 2:46
Octave
Freq.: 1.7 MHz/3.3 MHz
FPS: 55.4
V
5
10
87
1:2
HR

sector width

- this determines the number of scan lines that go to make one frame, with increasing number of scan lines reducing the *temporal resolution* (frames/sec).
- Although temporal resolution is better with a narrow sector width, in FEEL echo best practice is to start with a large sector width to allow you to see as much of the heart as possible, and then reduce the sector width if subsequent images are taken and the scenario allows.



www.martinreferrals.co.uk
2
4
6
8

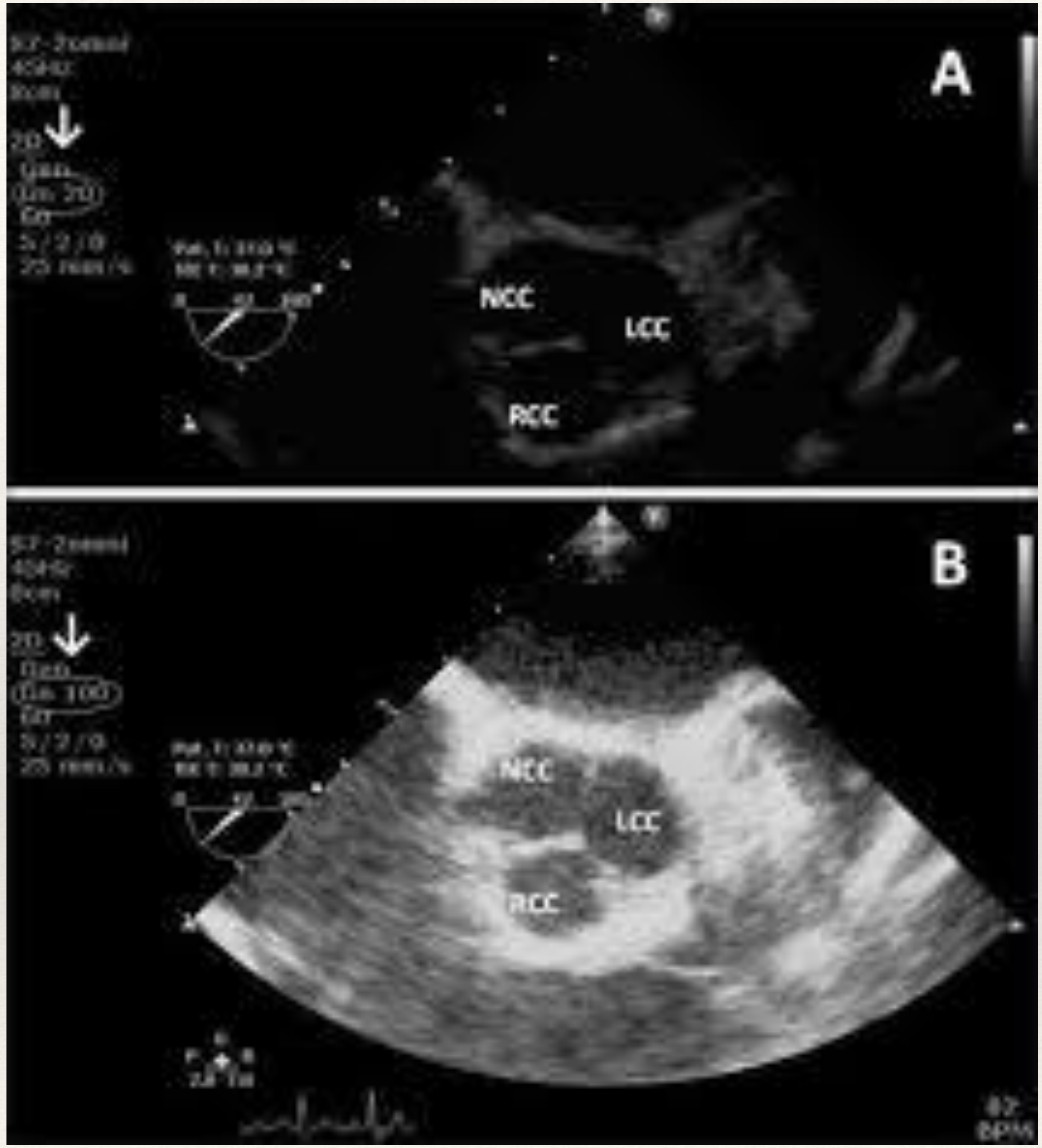
Focus

- This is displayed to the side of the echo display. In general this will not need adjusting in FEEL echo. If the depth is changed, in most US machines the focus will change accordingly. If the image is unclear it is worth reviewing where the focus position is located.

Posterior Leaflet
Left Atrium
Chordal Apparatus
Anterior Leaflet
LA Appendage
11cm
2D
C 45
P Off
Gen

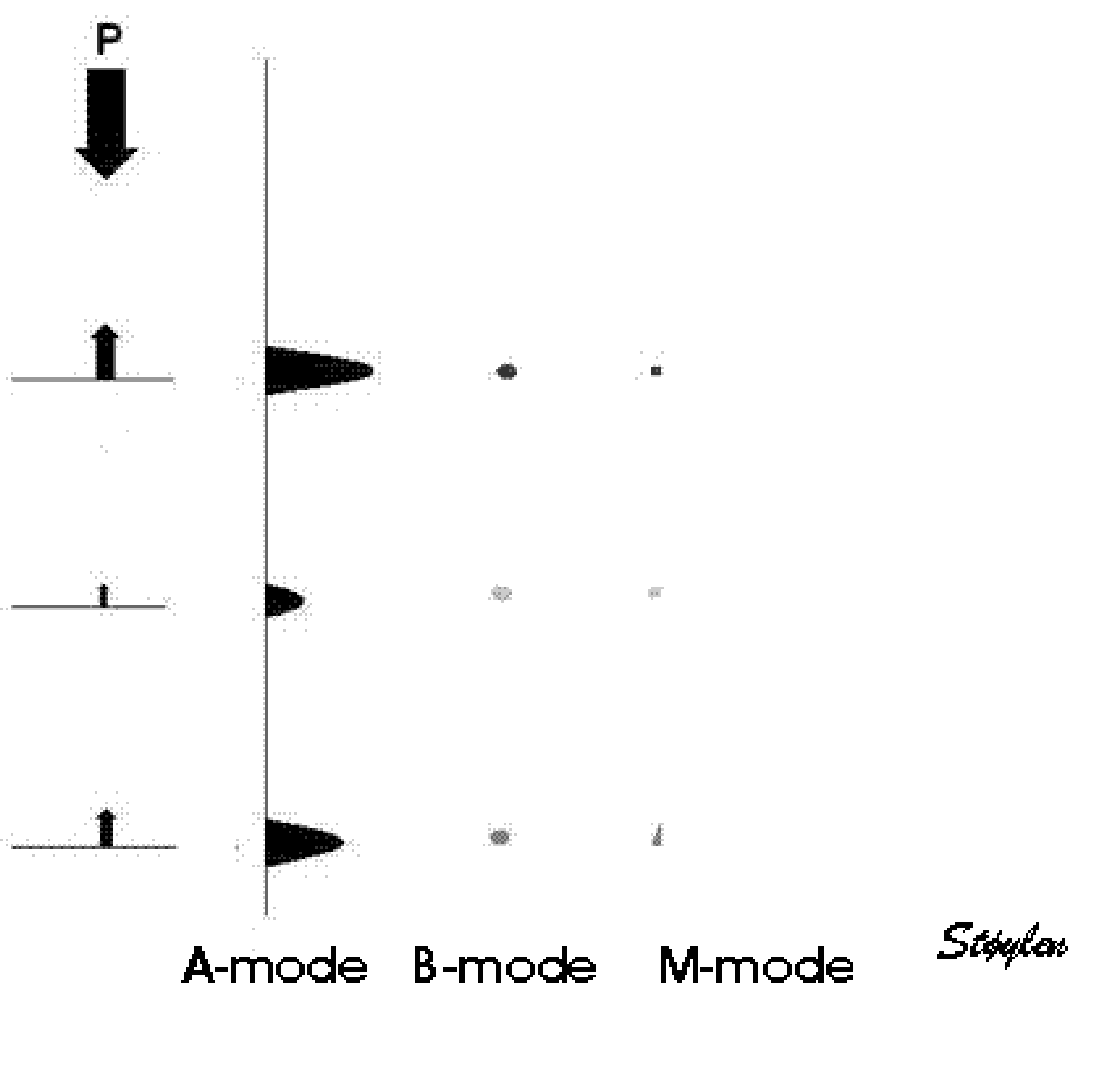
Gain

- This represents the power output from the transducer. Too little gain and the images are very dark, too much gain and the images are too light (leading to loss of tissue definition). A common error in FEEL echo is to have the gain set too high.The usual range is 50-70 dB


A
NCC
LCC
RCC
B
NCC
LCC
RCC

Ultrasound modes

- When the US pulse is emitted from the transducer, it is reflected from tissue interfaces with different acoustic impedance, the received, reflected US is then used to form the image displayed.
- A-mode: *amplitude mode*: this is a plot of returned signal amplitudes against depth
- B-mode: *Brightness mode*-plot of brightness against depth (time to signal to return)
- M-mode: *motion mode* where a plot of the brightness is shown against time (y axis)

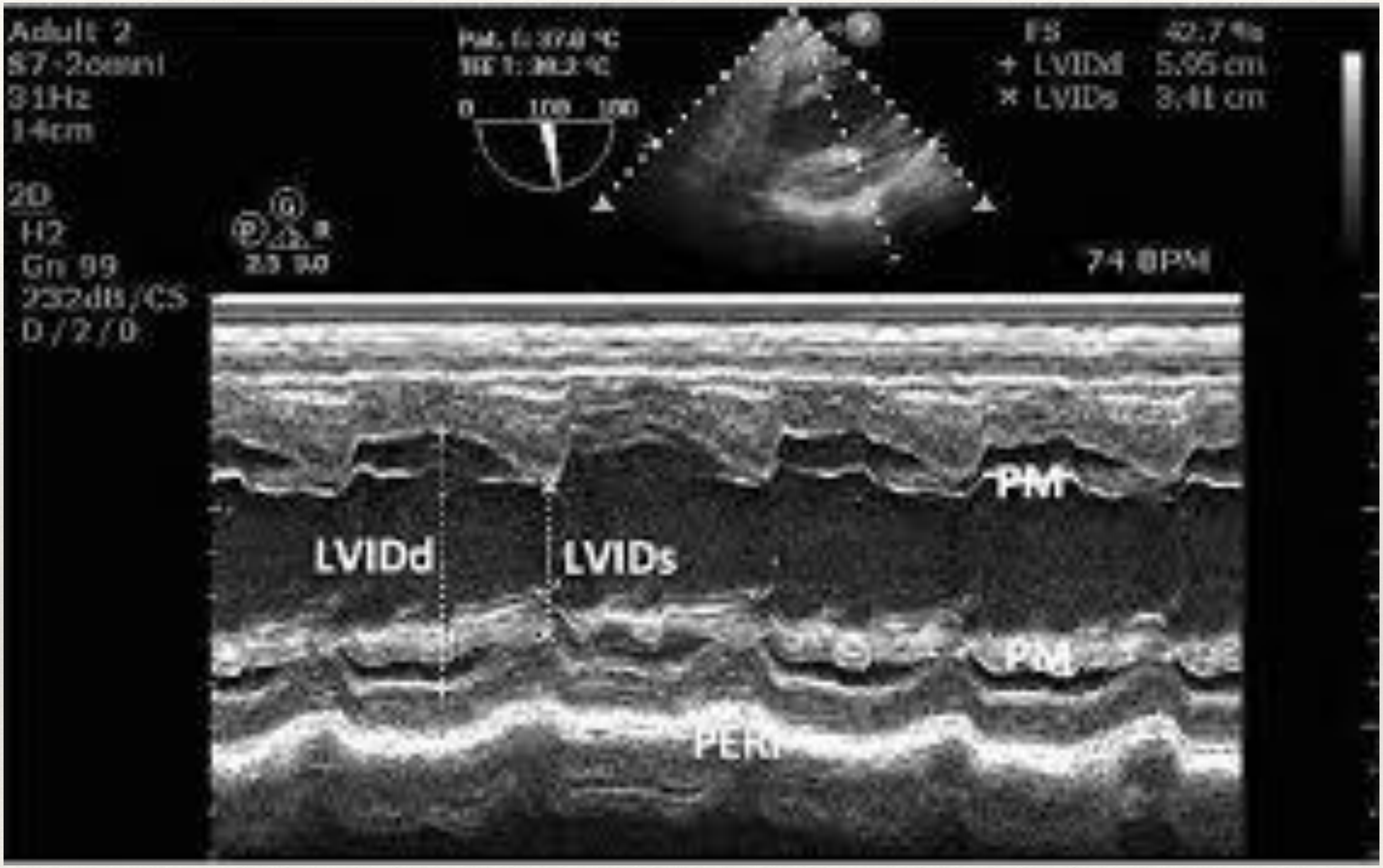

P
A-mode
B-mode
M-mode
Stylus

FEEL

- The usual imaging modality in FEEL is 2D echocardiography. In FEEL, the main use of M-mode is to estimate right ventricular function.
- **TAPSE**
- Tricuspid Annular Plane Systolic Excursion
- >16mm

M-mode echocardiography

- M-mode is derived by displaying the amplitude mode over time. Its temporal resolution means it is superior in demonstrating rapidly moving structures and timing events in the cardiac cycle. It is most frequently used for estimating FS and EF and right ventricular systolic function.


Adult 2
14cm
2D
H2
Gn 99
FS 42.7 %
+ LVIDd 5.95 cm
× LVIDs 3.41 cm
74 BPM
LVIDd
LVIDs
PM
PM
PERI

2D echo

- To display a 2D representation of the heart, repeated sweeps of M-mode scans are performed electronically , and these are reconstructed to provide real time 2D images of the scanned anatomical structures.
- In general 128 lines scanned cover 90 degree sector, with each sector generating one frame. The time to generate one 2D frame depends on the the time taken for US to make the required number of return trips. This time to generate one frame determines the frame rate and hence the temporal resolution of 2D echo images. In practice this means that since each sector scan forms one frame, the *temporal resolution is limited by the depth of scanning and the number of scan lines (sector width)*

- A number of basic controls will influence the quality of the US image obtained, and knowledge of the basic principles of US is required to be able to use these controls correctly. Most modern echo machines designed for focused studies will default to settings that are appropriate for FEEL, provided the cardiac preset is selected, together with a cardiac probe.