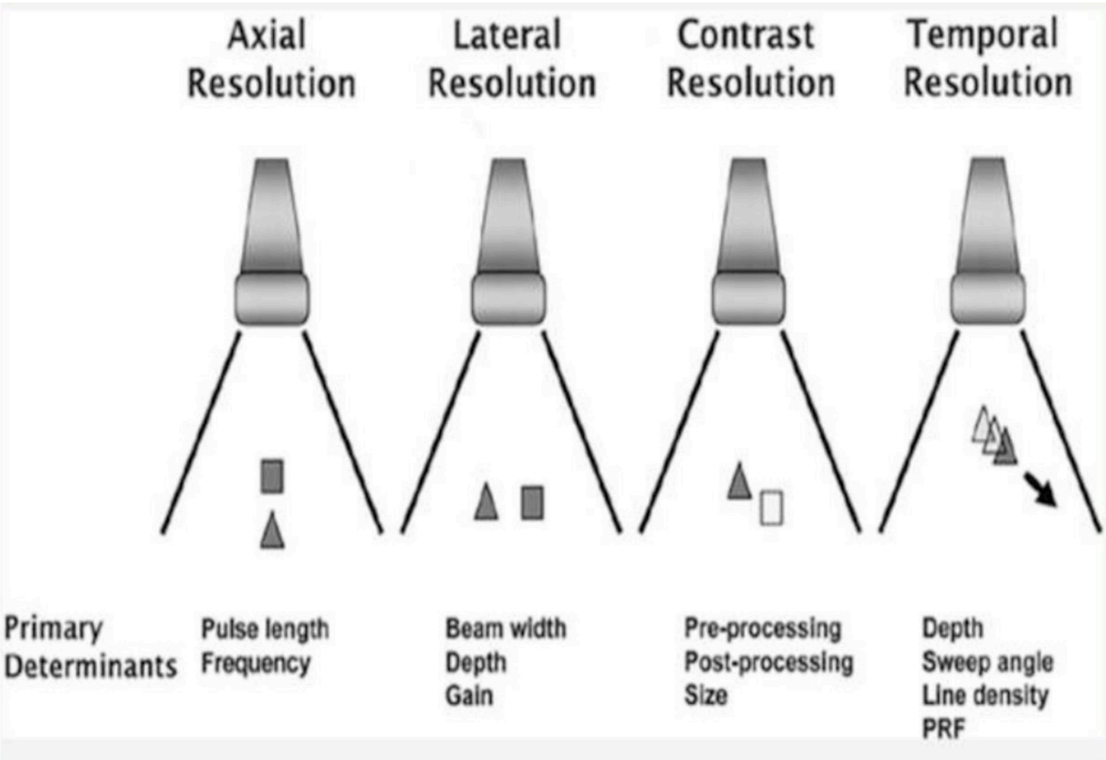
RESOLUTION

Resolution is defined, as the ability to distinguish echoes in terms of space (SPATIAL- Axial and Lateral), time (TEMPORAL) or strength (CONTRAST) and good resolution is thus critical to the production of high quality images.

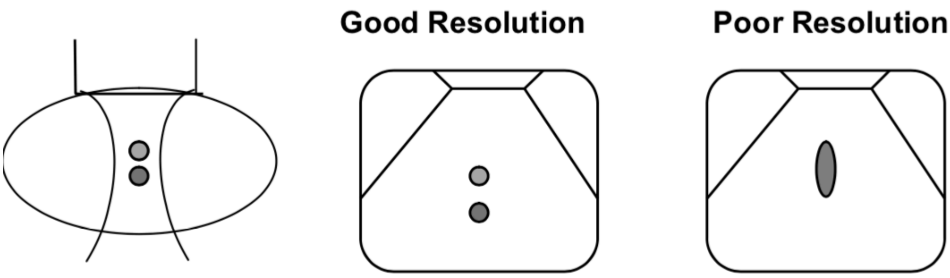


Source: Josefa Paredes- Back to Basics Ultrasound (Royal Brompton Hospital)

SPATIAL RESOLUTION

This is the ability to determine resolution between two point targets in an image and is considered in two dimensions, axial and lateral.

AXIAL RESOLUTION



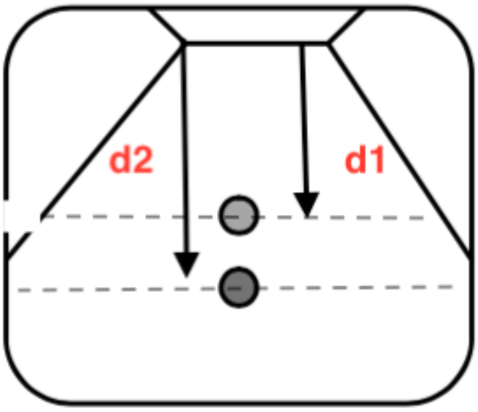
Source: Basic Principle of Ultrasound (AIU)

Ability to separate two points along the same line of sight- the minimum separation in depth that allows resolution is the axial resolution.

- The most important determinant of the axial resolution is the length of the transmit pulse used to form the beam:

- this is the spatial pulse length (SPL)
- the shorter the SPL the better the resolution

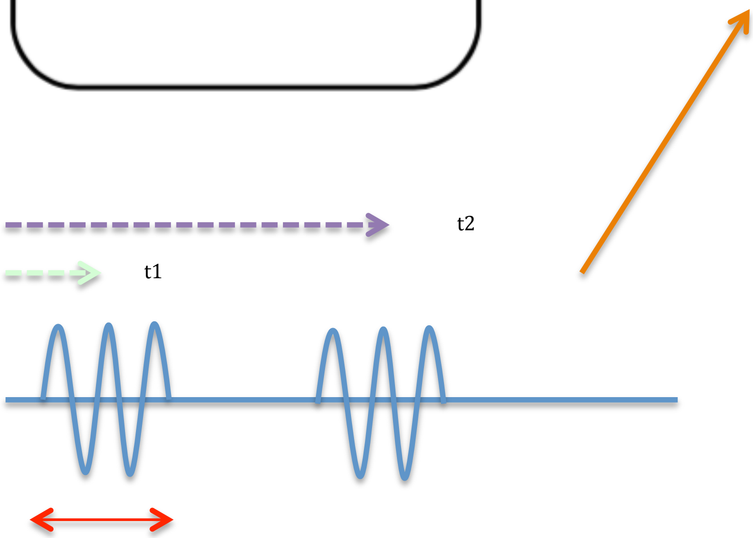
AXIAL RESOLUTION LIMIT ≈ ½ SPL



Two points along the same line of sight at depth d1 and d2 will be resolved if their echoes received do not overlap in time:

As long as the echo arrival times t1 and t2 differ by at leat τ, the transmit pulse duration then they will be resolved

$t2 - t1 > \tau$



τ= transmit pulse duration

Utilising the pulse echo principle : $t = {}^{2d}/_{c}$

Substituting this into $t2 - t1 > \tau$

$({}^{2d2}/_{c}) - ({}^{2d1}/_{c}) > \tau$

$2(d2-d1)/c > \tau$

$(d2-d1) > {}^{c\tau}/_{2}$

$c\tau \approx$ to the SPL and the AXIAL RESOLUTION LIMIT is $^{1}/_{2}$ SPL

- **The shorter the transmit pulse duration (τ) the better the axial resolution, which is achieved by:**

- Highest frequency for depth of penetration required (short τ)
- Having a broadband transducer, as bandwidth (B) is inversely proportional to transmit pulse duration (τ)

- As the transmit pulse duration is constant throughtout depth, the axial resolution is independent of the depth of imaging (Lateral resolution is dependent of depth)

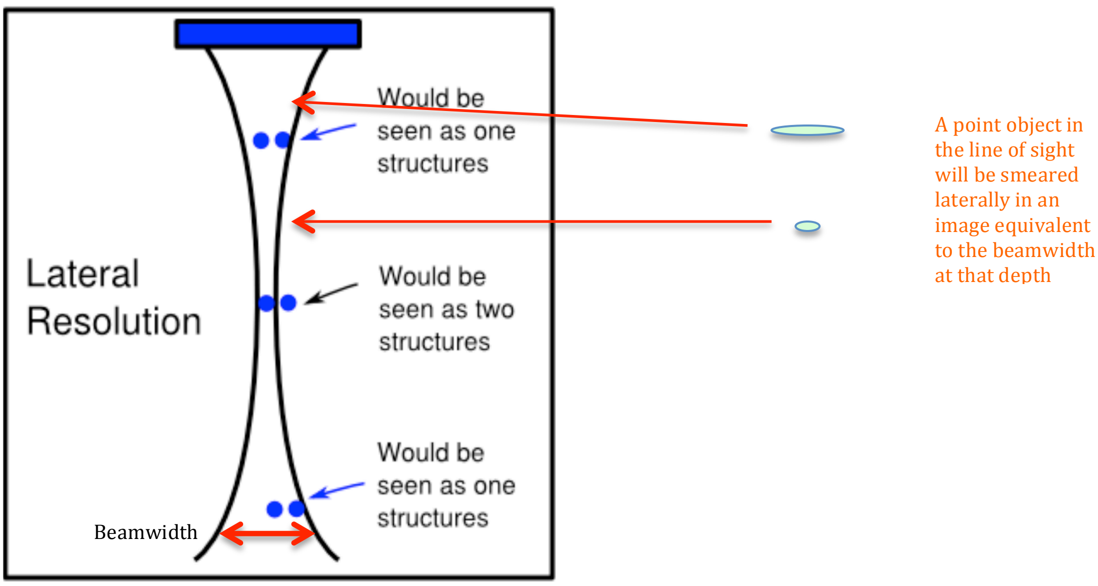
Other operator controlled determinants of axial resolution:

- ➢ Transmit power: the greater the amplitude of the voltage striking the crystal, the longer the ringing time and the longer the SPL, leading to a slight decrease in axial resolution
- ➢ Received gain settings: increases SPL 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, a smaller field of view makes best use of the available scan converter memory

LATERAL RESOLTUION

Lateral resoltion is dependent on the beamwidth at depth:

- If the lateral distance between two objects is > beamwidth at that depth then they will be resolved



Source: Josefa Paredes- Back to Basics Ultrasoiund (Royal Brommpton Hospital)

- The narrowest beamwidth at focus is achieved by using the highest frequency for depth and largest possible transducer aperture:

D = depth of focus
A= transducer aperture

$$\text{Beam width at focus} = {}^{2.44\lambda D}/_{A}$$

- Lateral resolution will be best at the focal depth ie. Narrowest beamwidth

- Lateral smearing varies with depth as beamwidth changes
- Axial smearing is constant with depth as the transmit pulse duration is constant over depth
- Lateral smearing is worse then axial smearing due to the greater dimension of the beamwidth relative to the SPL

- When measuring a structure (eg. Gallbladder wall thickness) scanning at a perpendicular incidence will provide the most accurate measure as the meaure will be only degraded by axial resolution and not lateral resolution.

<u>TEMPORAL RESOLUTION</u>

Ability to image movement and moving structures in real time:

- Represents the ability of the ultrasound system to distinguish between instantaneous events of rapidly moving structures, depends on:

- Frame rate (FR = PRF/N) {PRF= transmit pulses per second produced}
- Image depth
- Sector width
- Line density

- Imaging modes that require more transmit pulses per line of sight will cause a reduced FR (eg. Colour doppler, harmonics, compound imaging)

- The use of multi-beam technology helps to overcome this by using broad pulse transmits, with the echoes being received by a number of closely spaced receive elements adjacent ie. A single transmit pulse can provide information for multiple lines of sight simultaneously

We know:

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

Max $PRF = {}^{c}/_{2P}$ where P is the depth of penetration

Max $FR = {}^{max\ PRF}/_{N}$ where N is the number of transmits required for an image

If:

L = the number of lines of sight per image
E= the number of transmit pulse required per line of sight (1 for 2D/B mode)
M= the number of simultaneous beams formed
N= transmit pulse required per image

Then:

$N= {}^{L \times E}/_{M}$

Operating at maximal PRF for depth of penetration ie. Max PRF :

$FR = ({}^{c}/_{2P})\times({}^{M}/_{L \times E})$

$FR = {}^{c \times M}/_{2P \times L \times E}$

$\mathbf{FR \times P \times L \times E = M \times {}^{c}/_{2}}$

The formula gives the relationship between a relative constant ${}^{c}/_{2}$ and the other factors that will affect the temporal resolution:

↑FR

- reduce depth
- reduce lines of sight/line density (reduces lateral resolution)
- reduce transmit pulses per line of sight (dependent on mode of imaging)
- utilise multibeam imaging

Other factors affecting temporal resolution:

- reduced sector width increases FR (narrowed field of view reduced N)
- harmonics, persistence (pre processing to average images reducing speckle), and compound imaging (beams steered in different directions with combined image improving resolution) all reduce FR
- multiple focal zones also reduces FR

CONTRAST RESOLUTION

This is the important ability to distinguish between different echo amplitudes of adjacent structures. This determines the ability to identify differenences in adjacent tissues based on their echogenicity; and subtle differences in echogenicity are readily deteriorated by poor image quality.

- Contrast resolution is improved by reducing spurious artifacts and also by reducing speckle in particular in soft tissues/solid organs that reduce the ability to see differences in echogenicity:

- contrast resolution is improved by a variety of pre-processing (persistence, spatial compound imaging, tissue harmonic imaging) methods, and in particular optimisation of machine settings (frequency, depth, gain, TGC, and dynanmic range)

KEY POINTS

AXIAL RESOLUTION

- The most important detrminant of the axial resolution is the length of the transmit pulse used to form the beam

AXIAL RESOLUTION LIMIT ≈ ½ SPL

- **Higher the frequency the shorter the SPL**

LATERAL RESOLUTION

- Lateral resoltion is dependent on the beamwidth at depth
- The best lateral resolution is in the focal zone where the beamwidth is narrowest
- The narrowest beamwidth at focus is achieved by using the highest frequency for depth and largest possible transducer aperture

TEMPORAL RESOLUTION

- Represents the ability of the ultrasound system to distinguish between instantaneous events of rapidly moving structures dpends on FR

CONTRAST RESOLUTION

- The ability to identify differenences in adjacent tissues based on their echogenicity
- Dependent on image/machine optimisation and machine imaging modalities such as persistence, spatial compound, and tissue harmonic imaging

REFERENCES

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

Artifacts in Diagnostic Medical Ultrasound: Volume 1 Grayscale Artifacts. By Martin Necas

Back to Basics Ultrasound. Royal Brompton and Harefield Hospital. By Dr Josefa Paredes.

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