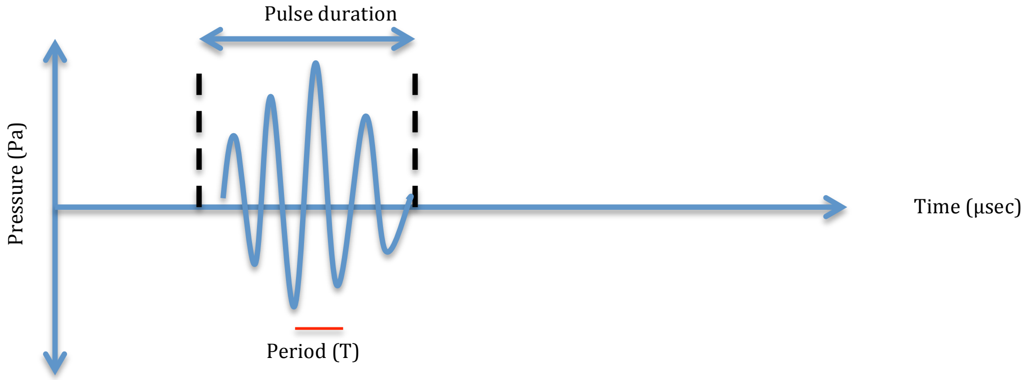
PULSED ULTRASOUND PRINCIPLES

PULSED ULTRASOUND

PULSE DURATION

Diagnostic ultrasound uses pulsed ultrasound, short duration transmits (transmit pulse) generally of 3-5 cycles in length.



We know:

$f = {}^{1}/_{T}$

Period T = time for one cycle

λ is length of one cycle

If the ultrasound pulse duration is 5 cycles and the *f= 8MHz*

Then:

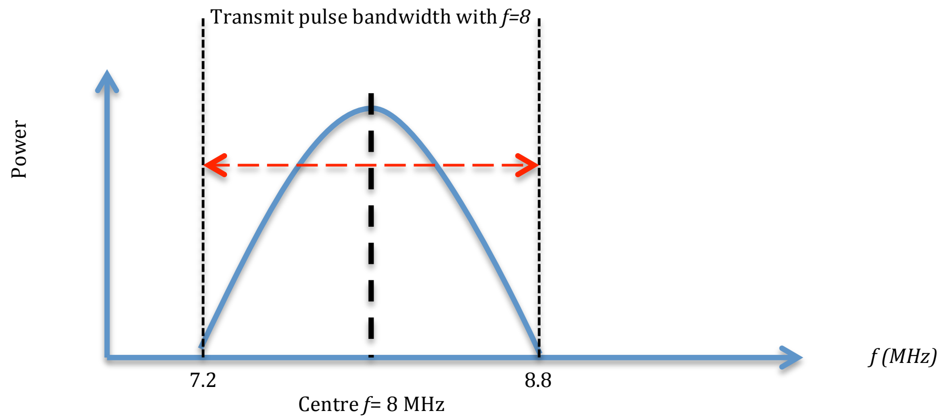
T= $^{1}/_{f}$ *= 1/8= 0.125 μsec (ie. Time for one cycle)*

The pulse duration of 5 cycles will = 5xT = 5x 0.125 = 0.625 μsec

- The echo of each transmit pulse will have the same shape and duration
- **short transmit pulses result in better axial resolution**
- **the higher the *f* the shorter the period (T) and so the pulse duration (τ) will be shorter**

BANDWIDTH

Pulses of ultrasound mathematically can be broken up into an infinite number of sinusoidal waves across a defined frequency spectrum with a bandwidth (B)



The centre *f* is 8MHz the bandwidth (B) is related to the pulse duration (τ):

$$B = {}^{1}/_{\tau}$$

If τ= 0.625 μsec then the B= 1.6 MHz

- **inverse relationship of B and τ means as the pulse duration gets shorter the bandwidth increases**

- **this is an important principle as transducers can only detect a defined limited bandwidth of frequencies, so a transmit pulse is constructed so that its frequencies fall within this**

- if transducer bandwidth is too narrow the transmit pulse becomes longer and hence leads to reduced image resolution

PULSE ECHO PRINCIPLE

The depth of an interrogated object can be determined by the time taken for the transmission of a pulse and reception of an echo by the transducer.

- **depth of an object is directly proportional to time taken for reception of the related echo**

$$t = {}^{d}/_{v\,(m/s)}$$

Where:

2d= roundpath distance
t = arrival time for an echo
c = propagation speed in tissue (this is an assumed average)

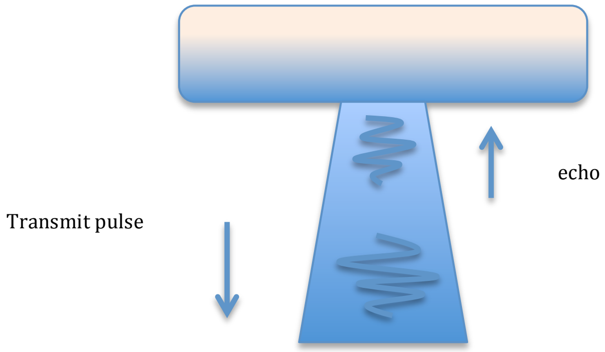
$$t = {}^{2d}/_{c}$$

Therefore:

d (depth of object)= $^{(c x t)}/_2$

PULSE REPETITION FREQUENCY (PRF)

The transducer probe must send out repeated transmit pulses along a path receiving echoes along the same path. This is repeated mulitple times to create a dynamic image. The transmit pulses and echo reception occurs along different active elements of the transducer and potentially at different angles to create and area of interrogation.



- each image (frame) requires a certain number of transmit pulses (N), and at a certain frame rate (frames/sec) to create a dynamic image

- frame rate (FR) is typically between 10-30 frames/sec (higher in echo)
- typical PRF (transmit pulses per sec) is 1-10 kHz (PFR = N x FR [Hz])

- **Frame rate and PRF are important determinants of temporal resolution**

PULSE REPETITION FREQUENCY LIMITATIONS

- **The transducer cannot transmit a pulse until detectable echoes from the last transmit pulse are diminished to being undetectable**

- this limits the potential rate of imaging
- **an increased depth of imaging will reduce PRF as we know depth of an object/field of view is directly proportional to time for the echo reception**
- breaking this rule leads to range ambiguity artifact

If imaging at 20cm and c= 1540m/s

P= max depth of imaging penetration
t= time from transmit pulse to last detectable echo of that pulse

We know:

$t = {}^{2P}/_{c}$

$t = {}^{2 \times 0.2\,(m)}/_{1540}$=260μsec (this is the shortest time between each transmit pulse)

Maximum PRF can be determined from the above shortest time between each transmit pulse

As we know:

$f = {}^{1}/_{t}$ and $t = {}^{2P}/_{c}$

$PRF \cong f$

Then the reciprocal of minimum time between transmit pulses will = maximum PRF :

$$\text{max PRF} = {}^{c}/_{2P}$$

- **as the depth of penetration increases then max PRF reduces**

- **as the time between transmit pulses increases then max PRF reduces**

FRAME RATE LIMITATIONS

FR= is the number of images/frames created per second
N= is the number of transmit pulses required to create an image
PRF = number of transmit pulses per second

Then PRF (Hz) = FR (images created per sec) x N (number transmit pulses required to create image)

$$FR = {}^{PRF}/_{N}$$

- **FR is directly proportional to PRF**

Maximum possible FR can be found by utilising substituted formula for max PRF:

$$FR = {}^{c}/_{(2P \times N)}$$

Rearranging the formula shows that frame rate, max depth penetration, and number of transmit pulses for an image, are related by a constant:

$$(FRxPxN) = {}^{c}/_{2}$$

Relative constant is propagation speed c /2

Consequentially:

- **to increase in any of the variables FR/N/P then one or both of the other variables would need to be decreased**
- **therefore FR degradation will occur when attempting to image at large depths beyond machine compensation, reducing temporal resolution**

PRINCIPLES OF IMAGE FORMATION

- Utilises **pulse echo principle** along line of sight of the beam generated.

- 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.
- the effects of attenuation; reflection, scattering, absorption, and refraction produce the returning echoes to the transducer which are converted to an image

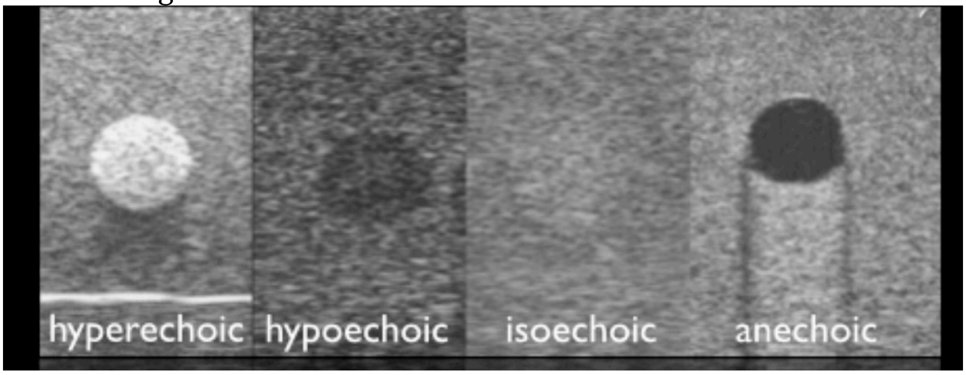
ECHOGENICITY

Echoegenicity reflects the degree of attenuation and reflection that is occurring:

- Brightness of an area in an image created is determined by the intensity of the returning echoes

- a weak echo is shown as dark grey
- a moderate echo is mid/light grey
- an intense echo is white or hyperechoic (ie. Diaphram-highly reflective)
- a lack of echo is represented as black or anechoic (ie Bladder containing urine – no reflection)

An object or areas echogenicity in an image is described relative to the surrounding echotexture:



Source: Michele Schroeder- Introduction to Ultrasound

MODES OF IMAGING

Standard ultrasound imaging uses B (Brightness) or 2D mode:

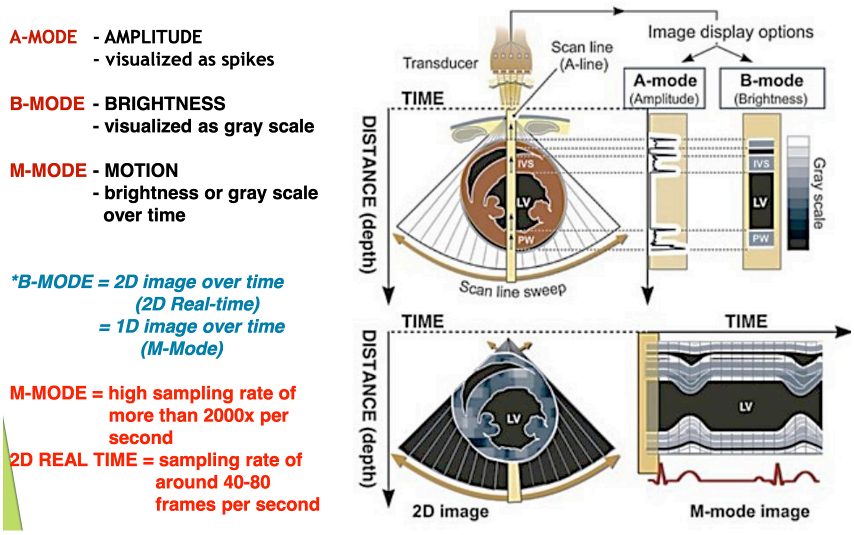
- images a volume in time repeatedly in rapid succession to create a dynamic 2D image

M-mode is a single dimension scanning:

- single fixed beam repeatedly transmiting and receiving over time
- echoes displayed on the screen from left to right over time
- this displays any change in motion of an area at depth in this fixed beam position and also speed of movement
- used commonly in echo assessing chamber size and valve function
- also used to assess foetal heart rate in early pregnancy

A-mode (amplitude):

- single fixed beam position displying echo amplitide over depth
- not utilised clinically in current scanning



Source: Josefa Paredes- Back to Basics Ultrasound (Royal Brompton Hospital)

KEY POINTS

PULSED ULTRASOUND

- Diagnostic ultrasound uses pulsed ultrasound, short duration transmits (transmit pulse) generally of 3-5 cycles in length.

- higher *f* scannning will have shorter cycle periods and therefore a shorter pulse transmit duration resulting in better axial resolution

BANDWIDTH

- Pulsed transmits are made up of a frequency spectrum of infinite sinusoidal waves around a central frequency, across a bandwidth

- as the **pulse transmit duration becomes shorter at higher frequencies the bandwidth becomes wider**

- **transducers have a limited receiving bandwidth of frequencies**

PULSE ECHO PRINCIPLE

- **Depth of an object is directly proportional to time taken for reception of a related echo**

PRF and FR

- Each image requires a certain number of transmit pulses (N), and at a certain frame rate (images/sec) to create a dynamic image

- PRF is the number of transmit pulses created per second

- **the transducer cannot transmit a pulse until detectable echoes from the last transmit pulse are diminished to being undetectable**

- increased depth of imaging will reduce PRF due to this

- FR is directly proportional to PRF

- **FR x N x PRF = constant (propagation speed/2)**

- increasing one variable will require a decrease in one or both of the others

REFERENCES

The Physics and technology of Diagnostic Ultrasound: A Practitioner's Guide. By Dr Robert Gill.Artifacts in Diagnostic

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