

WEBINAR

Imaging Equipment: Ultrasound

Technology, usage, and service

WEDNESDAY
SEPTEMBER

14

6 PM

UNIVERSAL TIME (UTC)

2 PM

NEW YORK TIME (ET)



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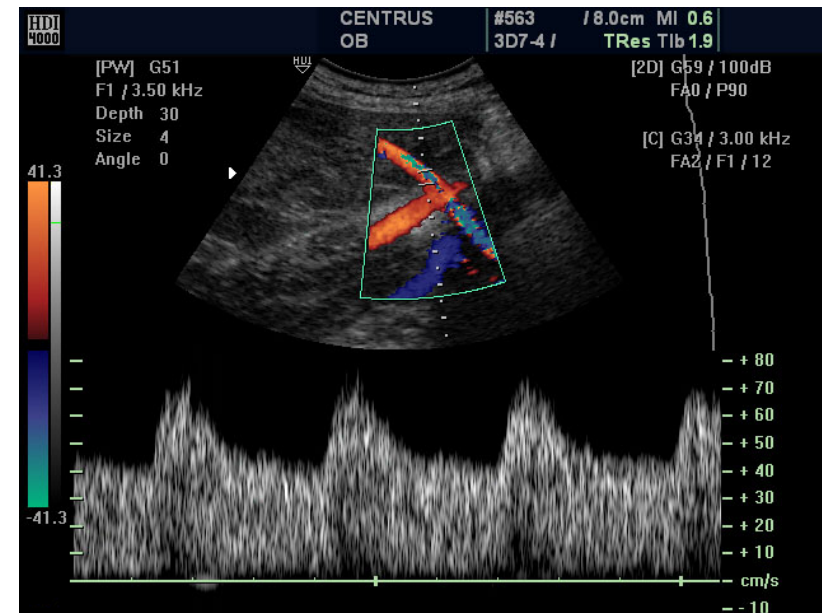


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Ultrasound Imaging

Basic Principles



History of Ultrasound

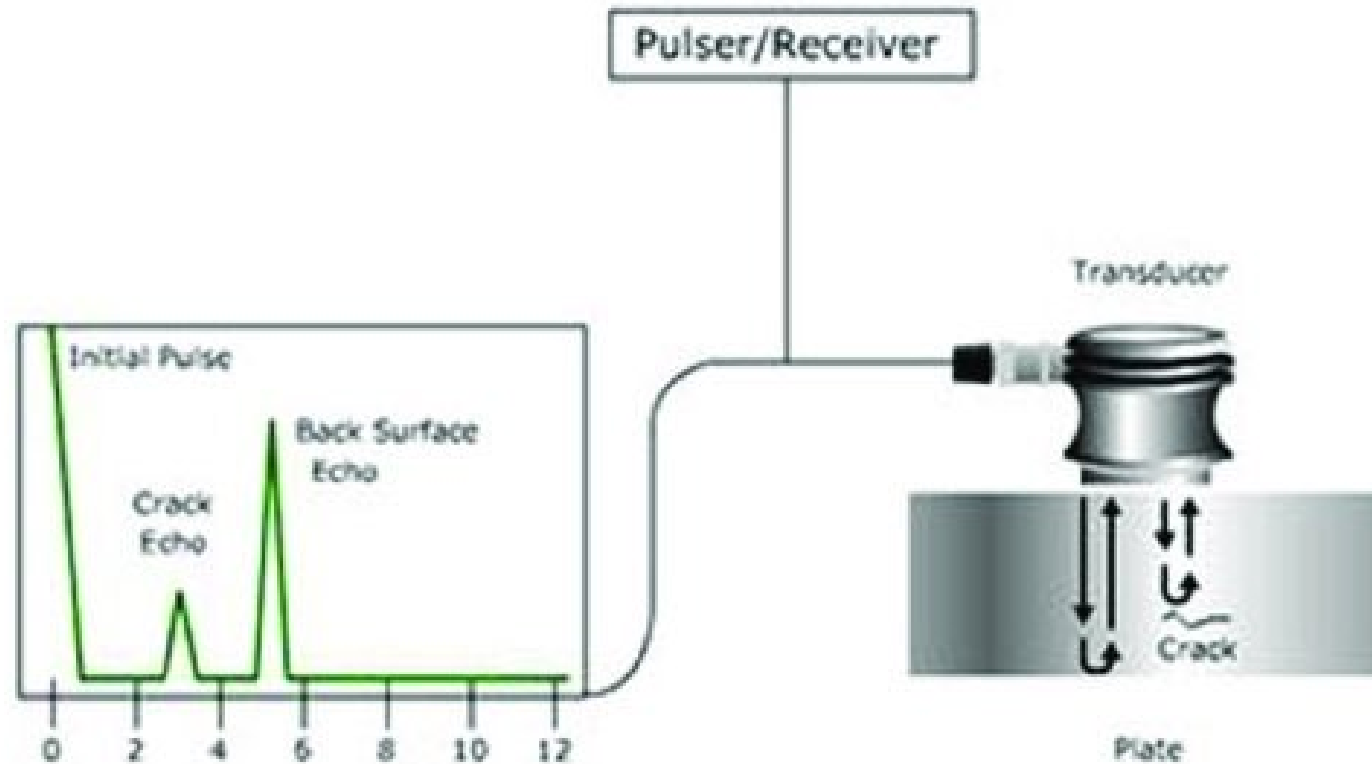
- Discovery of high frequency sound waves (ultrasound) by **Lazzaro Spallanzani**, when he demonstrated the ability of bats to navigate through backscattering sound waves of inaudible sound (1794).
- First mathematical description of sound waves by Lord Rayleigh (1877).
- Breakthrough in the evolution of ultrasound with the discovery of **piezoelectric effect** by Pierre Curie (1880):
 - Generation and
 - Reception of ultrasound waves was possible for the first time.

Precursors of Medical Ultrasonic Systems

- After the development of navigational systems, the development of ultrasonic systems came from 20th century.



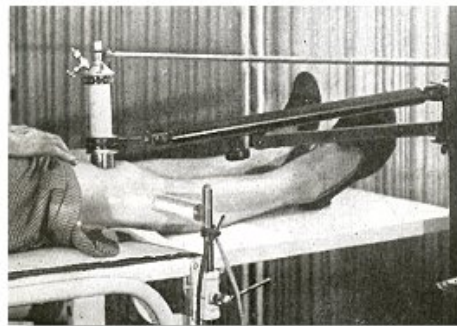
- Ultrasonic systems were used for the construction of the armor plates of battle tanks (1930's).



Evolution of Medical Ultrasound Systems

First use of ultrasound in medicine was done for therapy and not for diagnosis.

- Using the heating and disruptive effects of ultrasound, **Russell Meyers** performed craniotomies and used ultrasound to **destroy parts of the basal ganglia** in Parkinson patients.

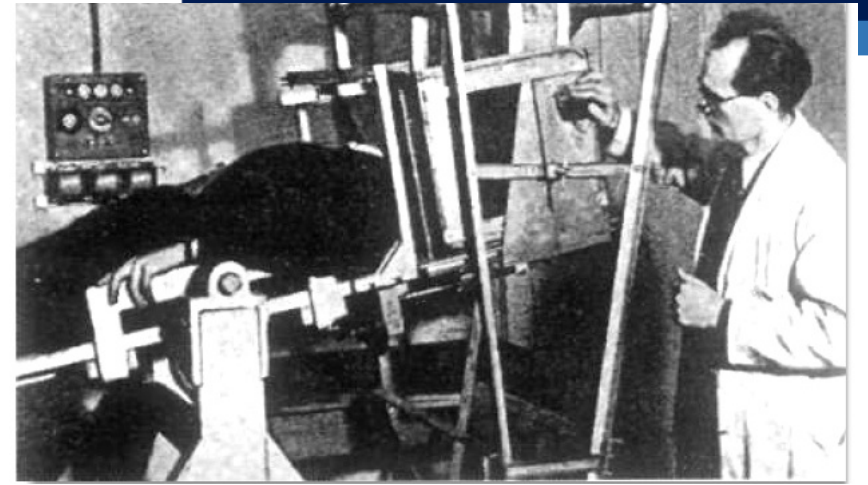


- Ultrasound was used extensively in **physical and rehabilitation medicine** for the treatment of patients with gastric ulcers and rheumatic arthritis.

- In 1940 first claims on the effectiveness of ultrasound as an curing modality were made.

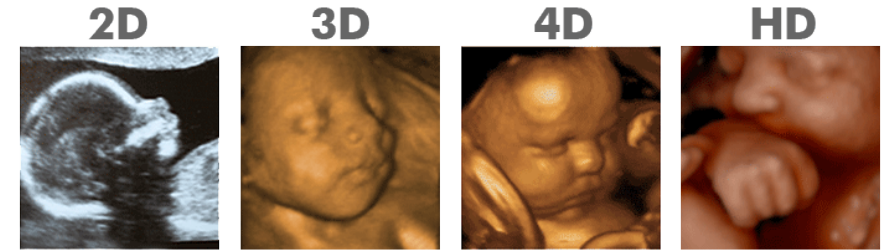
Diagnostic Ultrasound

- In 1940, Goht and Wedkid presented the first paper that explored the possibility of using ultrasounds as a **diagnostic tool**.
- Dussik in **1946** was the first physician that employed ultrasound **in medical diagnosis** and called the new technique “hyperphonography”.
- Donald and MacVicar team in 1963 were the first to produce a **2D image (B-mode)**, visualising the gestational sac.
- In **1963** the first commercial medical imaging ultrasound device called “**Diasonograph**” was built at Kelvin & Hughes at Hillington, Glasgow
- Baker and Raid in 1974 were the first who constructed a **duplex pulsed-doppler scanner** that enabled 2D grayscale imaging where the volume **blood flow** could be determined.



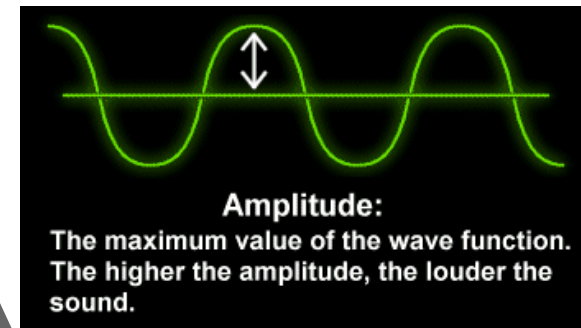
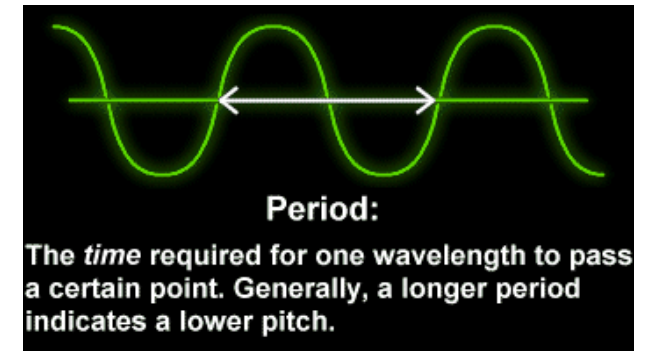
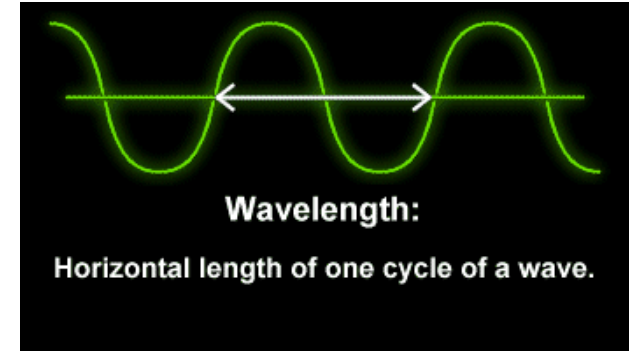
Diagnostic Ultrasound

- Since then enormous progress has been made :
 - Real-time high resolution images of anatomy and blood flow
 - 3D imaging
 - Use of Ultrasound Contrast Agents
- Nowadays **25% of all medical imaging** clinical procedures are done with ultrasounds :
 - Economical
 - Portable
 - Real time imaging
 - Safe for the patient
 - Integrate anatomical information with blood velocity monitoring in real time



Parameters of Sound Wave

- Wave Length $\rightarrow \lambda$ (m)
- Period $\rightarrow T$ (sec)
- Amplitude $\rightarrow A$
- Frequency $\rightarrow f = 1/T$ number of periods per second (Hz)
- Speed $\rightarrow C = \lambda \times f \Leftrightarrow \lambda = \frac{C}{f} = C \times T$ (m/s)



Speed of Sound

- The speed of sound is **independent** of the parameters of the **soundwave**

- **Depends** on the properties of the **medium** :

- κ = Compressibility of the medium [m²/N]
- B = Adiabatic bulk modulus (modulus of elasticity) [N/m²]
- ρ_0 = Mean density of the undisturbed medium [kg/m³]

$$c = \sqrt{\frac{1}{\rho_0 \kappa}} = \sqrt{\frac{B}{\rho_0}}$$

- Since the speed (c) and the insonifying frequency (f) are predefined, the wavelength changes in each medium based on equation: $\lambda = c/f$
- If the speed is kept constant (propagation in the same medium), when the **frequency increases** the **wavelength decreases**.

$$\uparrow f \Rightarrow \downarrow \lambda$$

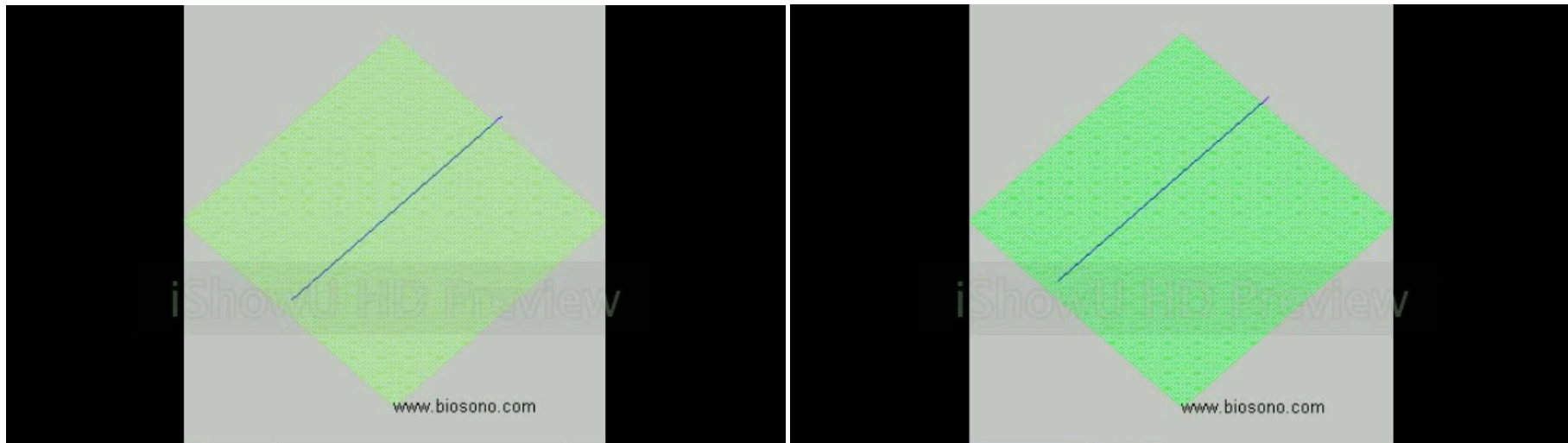
Speed of Sound

| <i>Medium</i> | <i>Density [kg/m³]</i> | <i>Speed of sound [m/s]</i> |
|-----------------|-----------------------------------|-----------------------------|
| Air | 1.2 | 333 |
| Lung | 0.40×10^3 | 650 |
| Distilled water | 1.00×10^3 | 1480 |
| Blood | 1.06×10^3 | 1566 |
| Fat | 0.92×10^3 | 1446 |
| Kidney | 1.04×10^3 | 1567 |
| Liver, spleen | 1.06×10^3 | 1566 |
| Muscle | 1.07×10^3 | 1542-1626 |
| Bone | $1.38 - 1.81 \times 10^3$ | 2070-5350 |
| Brain | 1.03×10^3 | 1505-1612 |

Reflection - Transmission Coefficient

$$R_a = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2} \quad T_a = 1 - R_a$$

- When an ultrasound wave encounters a tissue interface between two media with different acoustic impedances, only a percentage of the wave's energy passes through.



Medical ultrasound is limited in soft tissue imaging with reflection coefficient around 10%

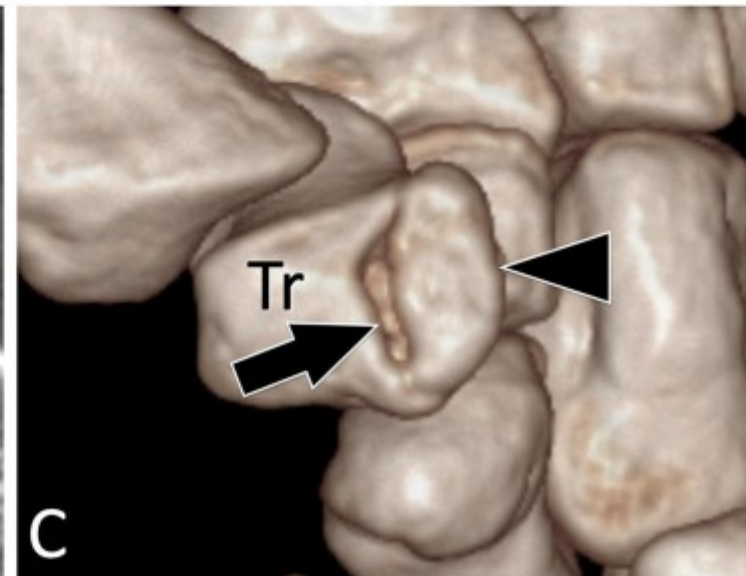
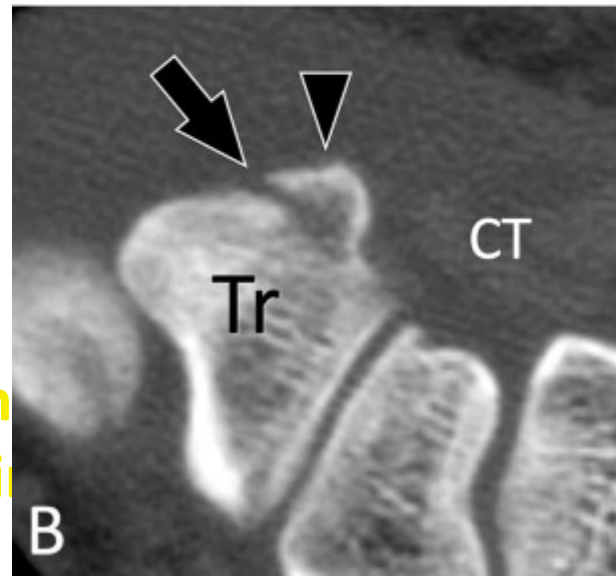
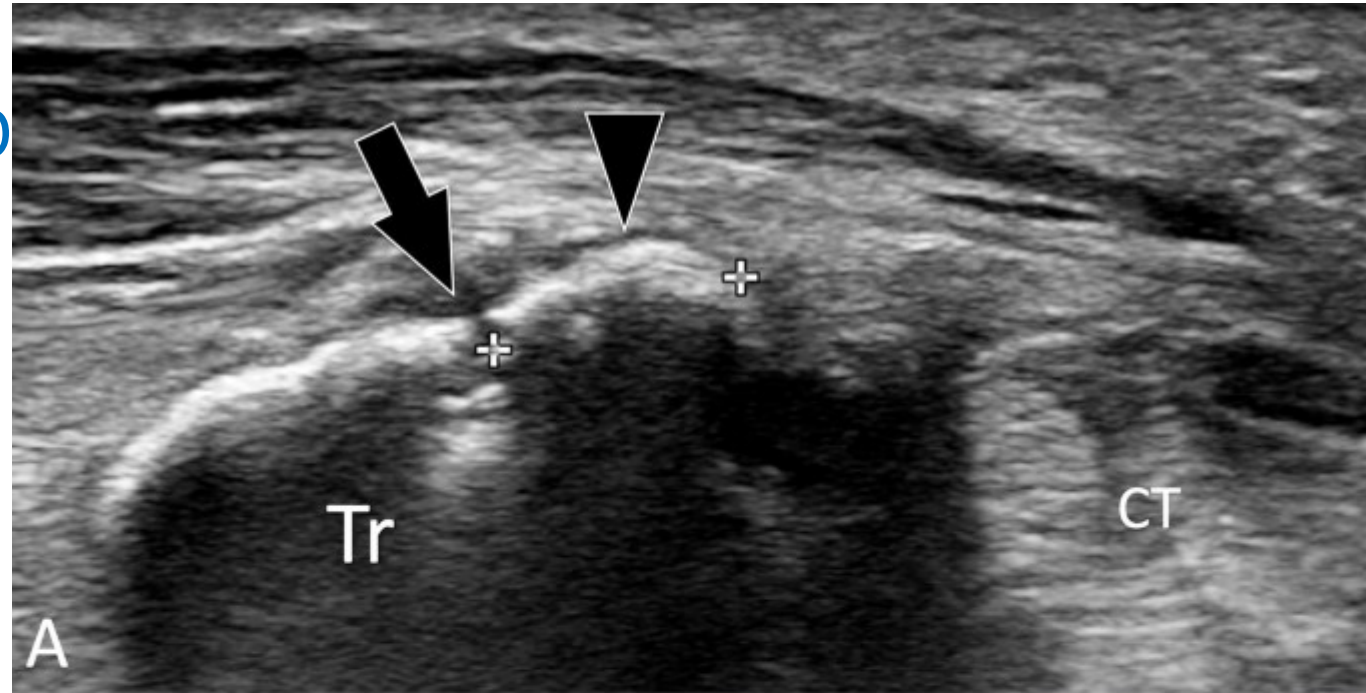
Attenuation

- Attenuation is the energy loss of an ultrasound wave when it propagates through the tissues.
- Causes of the loss:
 - Scattering inside the tissue
 - Absorption (the conversion of acoustic energy into heat)

$$A(f, r) = e^{-2\pi\beta fr} \quad \left(\frac{\text{dB}}{\text{MHz}\cdot\text{cm}}\right)$$

- Increases with:
 - frequency
 - depth (distance from the transducer)

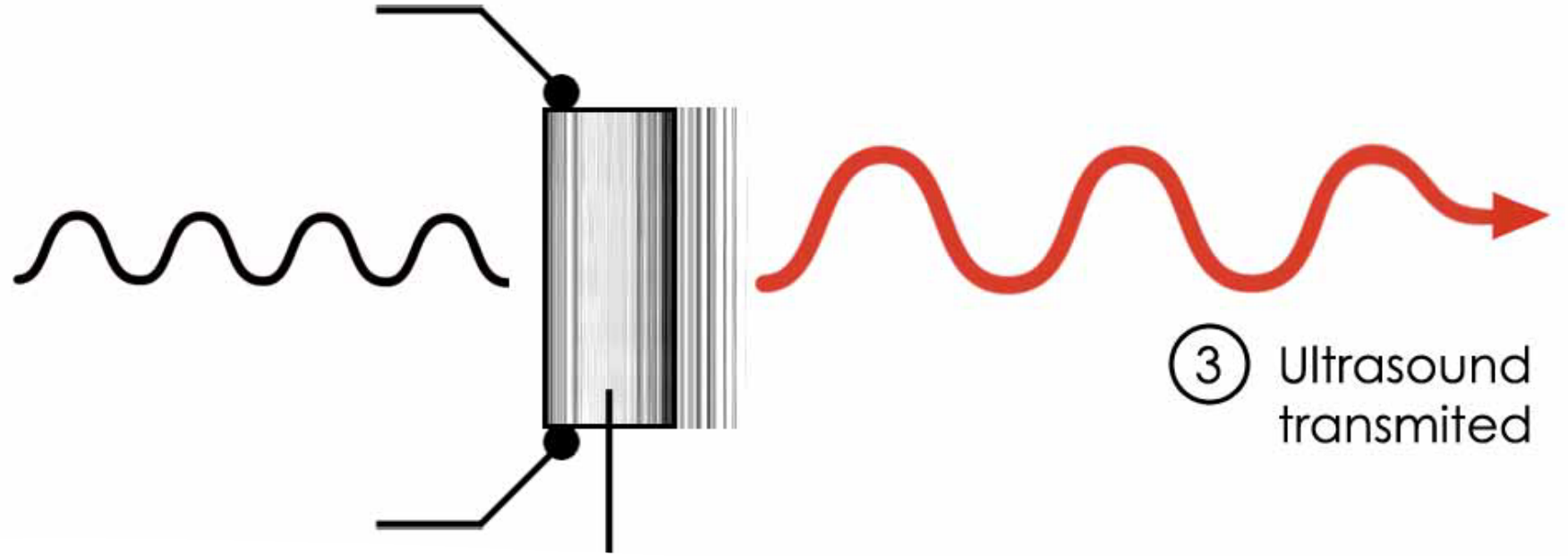
Attenuatio



Ultrasound
i

tically

① High Frequency changes in voltage



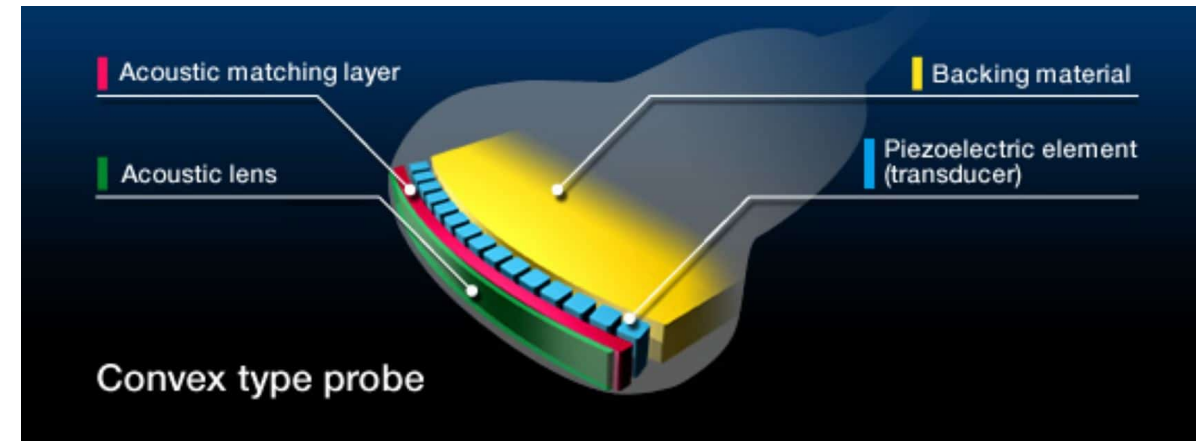
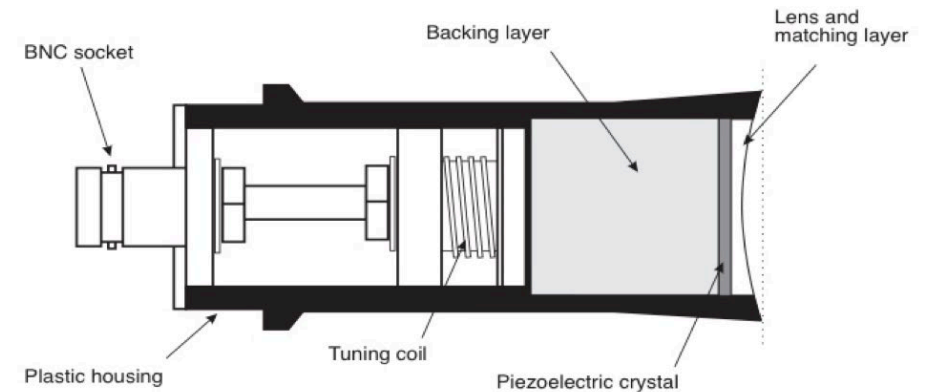
③ Ultrasound transmitted

Generation of Ultrasound

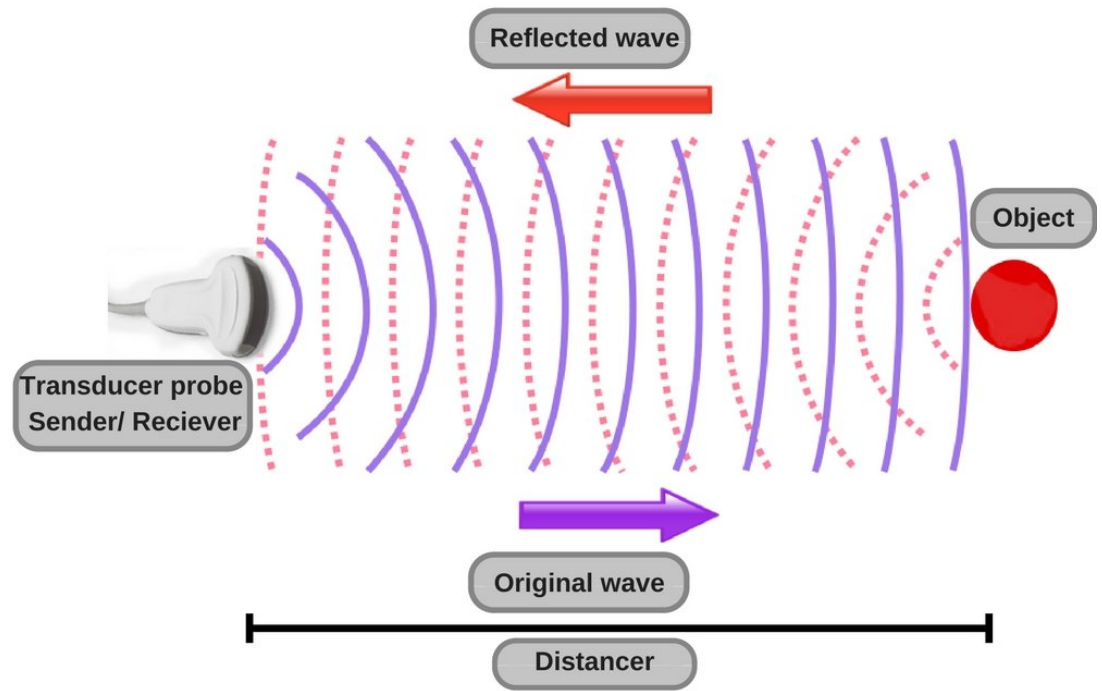
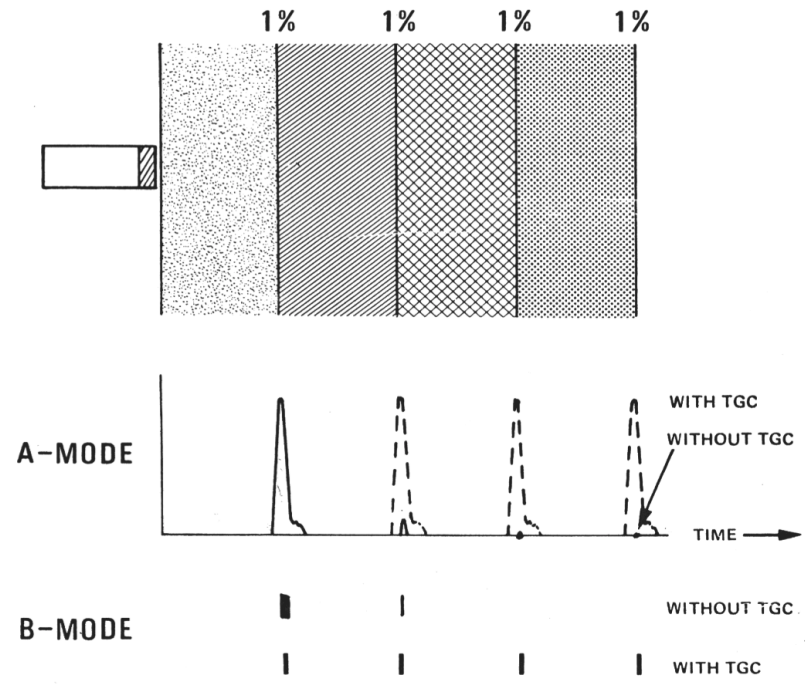
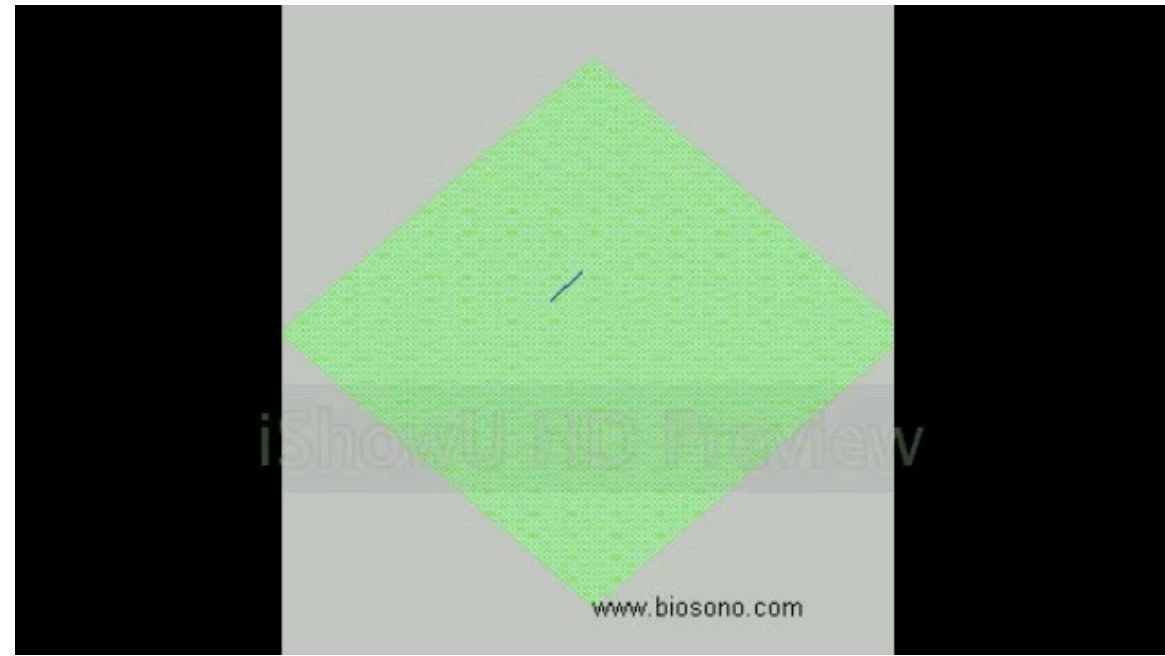
- Ultrasound transducers generate ultrasound with the use of **piezoelectric crystals**
- Piezoelectric crystals : *materials that convert electrical signal to pressure oscillations in their surface via mechanical deformation*
- **Inverse piezoelectric** effect is used for reception of backscattered echo
- Medical ultrasound systems operate in frequency range of **1 to 30 MHz** (audible range 20Hz to 20 kHz)

Probes

- Electrical signal applied on the ultrasound transducer
- Based on the piezoelectric effect an ultrasound wave is created
- Types of transducers:
 - **Single frequency transducer** → transmit in one central frequency, lower amplitude in near frequencies
 - **Broadband transducers** → transmit equal amplitudes in a range of frequencies
 - **Multi frequency transducers** → Choise of central transmitting frequency i.e. 5.0 MHz, 7.5 MHz etc.

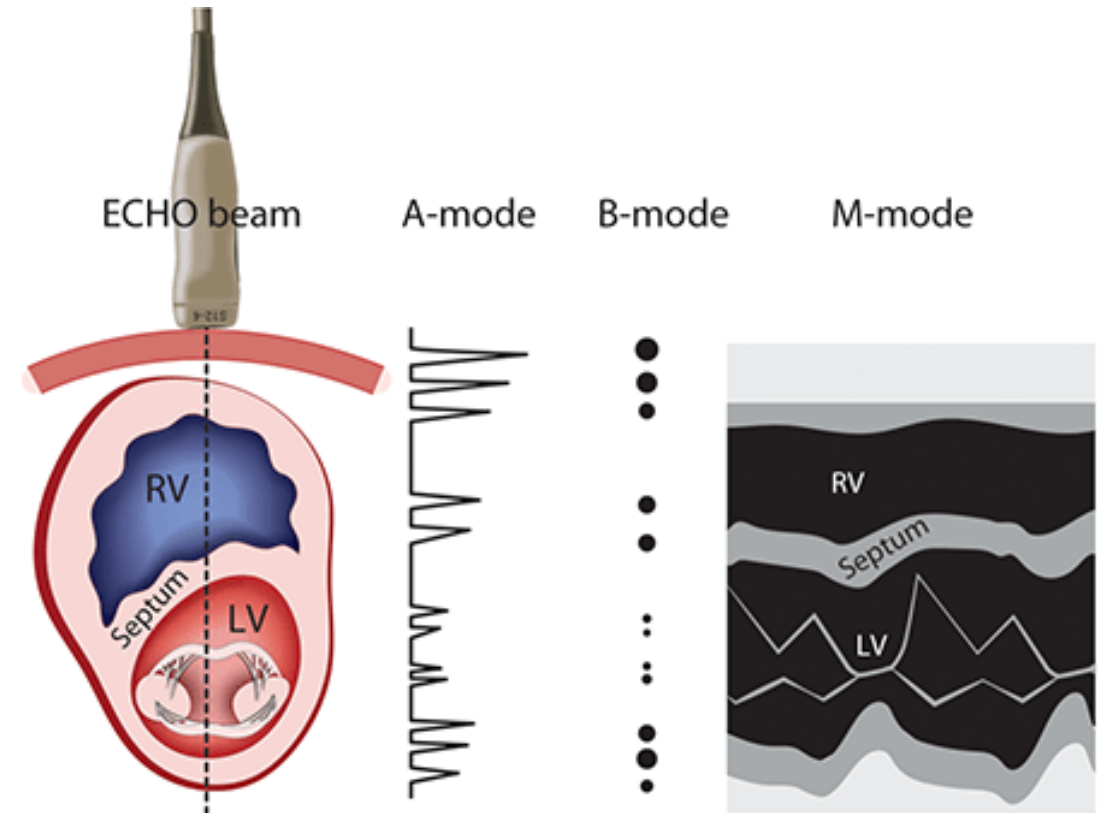


Ultrasound Imaging



Display

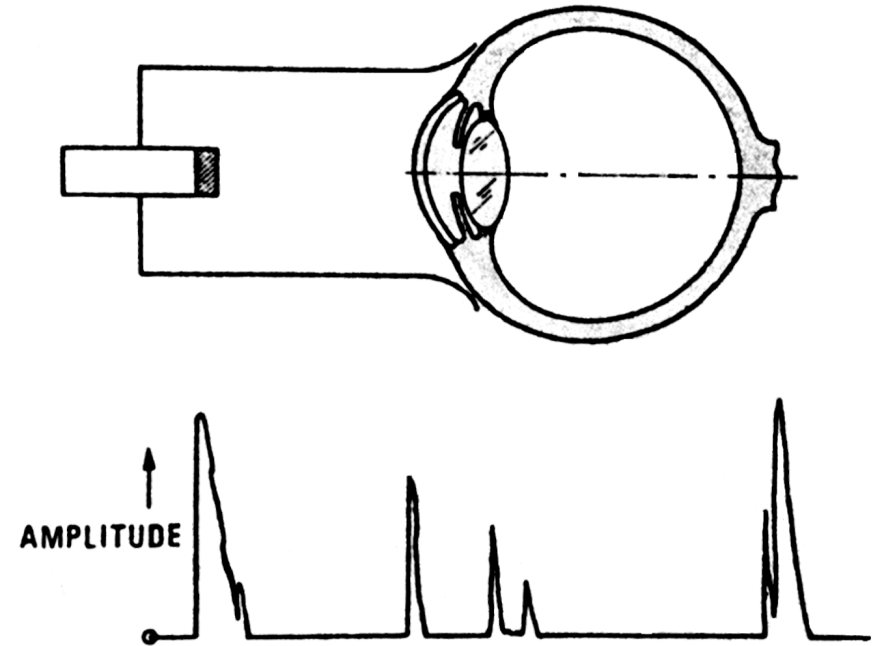
- **A-Mode** → Amplitude Mode was the first mode ever used, nowadays used only to measure distance
- **M-Mode** → Motion Mode provides information about the motion, nowadays used in diagnosing heart valve diseases
- **B-Mode** → Brightness Mode provides a 2D image of the tissue, used in all modern scanners as the standard display mode for displaying anatomic data
- Combination of all these modes along with other technics, such as doppler flow imaging, are used in modern ultrasound systems



Source: Bijan Siassi, Shahab Noori, Ruben J. Acherman, and Pierre C. Wong: *Practical Neonatal Echocardiography* Copyright © McGraw-Hill Education. All rights reserved.

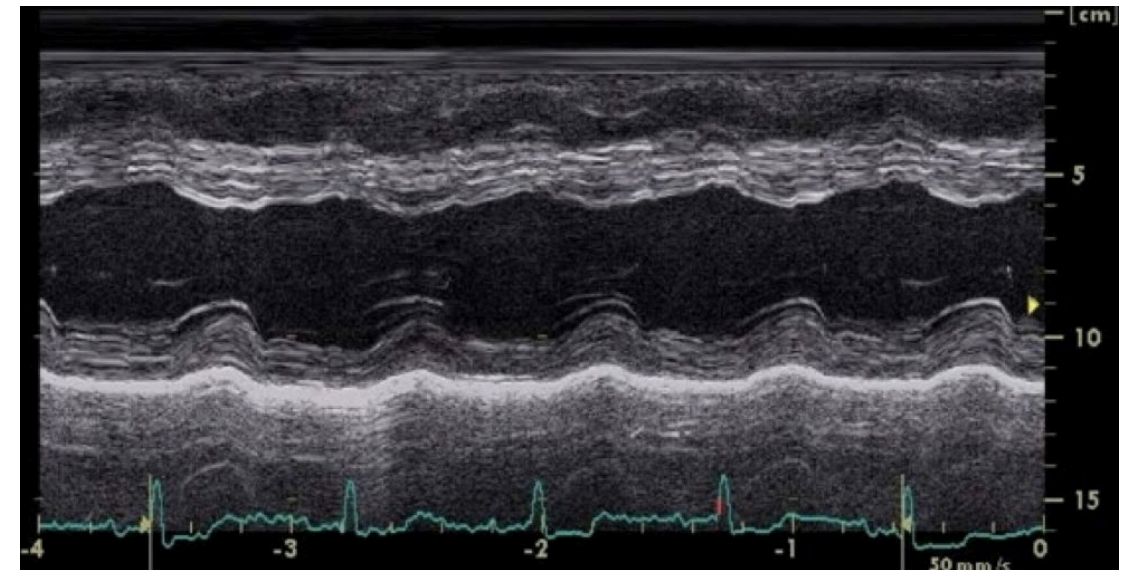
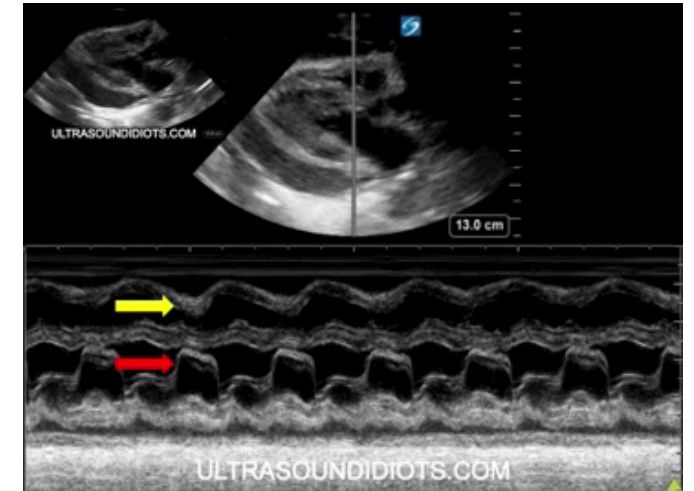
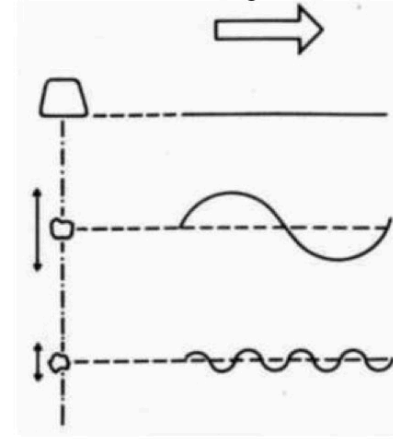
A-Mode

- In the Amplitude-mode the back scattered signal was shown as a function of depth
- The produced image was one-dimensional and only depth data could be measured.
- Ultrasound pulse was sent in only one direction
- The backscattered echo was captured (A-Line) and was presented in X-Y axes, where X was the depth and Y the amplitude of the back scattered pulse



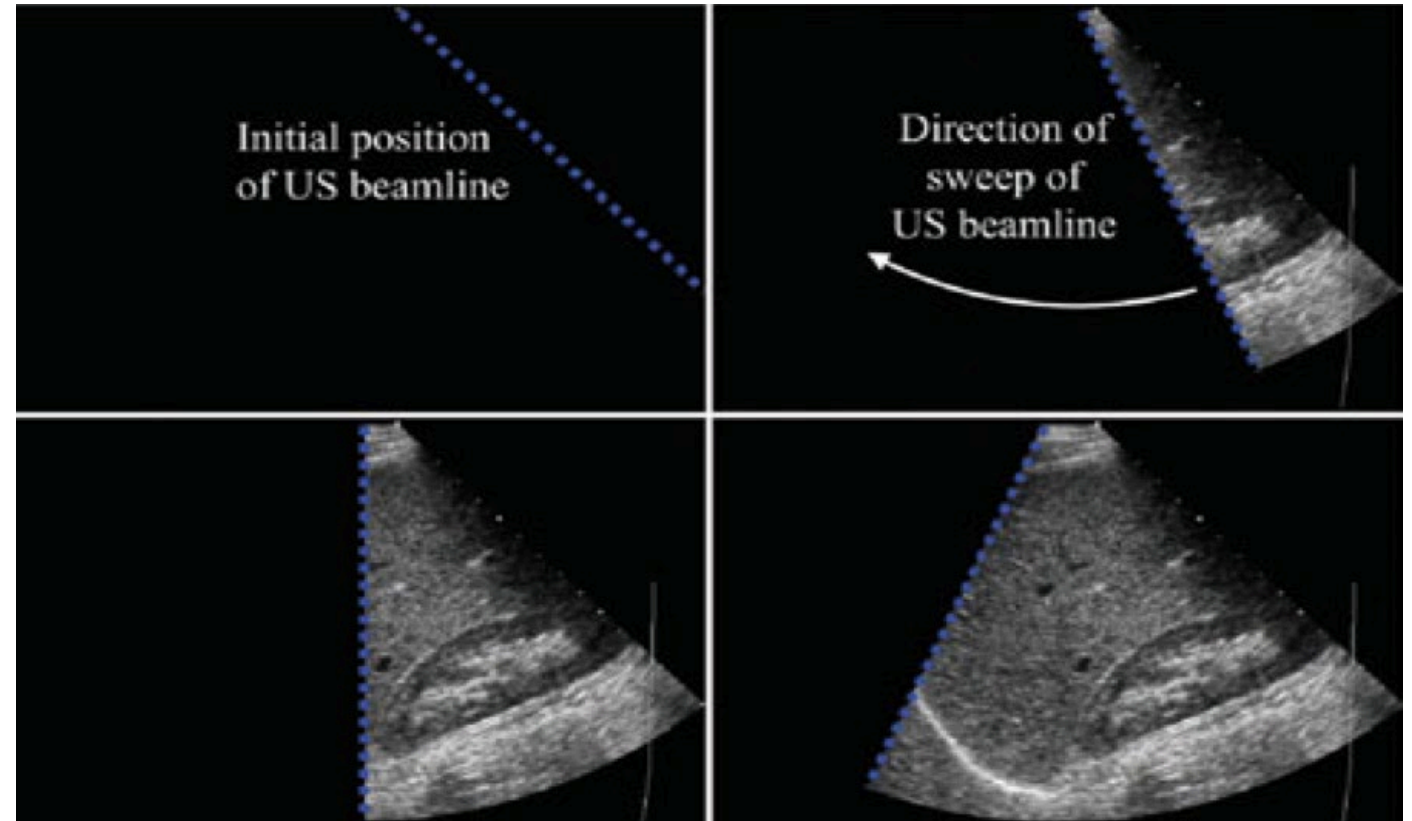
M-Mode

- An evolution of the A-mode, was the motion mode (M-mode)
- In the M-mode, several lines were emitted in the same direction and the backscattered echo was recorded (A-lines)
- By acquiring several A-lines and displaying each one side by side, information about the motion was seen.
- The acquired lines were presented in X-Y axes, where X axis corresponds to time and Y axis to the depth



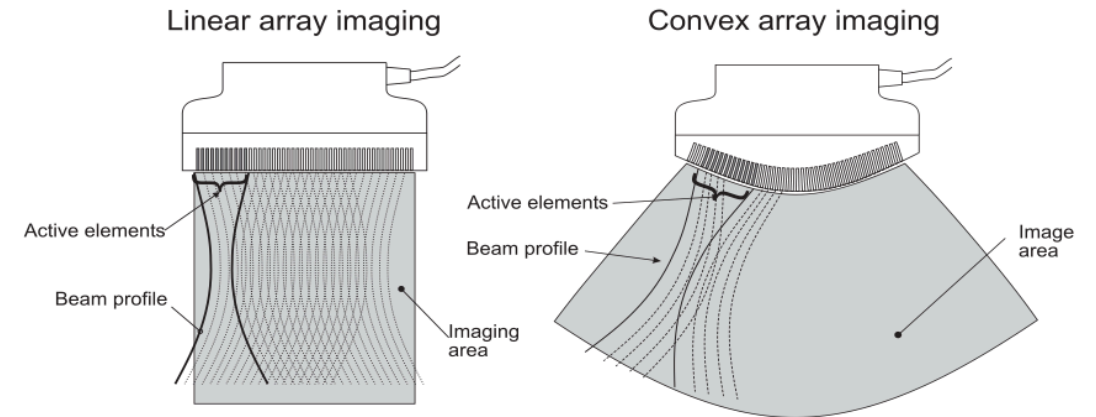
B-Mode

- The breakthrough in the field of medical ultrasound was done with the invention of Brightness mode
- In the B-mode a series of focused fields lines were transmitted in different direction, acquiring a series of A-lines that covered all the region of interest
- The A-lines were then merged missing data were interpolated and a 2D image was created



Linear - Convex Array Probes

- In linear and convex array transducers scanning is done by choosing the a set of active elements.
- The amount of active elements compromise the aperture.
- The scanning is done by exciting the next element of the aperture and resting of the last one. This is done sequentially, until the whole region under the transducer is scanned.
- In linear arrays the size of the transducer defines the size of the scanning region (~10 cm)
- In convex transducer larger scanning region is achieved by changing the shape of the transducer

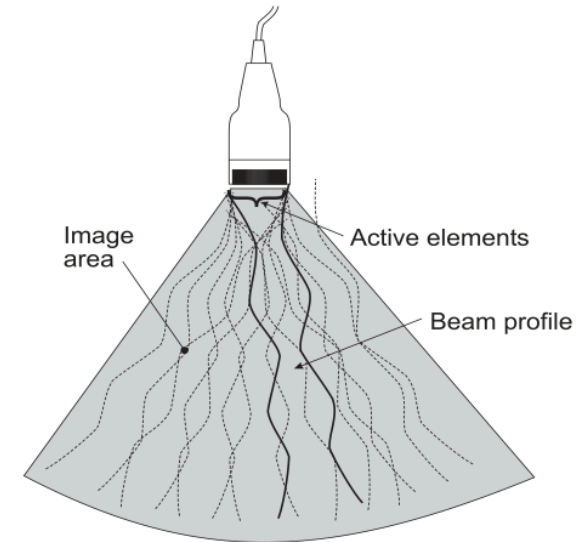


Phased Array Probes

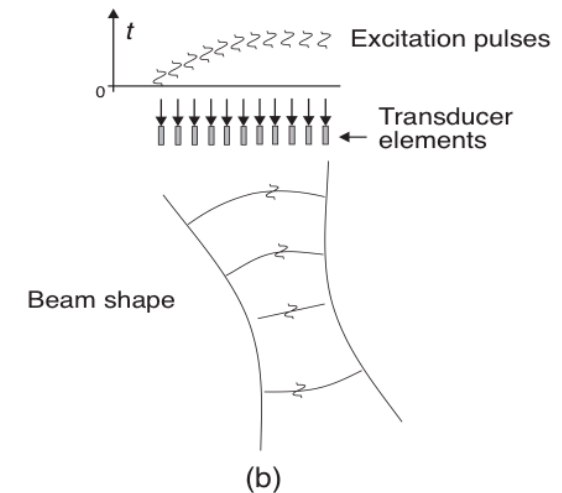
- They have the same geometry as the linear arrays.
- Much smaller footprint (1-3 cm) and scan an area much larger than the size of the aperture.
- Smaller number of elements (64 - 128).
- Pitch (centre to centre element distance) is less than $\lambda/2$.
- All elements are used both in transmit and receive.
- Scanning is done by steering the transmitted beam, by applying tilted delay profiles

Phased arrays are used in cardiology, where there is only a small “acoustic window” between the ribs and the lungs

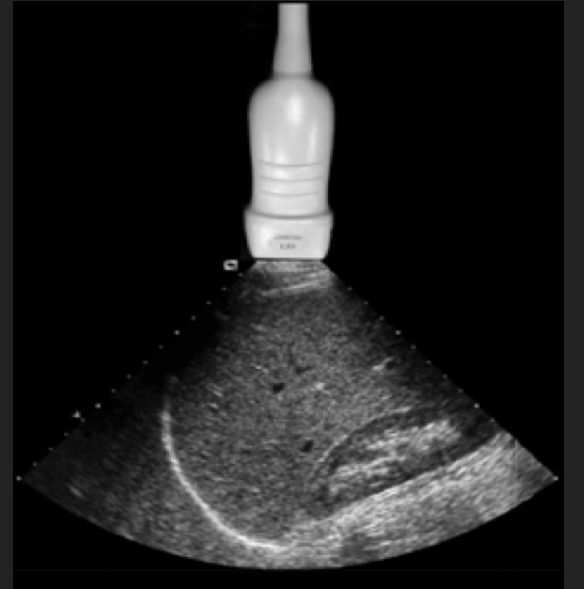
Phased array imaging



Beam steering and focusing



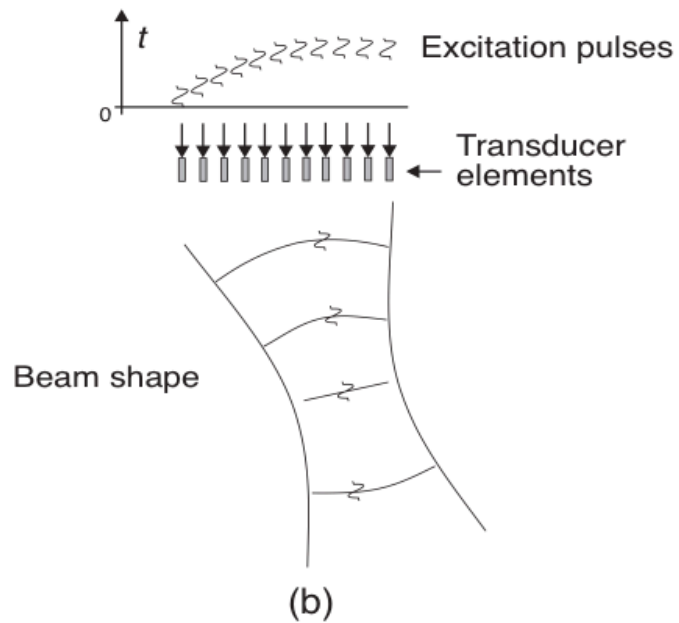
Array Imaging



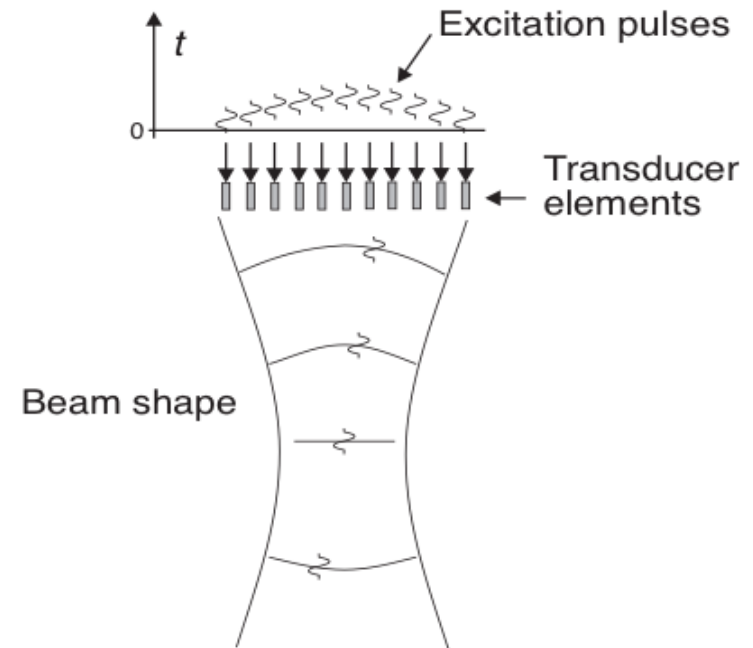
Beamforming

- Beamforming is the manipulation of the signals of the elements of array transducers to enhance focusing and shape directivity of the beam of the beam
- It is achieved electronically by changing the time delay (phase) and amplitude (apodization) of the voltage applies on each element.

Beam steering and focusing

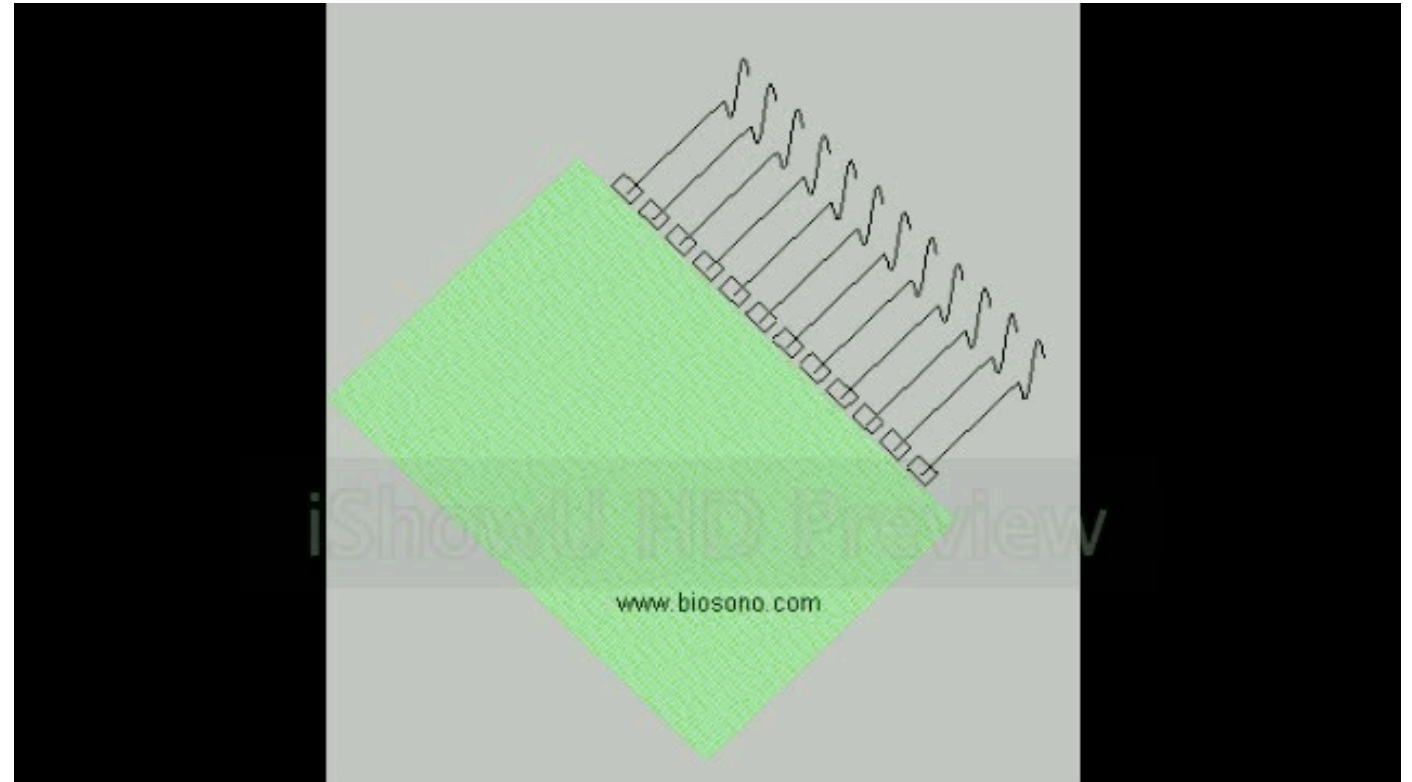


Electronic focusing

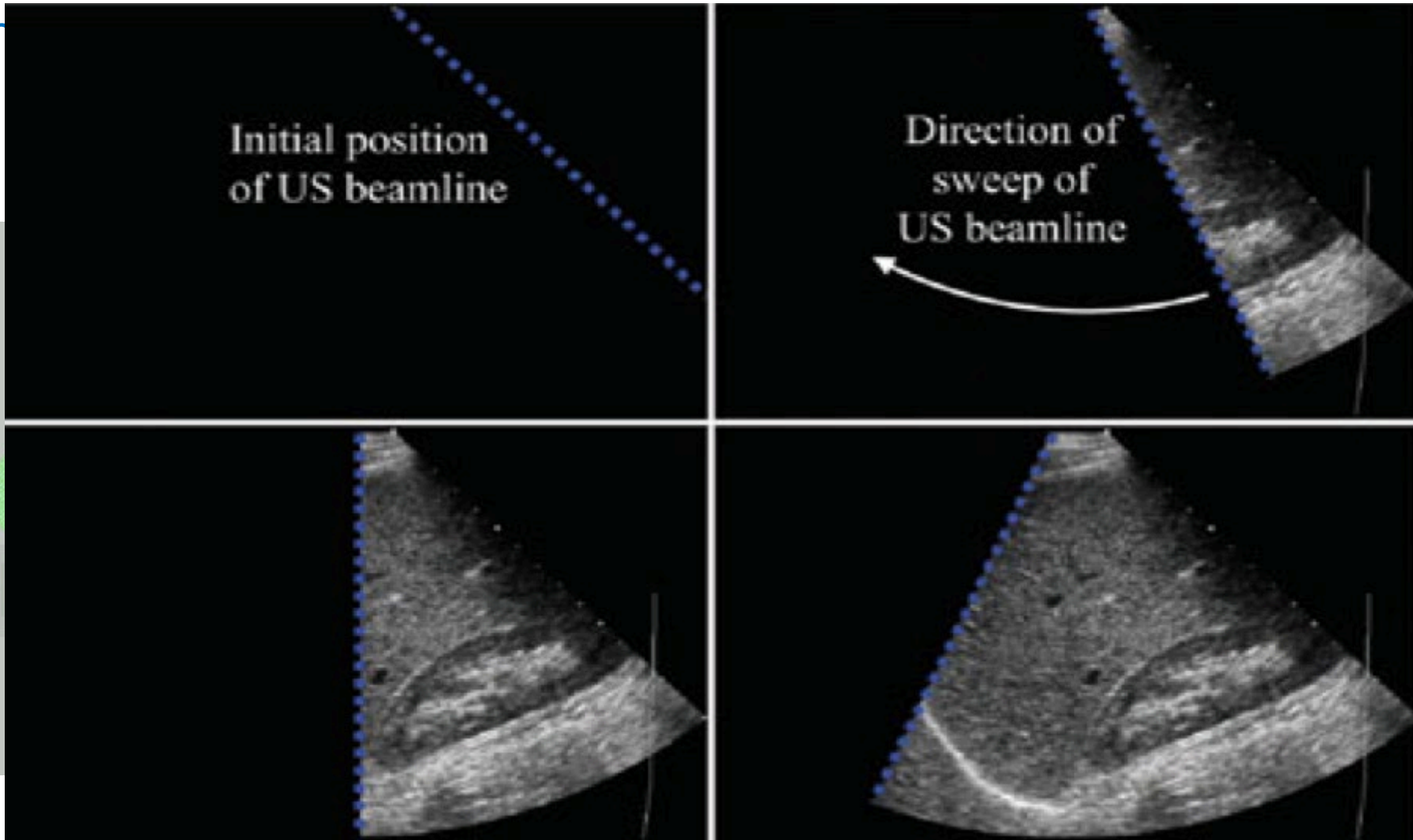


Beamforming

- Central Line Focus

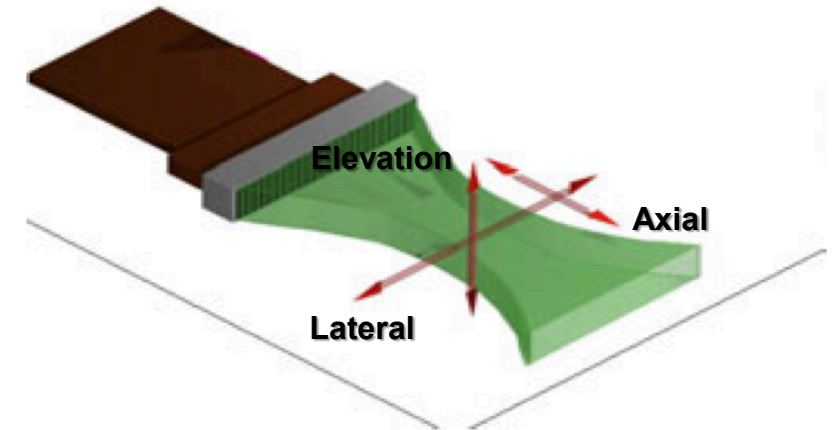
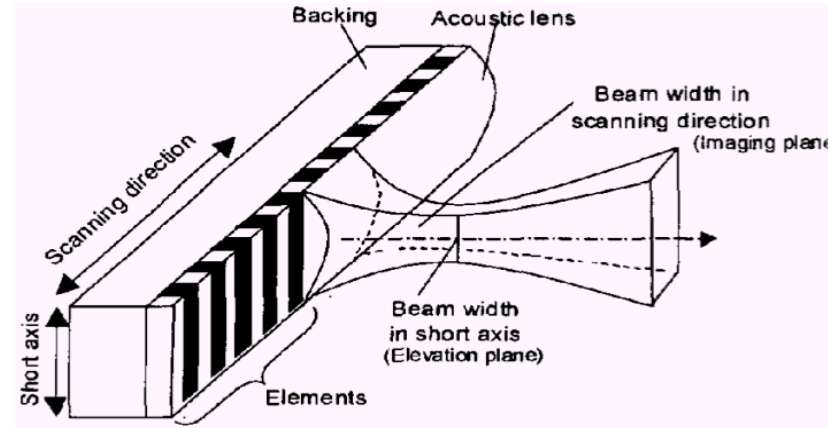


Beam



angle

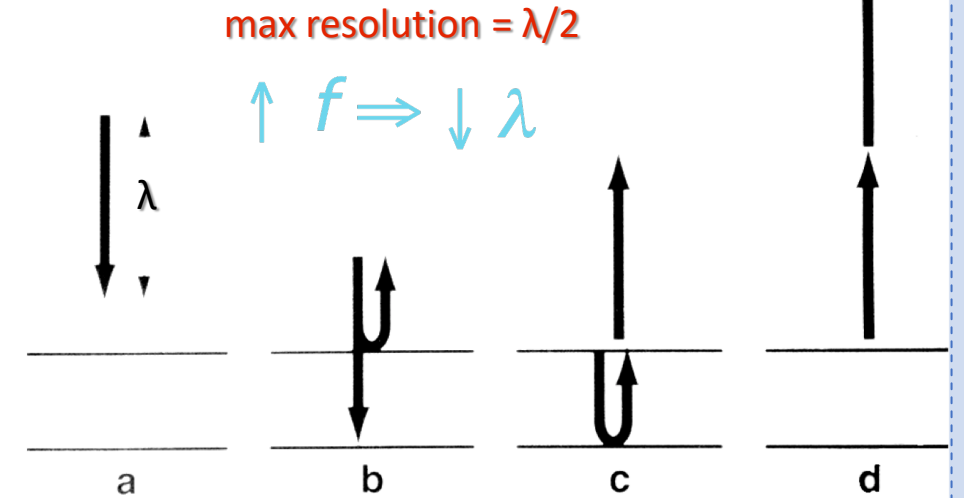
Image Resolution



- Spatial resolution is the ability of an imaging system to distinguish between closely-spaced scatterers.
- 3 components:
 - Axial
 - Lateral
 - Elevation

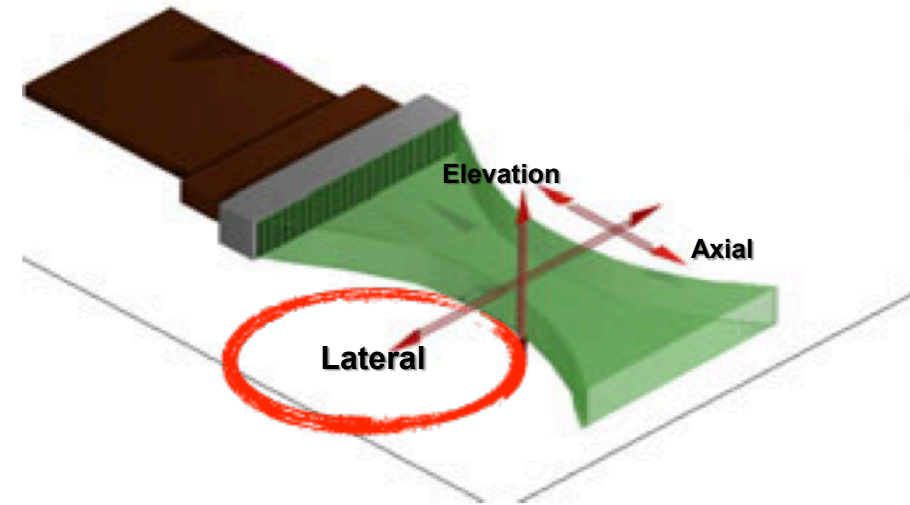
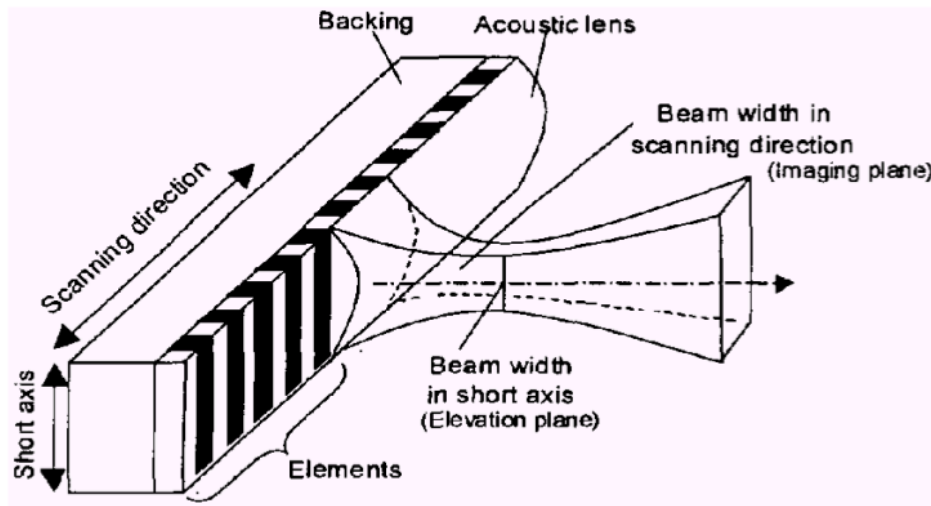
Axial (Range) Resolution

- Axial resolution is limited to half the wave length (λ) of the transmitted pulse
- It is determined by the duration of the acoustic signal of each element which is determined by the characteristics of the transducer:



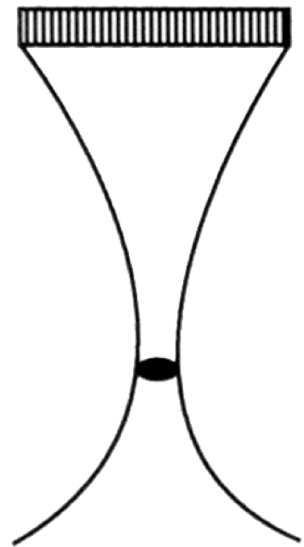
(\uparrow) High central frequency \rightarrow (\downarrow) short acoustic pulses \rightarrow (\uparrow) higher axial resolution \rightarrow (\downarrow) Lower penetration depth (due to attenuation)

Lateral (Azimuthal) Resolution

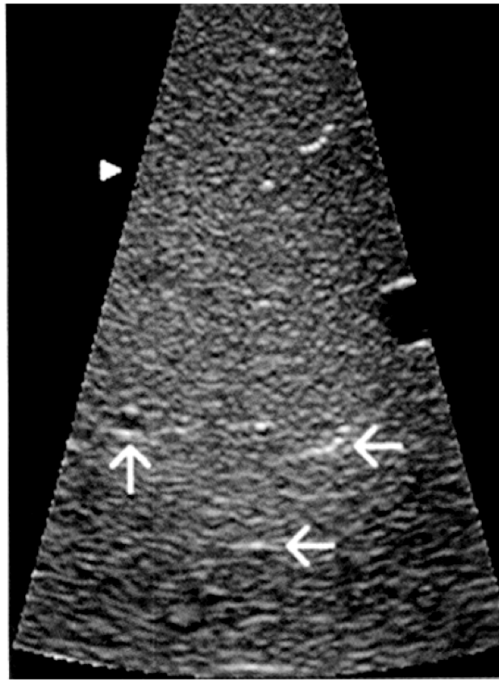


Lateral (Azimuthal) Resolution

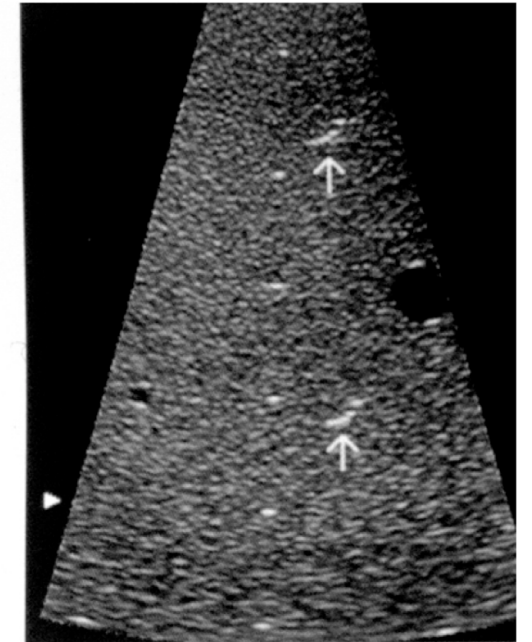
(↑) Wider Aperture size → (↑) higher axial resolution



**Wide Aperture/
Single Focus**

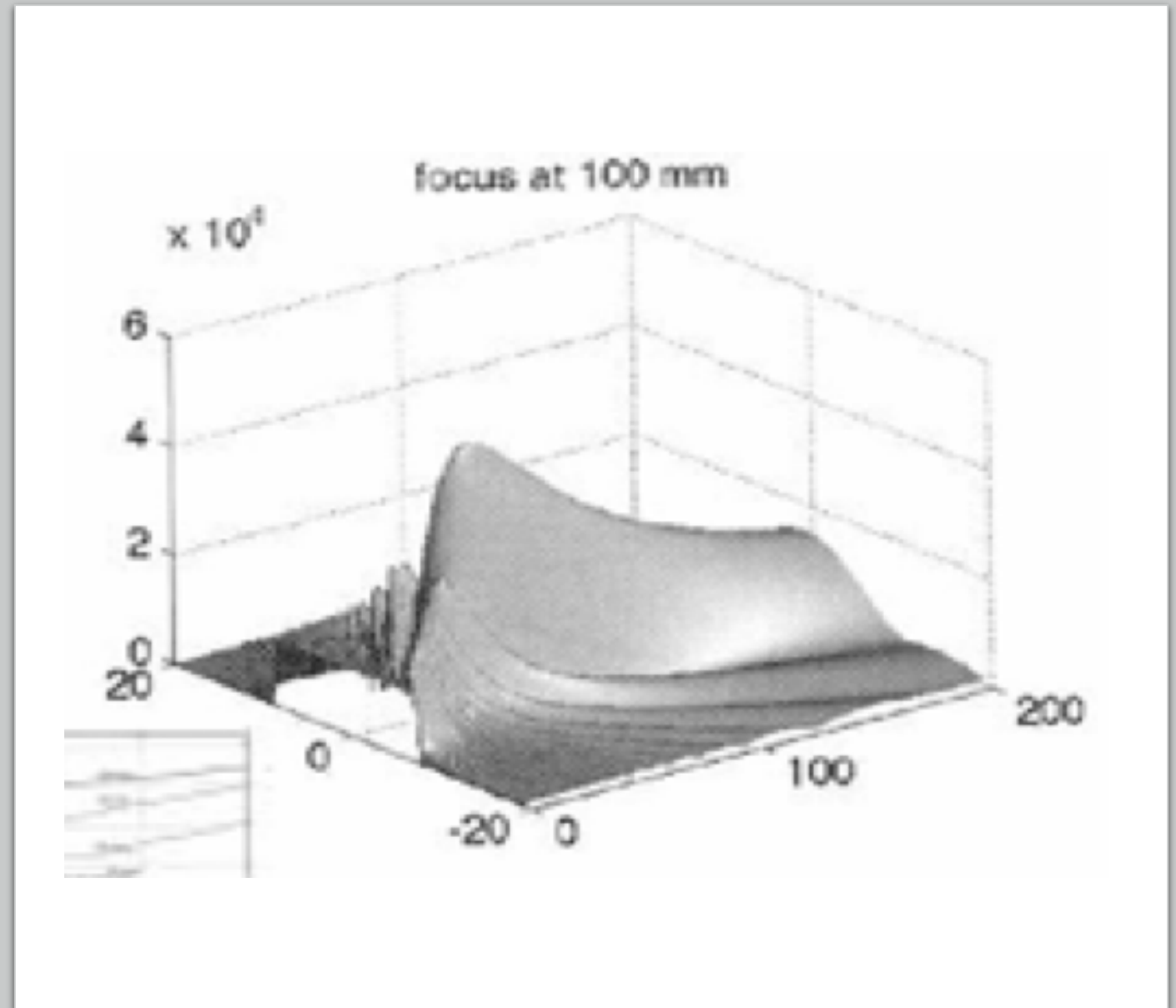


**Narrow Aperture/
Single Focus**

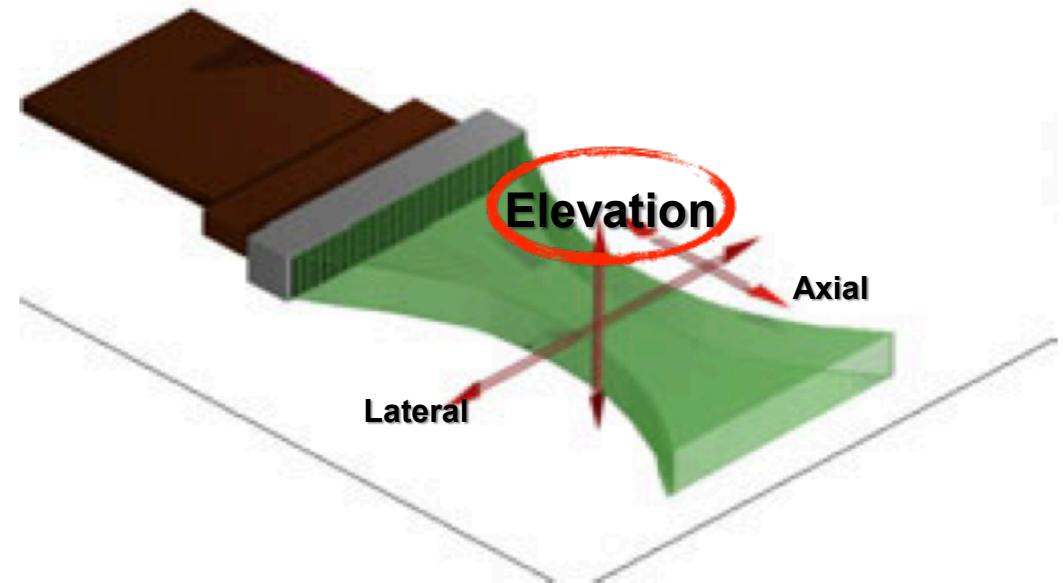
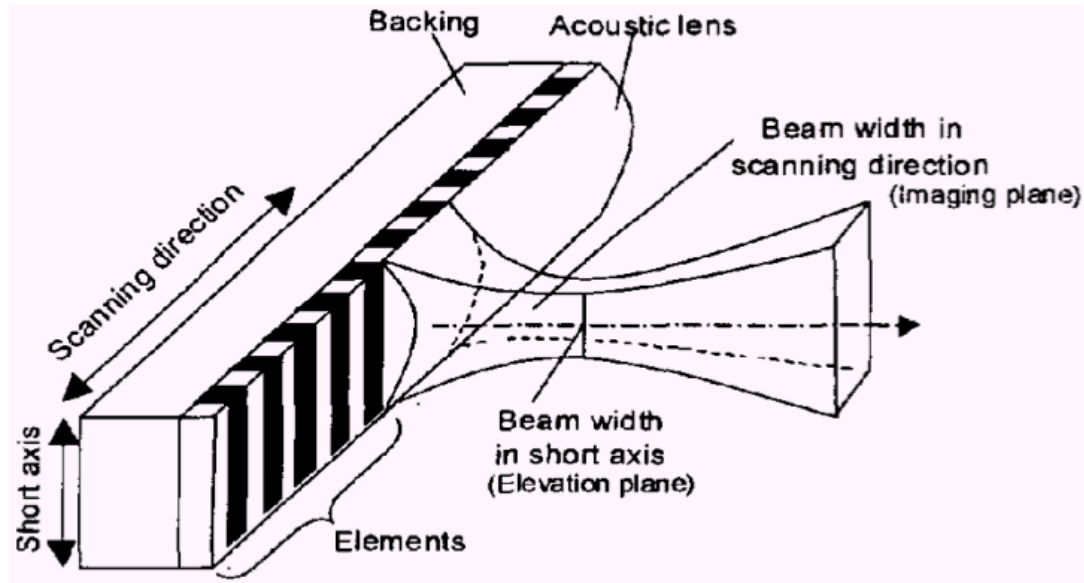


Lateral (Azimuthal) Resolution

- Lateral resolution is **inversely proportional** to the transmit frequency
- (↑) **Higher frequency** → (↓) **Smaller main lobe width** → (↑) **Higher lateral resolution** → (↓) **Lower penetration depth** (due to attenuation)

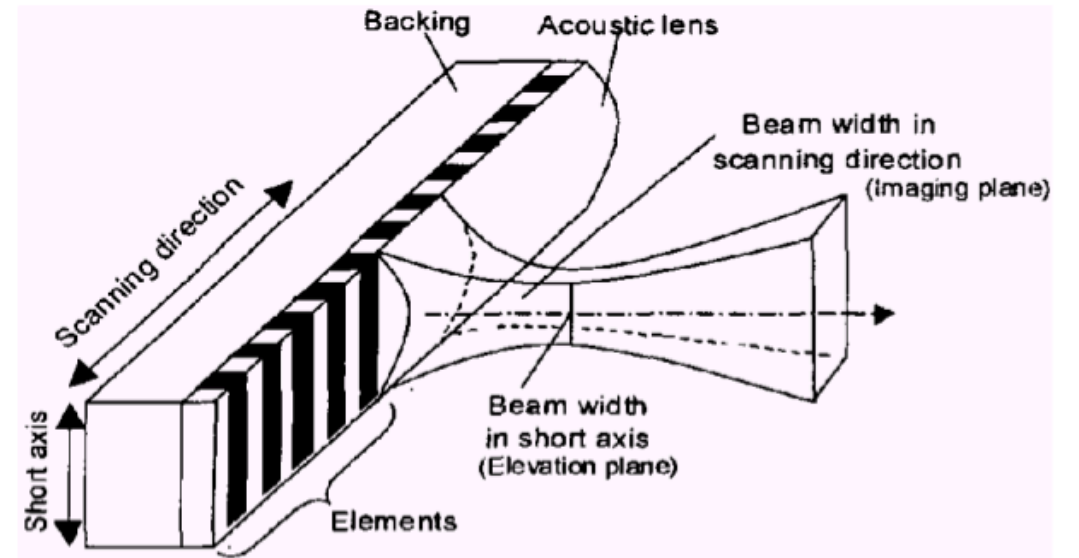
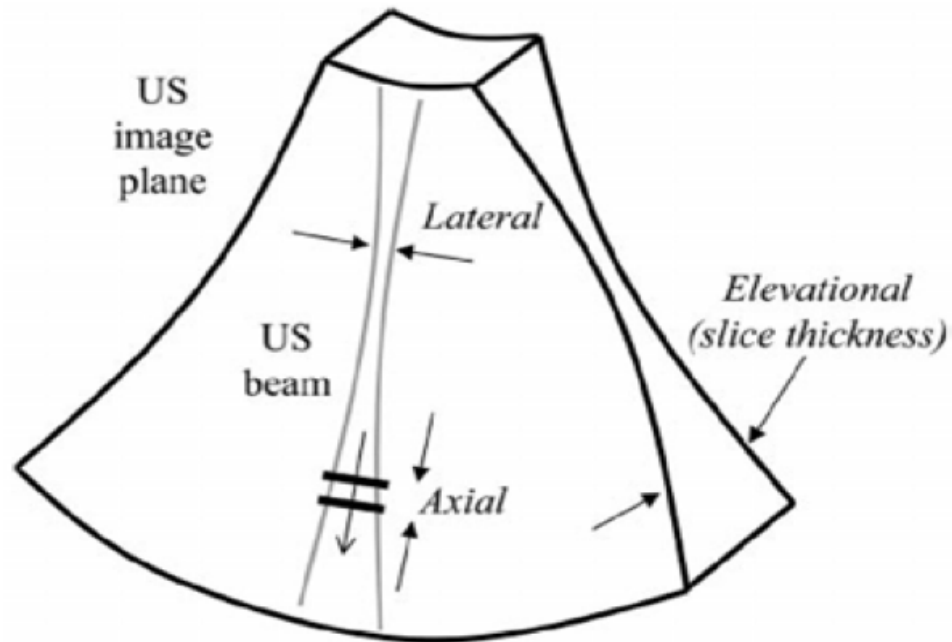


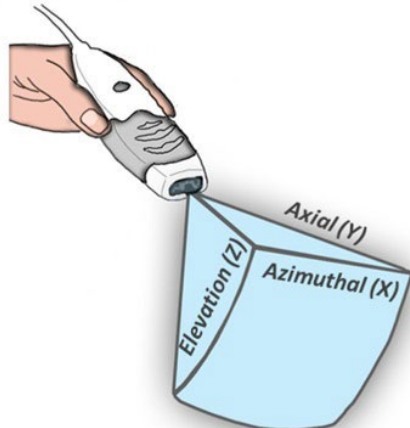
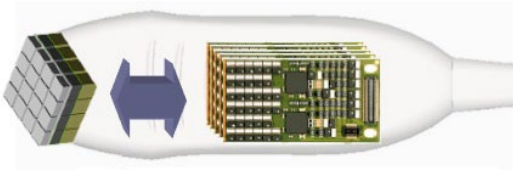
Elevation Resolution



Elevation Resolution

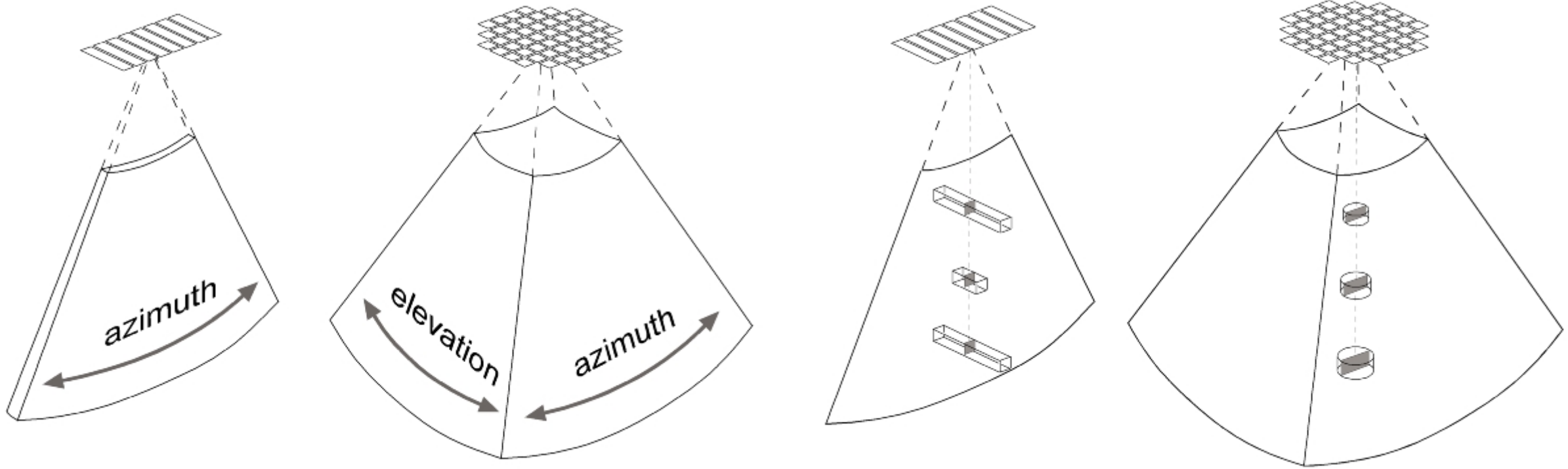
- Not directly visible in an ultrasound image, because it's plane is orthogonal to imaging plane.
- It is determined by the thickness of the slice in the elevation direction.
- Linear arrays are also called 1D arrays because elements are only in the lateral direction.
- Only one element is at the elevation direction → beam characteristics cannot be controlled with beam former → echoes outside of the imaging plane degrade image quality





2D Probes

2D Probes



3D Imaging



2D



3D



4D



HD





3D Imaging

3D Imaging



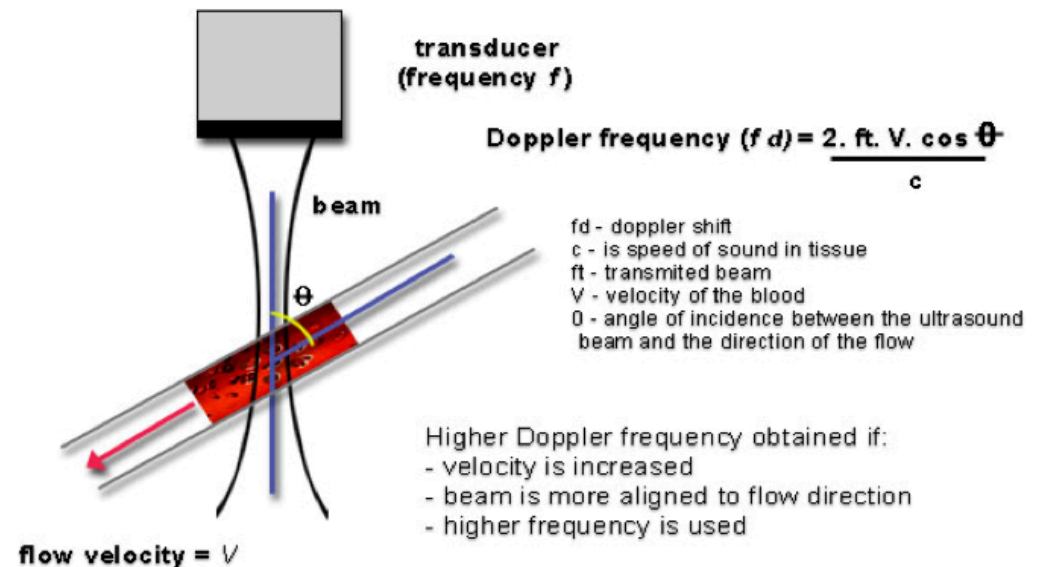
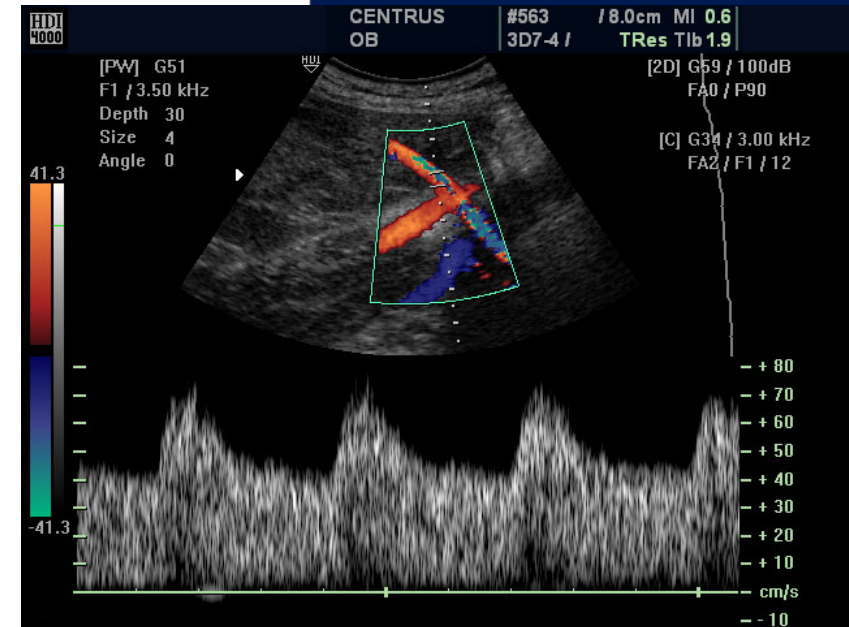
3D Imaging

- Inferior Vena Cava



Blood Flow Imaging

- Based on the Doppler Effect
- Super Impose Blood Flow on structural images
- As a convention, scatterers moving towards the tdr. are coloured **red**, while those moving away **blue**.
- Modern systems also use:
 - Phase Shift Velocity Estimators
 - Time Shift Velocity Estimators





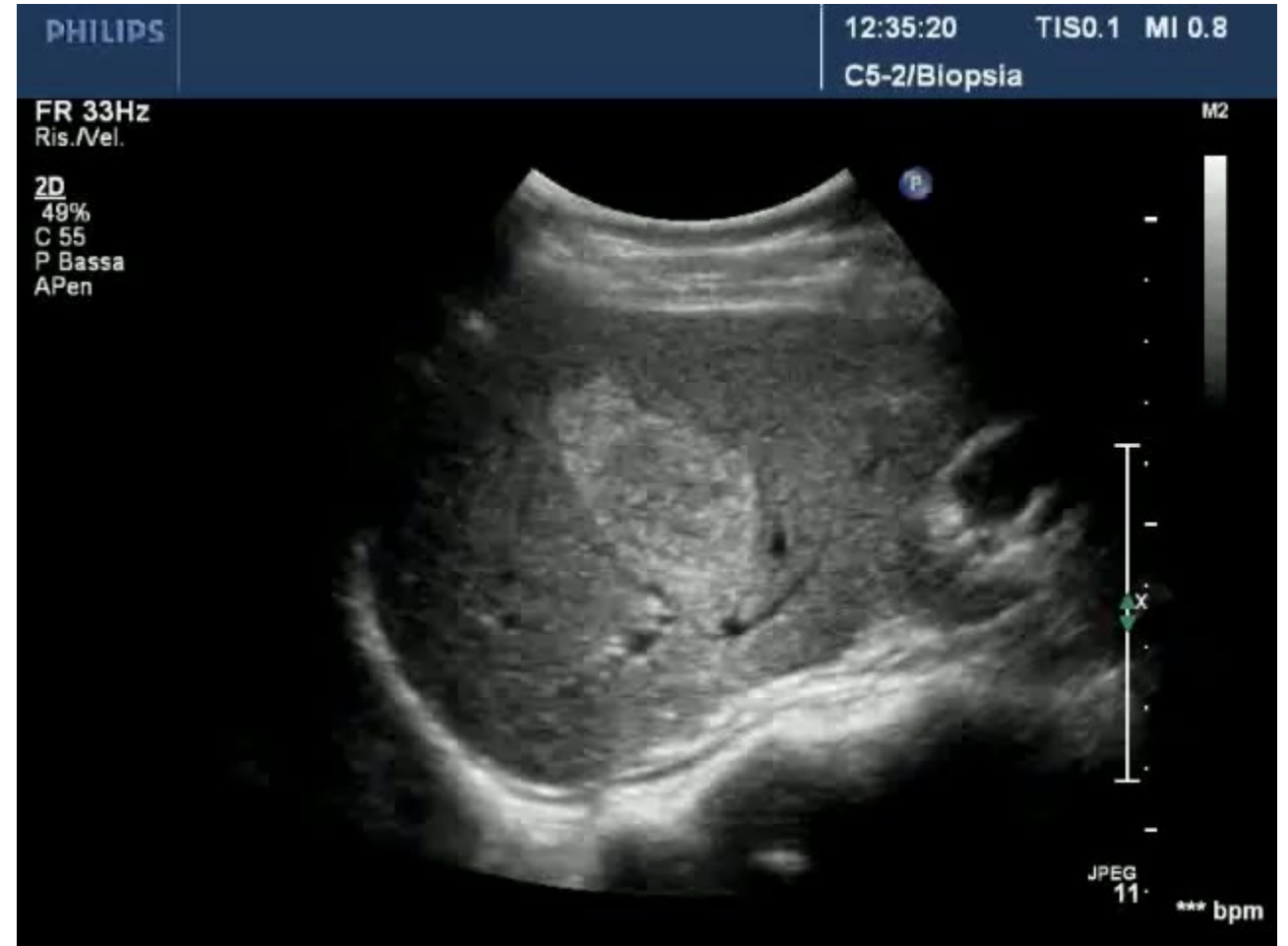
Ultrasound Contrast Agents (UCA)

- **Weak reflection** of ultrasound from the **blood** (60dB smaller than tissue)
- Microbubbles ($\sim 3 \mu\text{m}$) that contain gas that oscillate or brake when insonified.
- By injecting UCA (higher reflectors) blood signal increases and even blood flow in the microcirculations can me detected.
- Gas can be replaced with **drugs**, for **targeted drug delivery**.



Ultrasound Contrast Agents (UCA)

- Detection of Haemangioma



Thank You



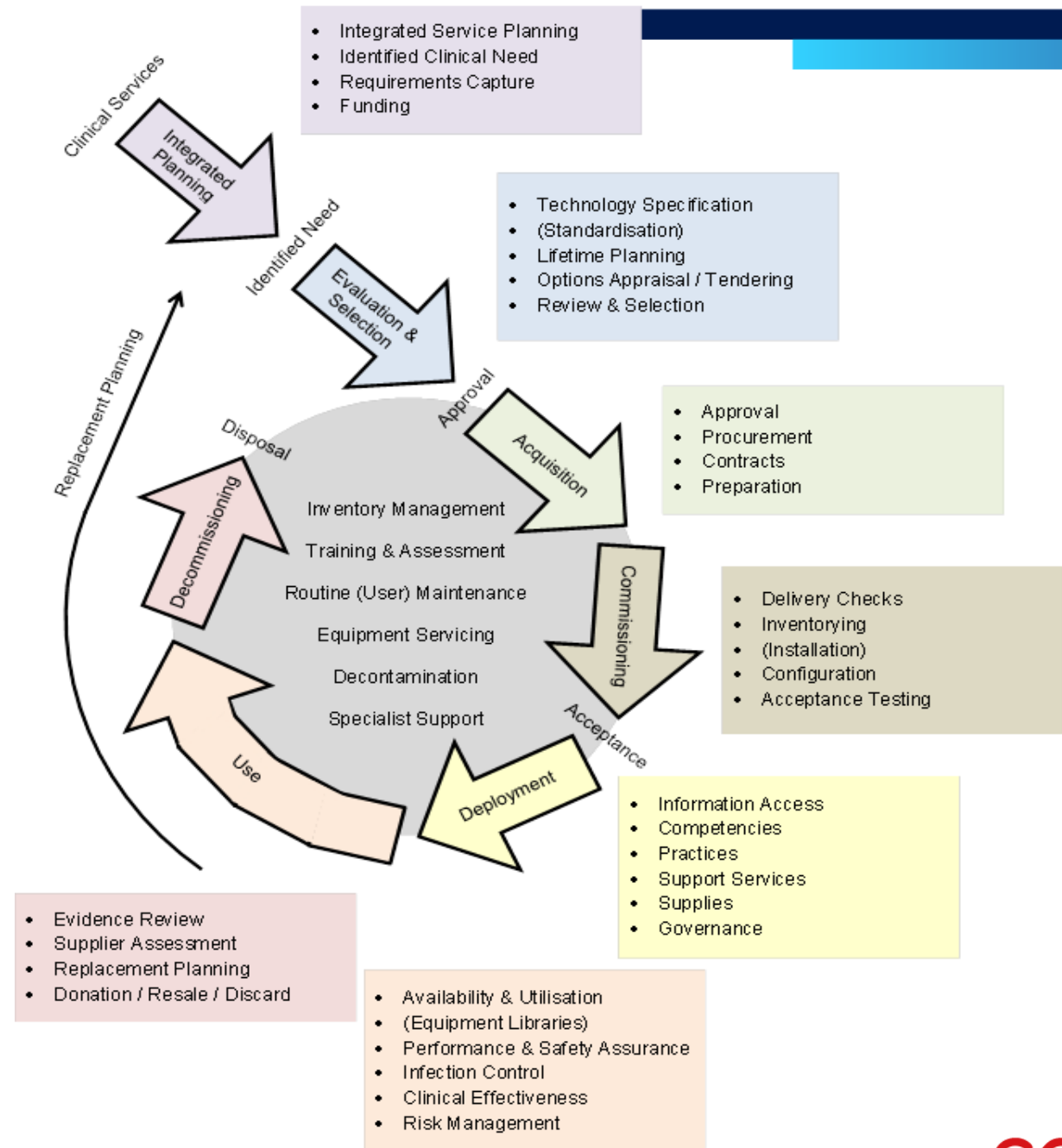
Maintenance of Ultrasound Machines in Hospitals

Prof Dan Clark OBE

Head of Clinical Engineering, Nottingham, UK



Health Technology Management

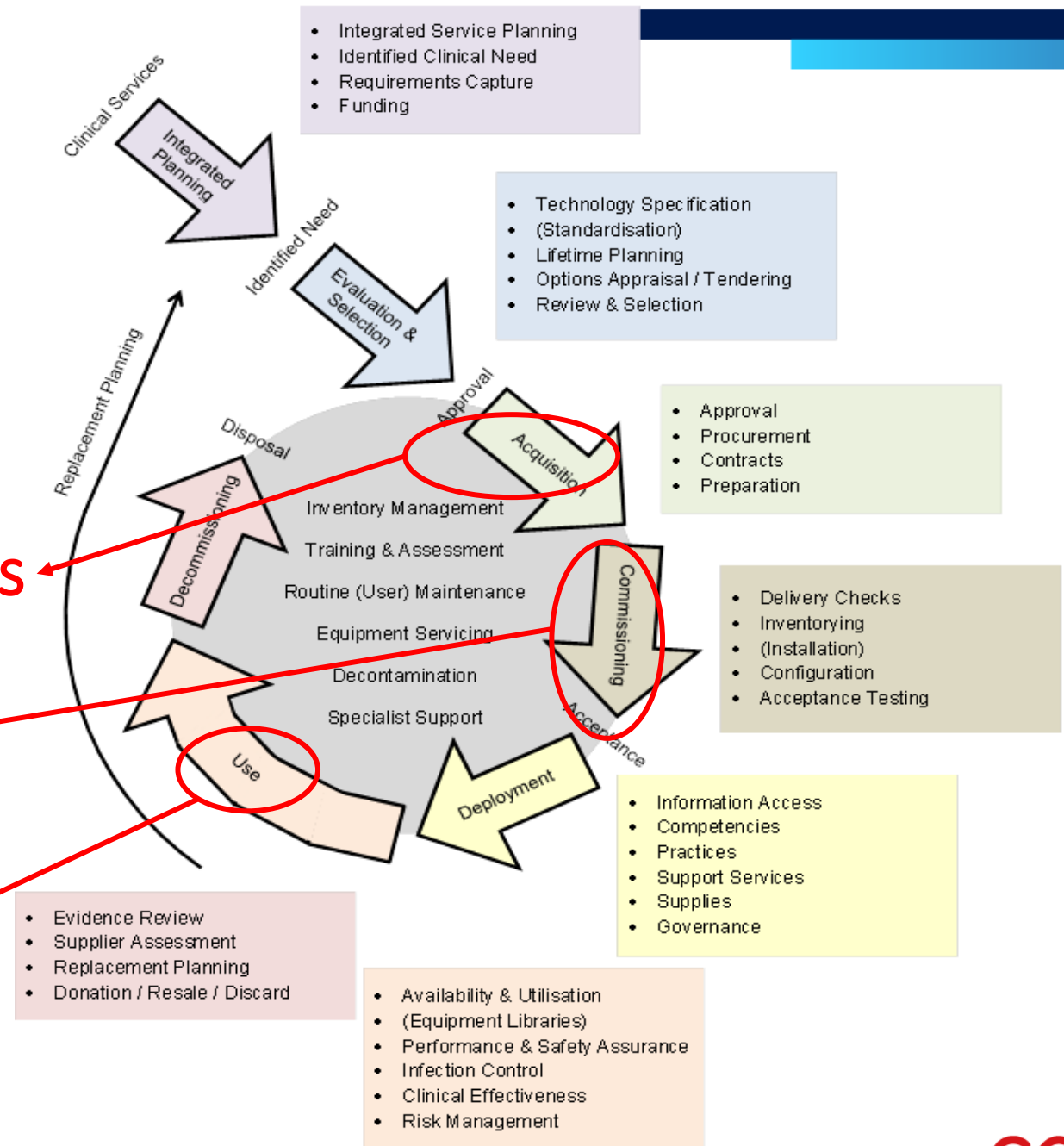


Health Technology Management

(1) Approvals

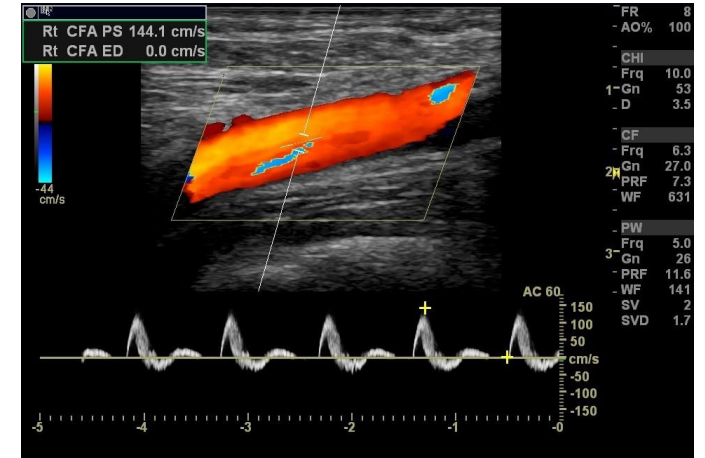
(2) Commissioning

(3) Equipment Maintenance
(Operational Management)



Challenges - 1

- Multiple, diverse clinical settings



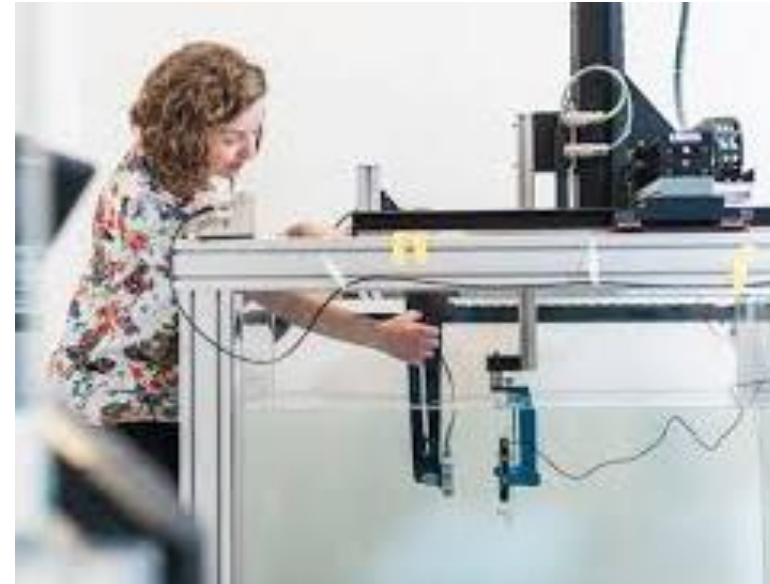
Challenges - 2

- Multiple makes and models



Challenges - 4

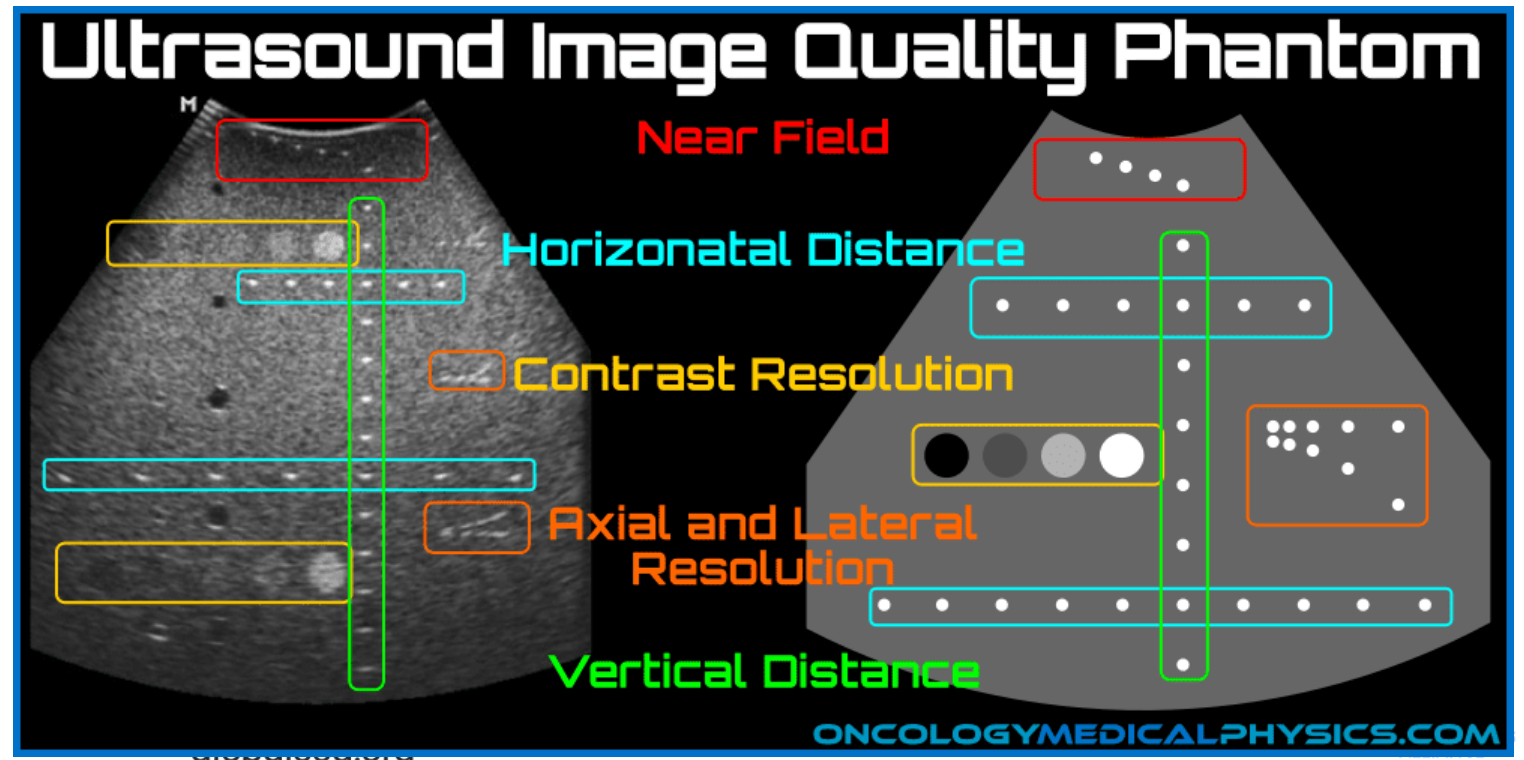
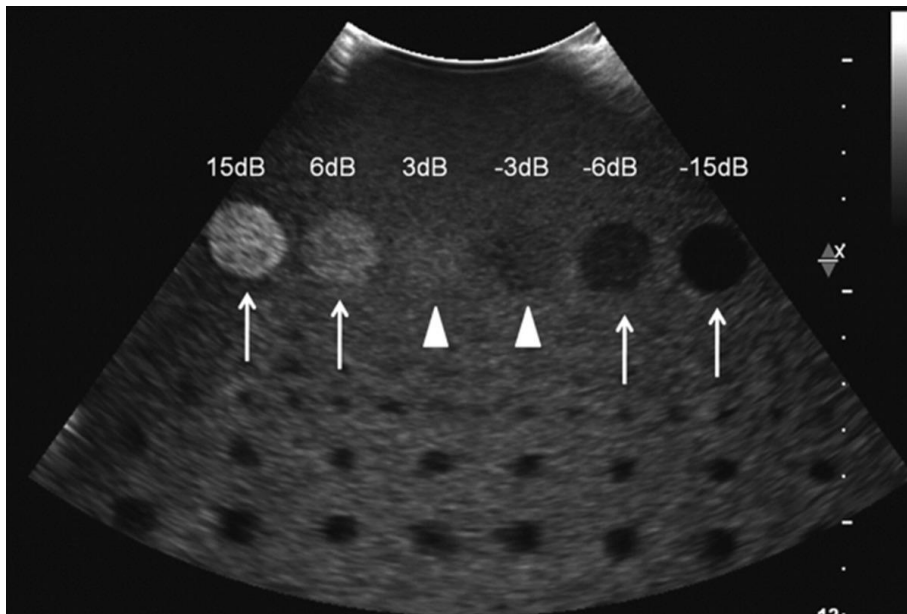
- Multiple skill sets needed
 - in house CEs, OEMs, imaging physics, Infection Control, Information governance



Our approach -2

Commissioning

1. Robust Internal Quality Assurance
 1. Probe Rejection rate $\sim 10\%$



Our approach - 3

1. Operational Management

1. Multiple stakeholders but whole process managed by Clinical Engineering
2. Technical delivery – external contracts
3. Patient Identifiable Data (PID)
4. Technical Quality
5. Image Quality
6. Audit
7. Decontamination



| Equipment | Serial no. | Signature | CE Team | Active | Last APM | Next APM | Description | Warranty Expiry | Recurring | Interval | APM type | Device Group | Location |
|-----------|------------|-----------|-----------|--------|------------|------------|-----------------------------------|-----------------|-----------|-----------|-------------|------------------------|--------------|
| 158017 | P1501922 | MESU QMC | MESU QMC | ✓ | 06/09/2022 | 06/09/2023 | Standard APM; most f... | | ✓ | 12 Months | APM Level-1 | Bladder ultrasound ... | Short Stay U |
| 158018 | P1501704 | MESU QMC | MESU QMC | ✓ | 24/08/2021 | 24/08/2022 | Standard APM; most f... | | ✓ | 12 Months | APM Level-1 | Bladder ultrasound ... | Gynaecology |
| 187626 | 11X031Q3 | MESU City | MESU City | ✓ | | 08/06/2025 | Standard APM; most f...04/04/2024 | | ✓ | 36 Months | APM Level-1 | Bladder ultrasound ... | Equipment Li |
| 187629 | 11X029Q3 | MESU City | MESU City | ✓ | | 08/06/2025 | Standard APM; most f...04/04/2024 | | ✓ | 36 Months | APM Level-1 | Bladder ultrasound ... | Equipment Li |
| 187630 | 11X005Q3 | MESU City | MESU City | ✓ | | 08/06/2025 | Standard APM; most f...04/04/2024 | | ✓ | 36 Months | APM Level-1 | Bladder ultrasound ... | Equipment Li |
| 187631 | 11X022Q3 | MESU City | MESU City | ✓ | | 08/06/2025 | Standard APM; most f...04/04/2024 | | ✓ | 36 Months | APM Level-1 | Bladder ultrasound ... | Equipment Li |
| 187632 | 11X027Q3 | MESU City | MESU City | ✓ | | 08/06/2025 | Standard APM; most f...04/04/2024 | | ✓ | 36 Months | APM Level-1 | Bladder ultrasound ... | Equipment Li |
| 187633 | 11X018Q3 | MESU City | MESU City | ✓ | | 08/06/2025 | Standard APM; most f...04/04/2024 | | ✓ | 36 Months | APM Level-1 | Bladder ultrasound ... | Equipment Li |
| 187634 | 11X001Q3 | MESU City | MESU City | ✓ | | 08/06/2025 | Standard APM; most f...04/04/2024 | | ✓ | 36 Months | APM Level-1 | Bladder ultrasound ... | Equipment Li |
| 187635 | 11X028Q3 | MESU City | MESU City | ✓ | | 08/06/2025 | Standard APM; most f...04/04/2024 | | ✓ | 36 Months | APM Level-1 | Bladder ultrasound ... | Equipment Li |
| 187636 | 11X021Q3 | MESU City | MESU City | ✓ | | 08/06/2025 | Standard APM; most f...04/04/2024 | | ✓ | 36 Months | APM Level-1 | Bladder ultrasound ... | Equipment Li |
| 187637 | 11X015Q3 | MESU City | MESU City | ✓ | | 08/06/2025 | Standard APM; most f...04/04/2024 | | ✓ | 36 Months | APM Level-1 | Bladder ultrasound ... | Equipment Li |
| 187638 | 11X004Q3 | MESU City | MESU City | ✓ | | 08/06/2025 | Standard APM; most f...04/04/2024 | | ✓ | 36 Months | APM Level-1 | Bladder ultrasound ... | Equipment Li |
| 187639 | 11X010Q3 | MESU City | MESU City | ✓ | | 08/06/2025 | Standard APM; most f...04/04/2024 | | ✓ | 36 Months | APM Level-1 | Bladder ultrasound ... | Equipment Li |
| 187640 | 11X009Q3 | MESU City | MESU City | ✓ | | 08/06/2025 | Standard APM; most f...04/04/2024 | | ✓ | 36 Months | APM Level-1 | Bladder ultrasound ... | Equipment Li |
| 187641 | 11X030Q3 | MESU City | MESU City | ✓ | | 08/06/2025 | Standard APM; most f...04/04/2024 | | ✓ | 36 Months | APM Level-1 | Bladder ultrasound ... | Equipment Li |
| 187642 | 11X013Q3 | MESU City | MESU City | ✓ | | 08/06/2025 | Standard APM; most f...04/04/2024 | | ✓ | 36 Months | APM Level-1 | Bladder ultrasound ... | Equipment Li |
| 187643 | 11X019Q3 | MESU City | MESU City | ✓ | | 08/06/2025 | Standard APM; most f...04/04/2024 | | ✓ | 36 Months | APM Level-1 | Bladder ultrasound ... | Equipment Li |
| 187644 | 11X017Q3 | MESU City | MESU City | ✓ | | 08/06/2025 | Standard APM; most f...04/04/2024 | | ✓ | 36 Months | APM Level-1 | Bladder ultrasound ... | Equipment Li |
| 187645 | 11X009Q3 | MESU City | MESU City | ✓ | | 08/06/2025 | Standard APM; most f...04/04/2024 | | ✓ | 36 Months | APM Level-1 | Bladder ultrasound ... | Equipment Li |
| 187646 | 11X014Q3 | MESU City | MESU City | ✓ | | 08/06/2025 | Standard APM; most f...04/04/2024 | | ✓ | 36 Months | APM Level-1 | Bladder ultrasound ... | Equipment Li |
| 187647 | 11X026Q3 | MESU City | MESU City | ✓ | | 08/06/2025 | Standard APM; most f...04/04/2024 | | ✓ | 36 Months | APM Level-1 | Bladder ultrasound ... | Equipment Li |
| 187648 | 11X008Q3 | MESU City | MESU City | ✓ | | 08/06/2025 | Standard APM; most f...04/04/2024 | | ✓ | 36 Months | APM Level-1 | Bladder ultrasound ... | Equipment Li |
| 187649 | 11X024Q3 | MESU City | MESU City | ✓ | | 08/06/2025 | Standard APM; most f...04/04/2024 | | ✓ | 36 Months | APM Level-1 | Bladder ultrasound ... | Equipment Li |
| 187650 | 11X032Q3 | MESU City | MESU City | ✓ | | 08/06/2025 | Standard APM; most f...04/04/2024 | | ✓ | 36 Months | APM Level-1 | Bladder ultrasound ... | Equipment Li |
| 187651 | 11X023Q3 | MESU City | MESU City | ✓ | | 08/06/2025 | Standard APM; most f...04/04/2024 | | ✓ | 36 Months | APM Level-1 | Bladder ultrasound ... | Equipment Li |
| 187652 | 11X003Q3 | MESU City | MESU City | ✓ | | 08/06/2025 | Standard APM; most f...04/04/2024 | | ✓ | 36 Months | APM Level-1 | Bladder ultrasound ... | Equipment Li |

Lessons Learnt

- Manage expectations
- Communications
- Understand (and accept?) quality limitations
- Allow time to manage the process
- Probe Library
- Finances



Thank You!



Questions



Q&A



A list of additional topics and dates for next webinars will be soon announced on our website www.GlobalCEA.org

THANK YOU
for your participation