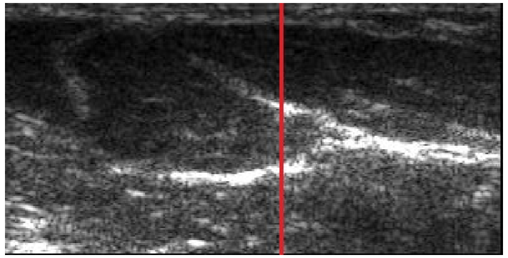
Lecture 17 – Ultrasound Imaging

This lecture will cover: *(CH4.8-4.13)*

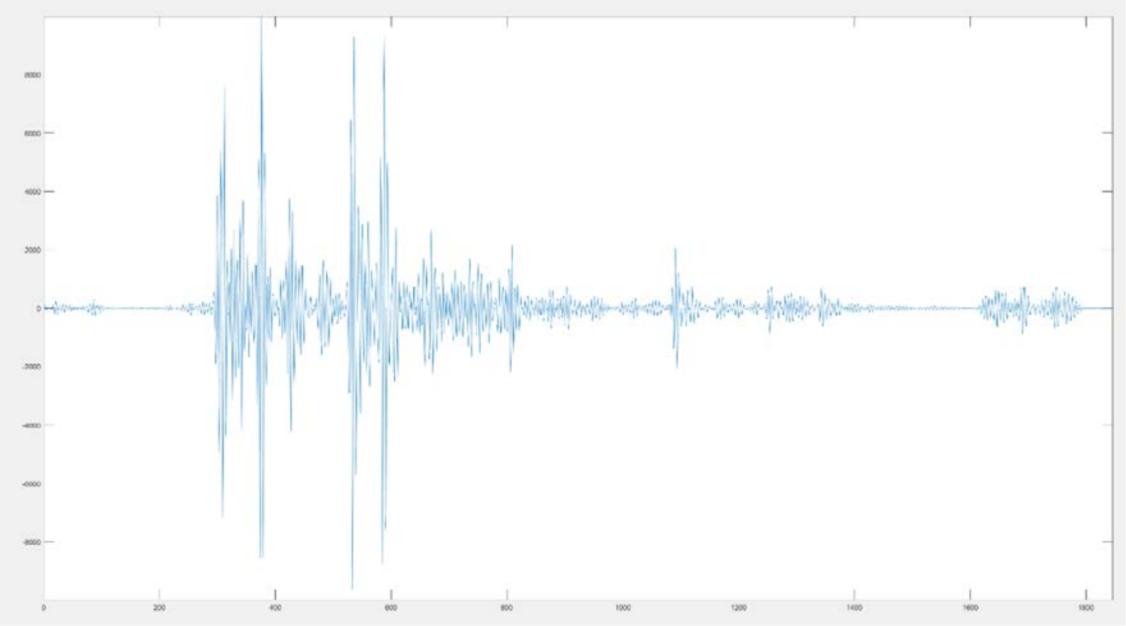
- – Ultrasound signal acquisition and processing
- – Clinical diagnostic scanning modes
  - ➢ A (amplitude) mode
  - ➢ M (motion) mode
  - ➢ B (Brightness) mode
- – Imaging characteristics
- – 3D/4D ultrasound
- – Ultrasound Tomography
- – Endoscopic Ultrasound
- – Elastography
- – EM wave induced imaging

(*Supplementary reading: The Essential Physics of Medical Imaging CH14.5-14.9, FMI 6.5)*

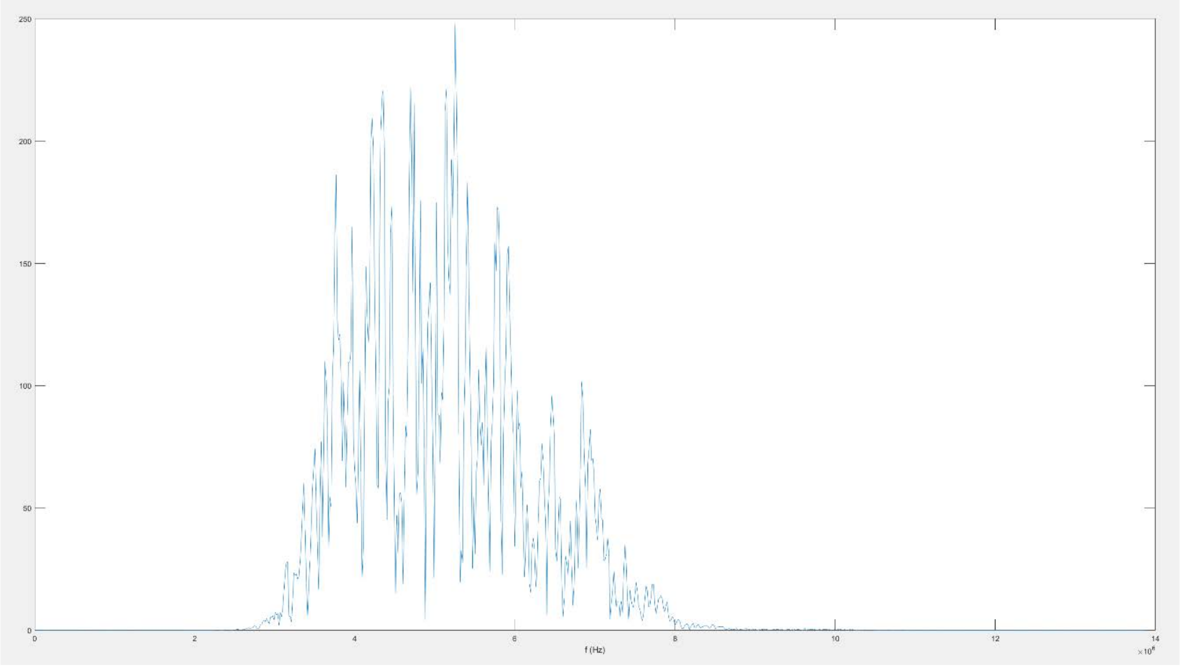
Ultrasound signal



Original time signal

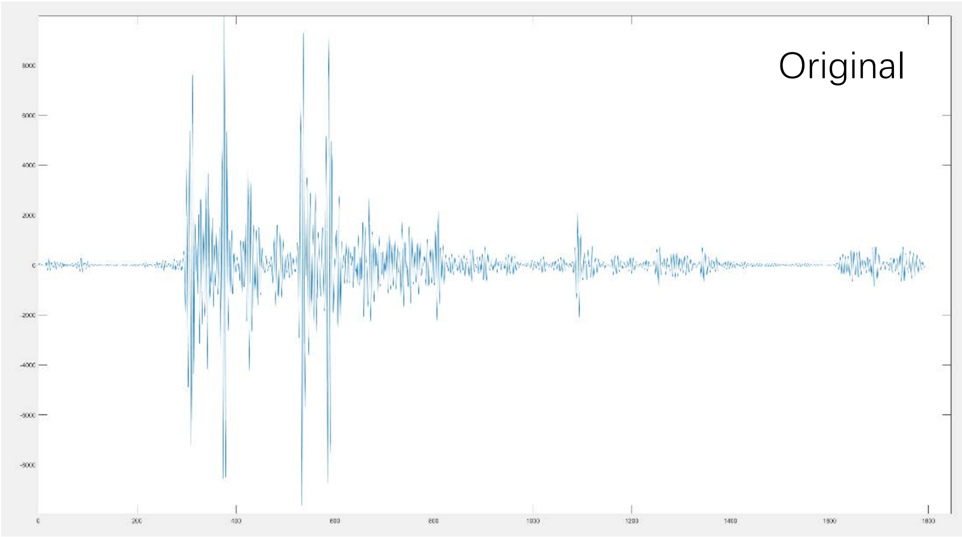


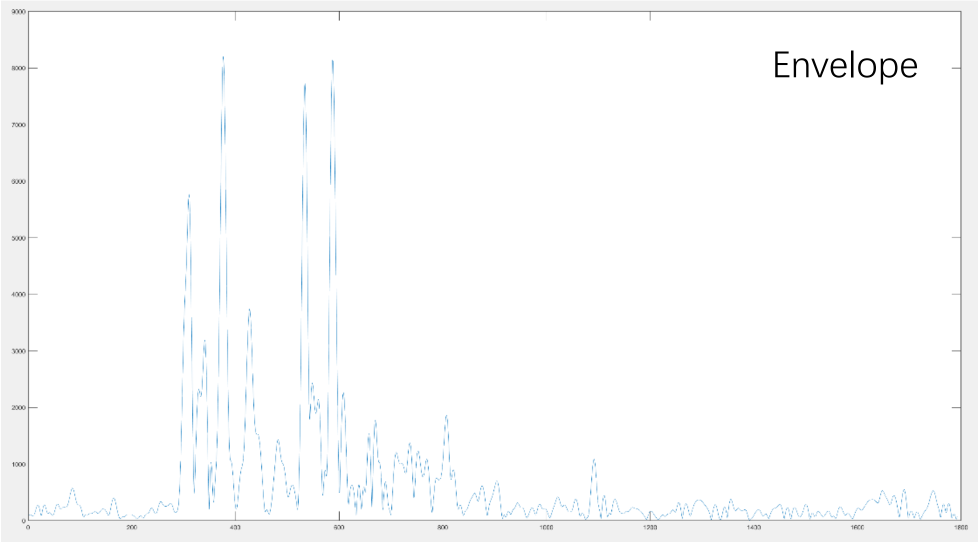
Spectrum

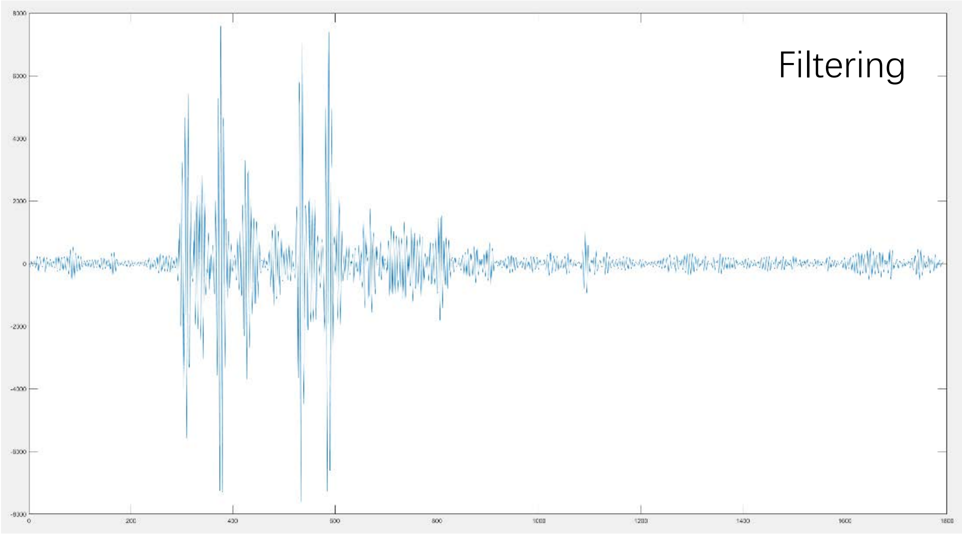


Ultrasound Signal Processing

- Filtering - noise deduction
- Envelope – peaks from interfaces
- Amplification – enhancement
- Other processing steps







Clinical diagnostic scanning modes

- **A (amplitude) mode :**

  a one-dimensional “line image” which is a plot of amplitude vs time

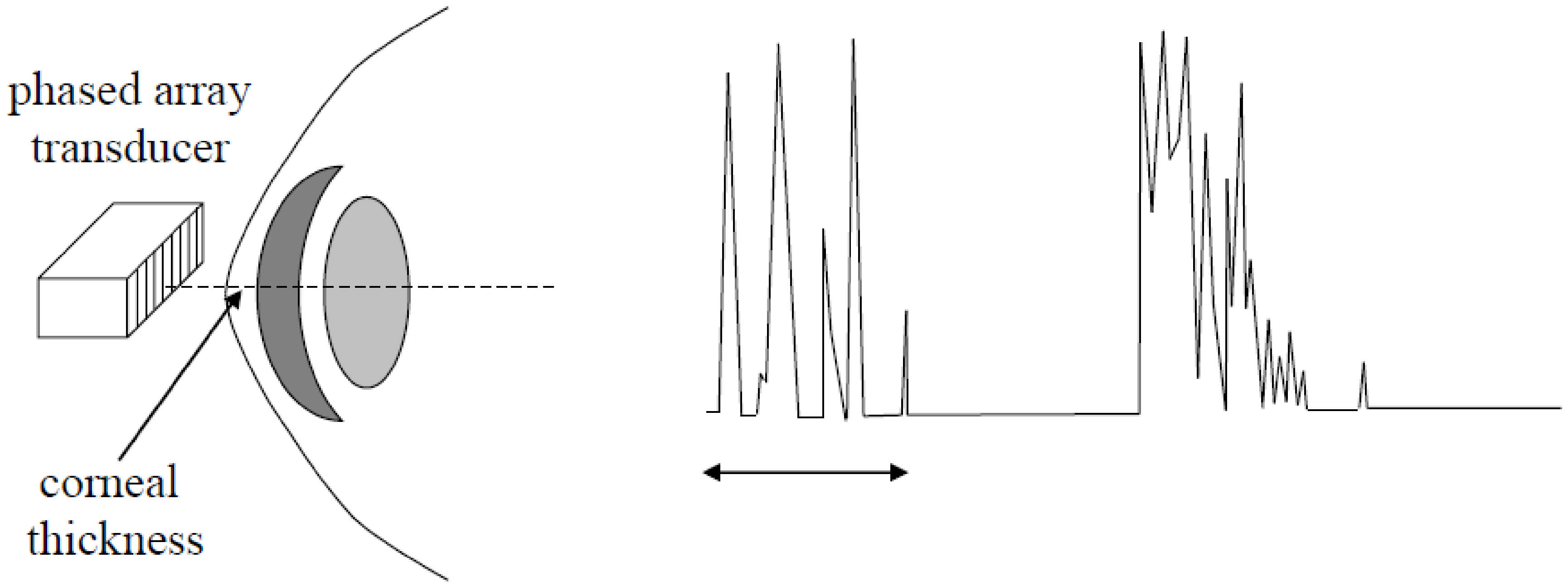


Fig. Use of A-mode ultrasound scanning to measure the corneal thickness of the eye. A single line of high frequency ultrasound is used, and the one-dimensional signal plot is shown on the right. The double headed arrow represents the thickness of the cornea..

Clinical diagnostic scanning modes

- **M (motion) mode:**

  a continuous series of A-mode lines and display them as a function of time.

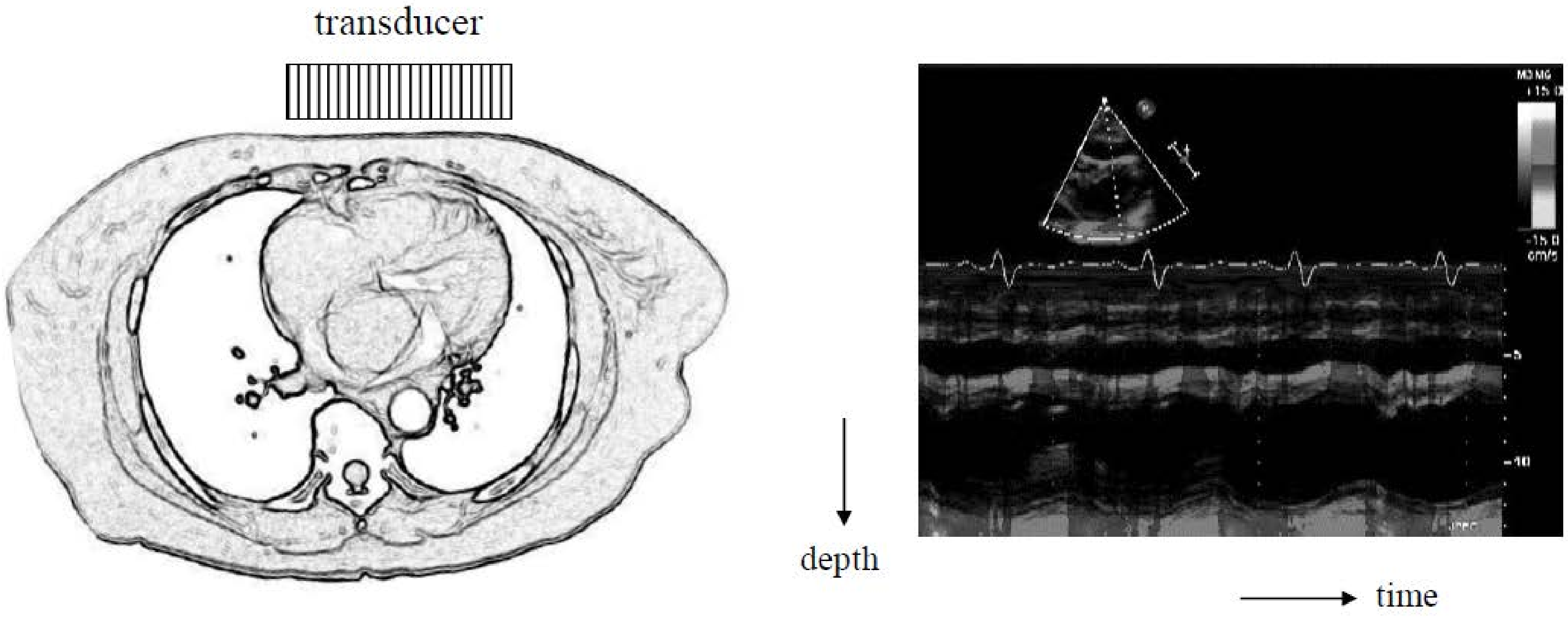


Fig. M-mode data acquisition. The transducer is placed above the heart and sends out a single line of ultrasound. An A-mode scan is recorded, and as soon as the last echo has been acquired, the A mode scan is repeated. The horizontal time-axis increments for each scan, and therefore a time-series of one-dimensional scans is built up. A straight line represents a structure that is stationary, whereas the front of the heart shows large changes in position.

Clinical diagnostic scanning modes

➢ B (Brightness) mode:

- most commonly used in clinical diagnosis
- a 2D image through a cross-section of tissue;
- 3D imaging can be performed by multi-dimensional arrays

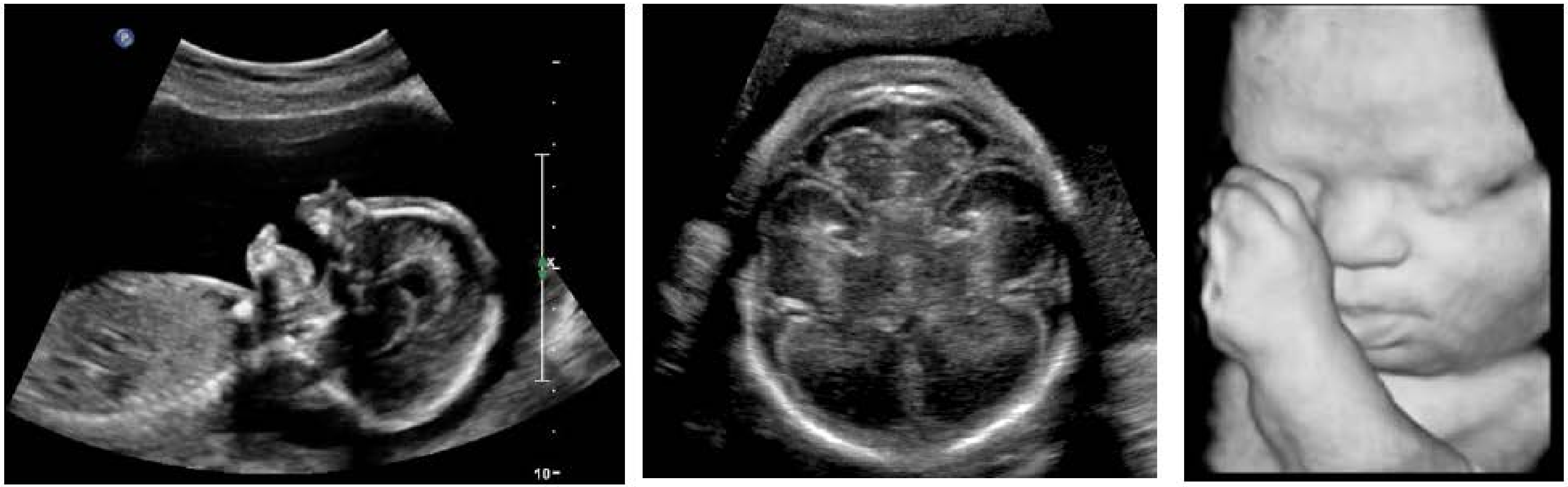


Fig. Two-dimensional B-mode scans of (left) 19 week fetus in the womb, and (centre) foetal brain. (right) Three dimensional foetal image using a two-dimensional array and mechanical steering.

Clinical diagnostic scanning modes

- **Compound scanning**
  - Acquire an ultrasound image from multiple angles and combine the images together;
  - Reduce the speckles caused by scattering;
  - Present the irregular curvatures without influence of structures parallel to the beam;
  - Reduce other artifacts such as acoustic enhancement and shadowing;

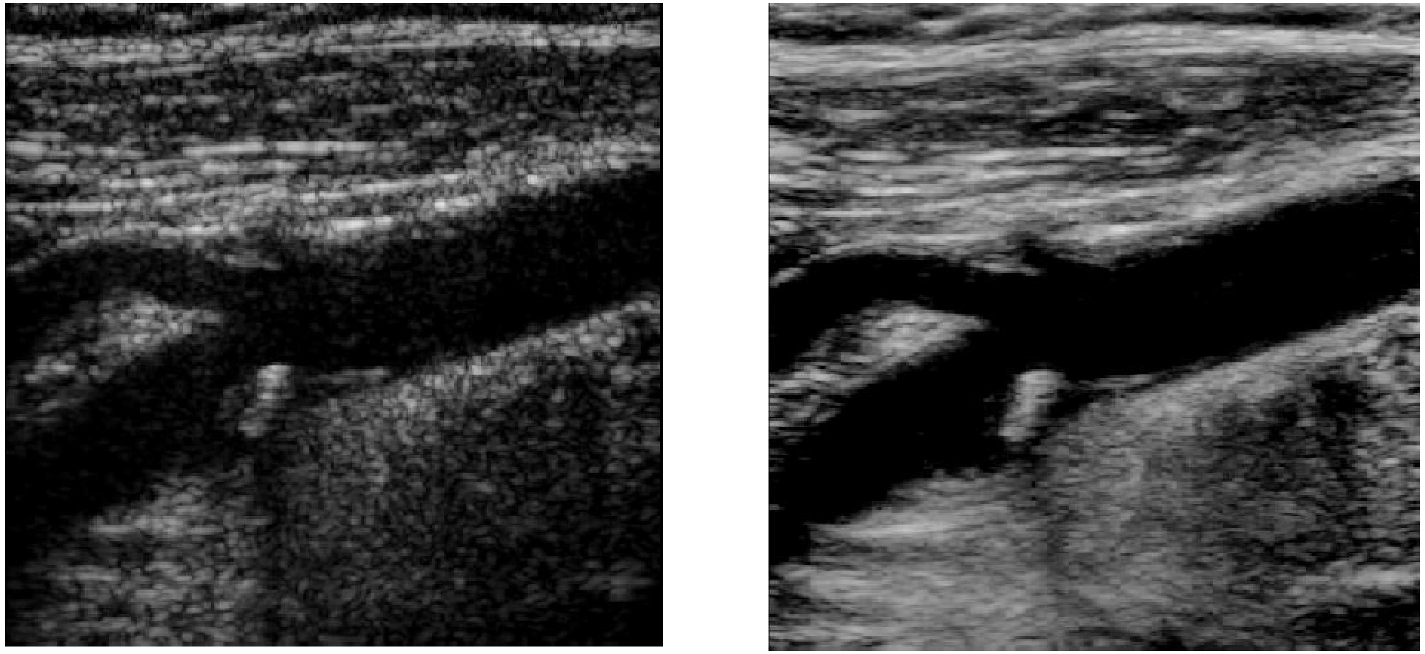


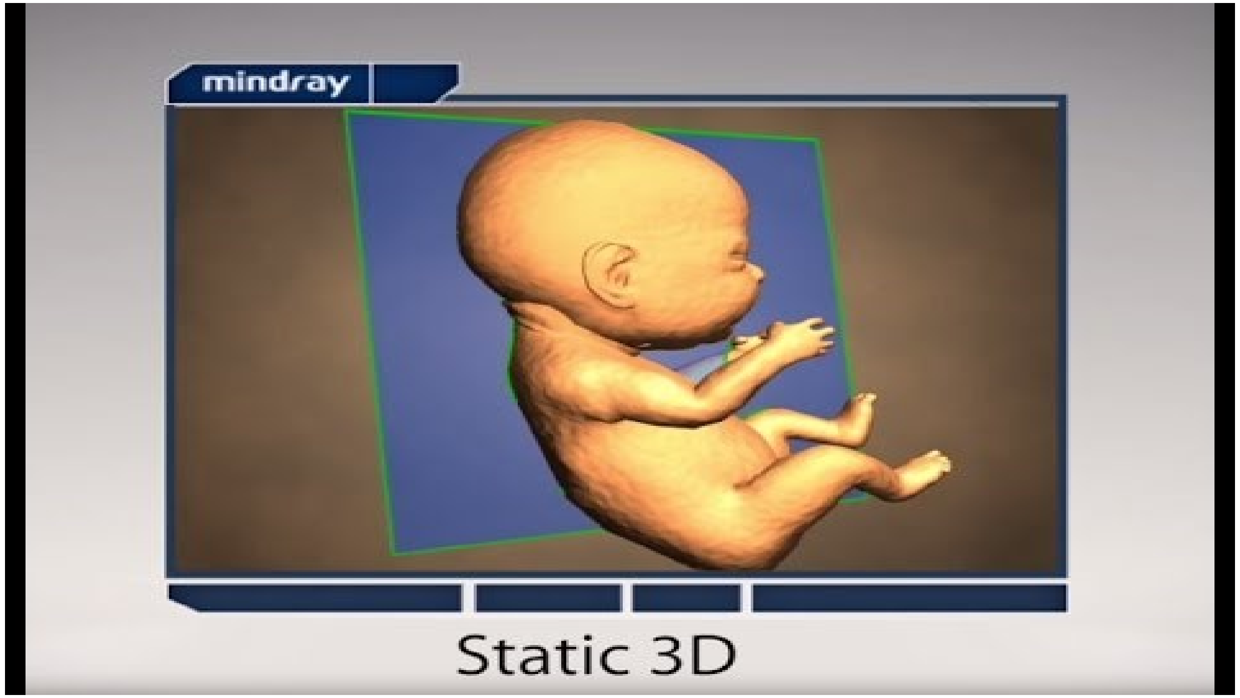
Fig. Comparison of a carotid artery bifurcation acquired using a conventional B-mode scan on the left, and a compound scan with nine different orientations on the right.

Image characteristics

- **Signal-to-noise**
  - The intensity of transmitted pulse;
  - The operating frequency of transducer: higher frequency, lower SNR;
  - The type of focusing: the higher focusing, the higher SNR at focal area, but lower SNR outside of depth-of-focus;
  - Noise sources: speckles from scattering and clutters from side lobes, grating lobes, multi-path reverberation and tissue motion;
- **Spatial resolution**
  - Lateral resolution: focusing and frequency, pitch of array transducer.
  - Axial resolution: ½ wavelength of ultrasound pulse, therefore higher damping, frequency provide better resolution
- **Contrast-to-noise:** similar to SNR

3D/4D Imaging

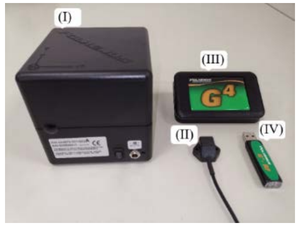
- ➢ Used in fetal, cardiac, trans-rectal and intra-vascular applications;
- ➢ Referring to the volume rendering of ultrasound data;
- ➢ Generating methods:
  - Freehand
  - Mechanically,
  - Endoprobe
  - 2D matrix array transducer



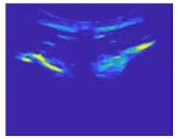
Portable 3D Ultrasound Imaging

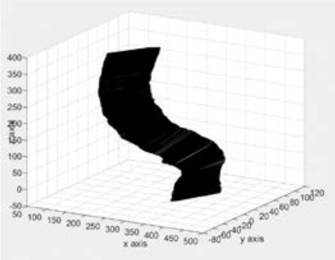
Compact 2D ultrasound scanner

Portable tracking system

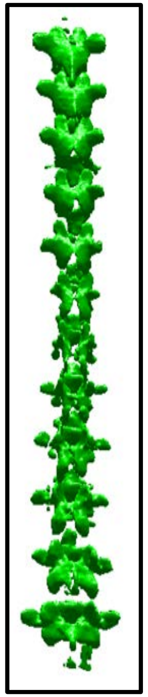


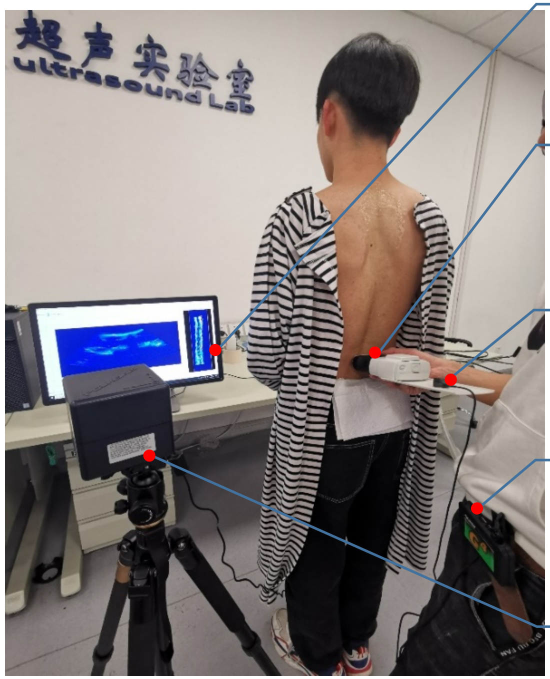
2D transverse frames





Location information





Monitor displays the reconstruction result
in real time

Scanner was used to transmit 2D frames continuously to the host computer by the WI-FI connection

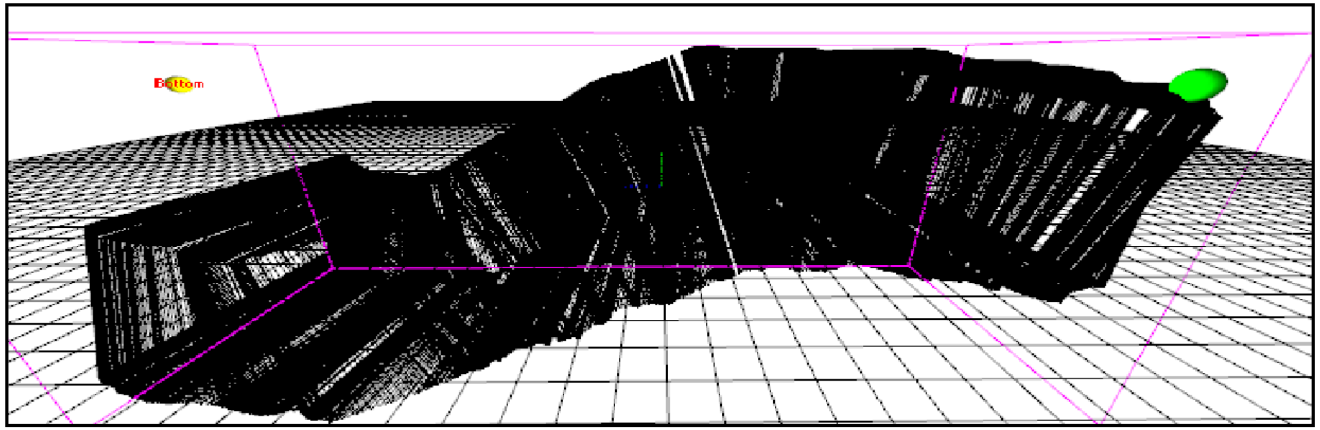
(II) Sensor was installed about 10*cm* behind the scanner

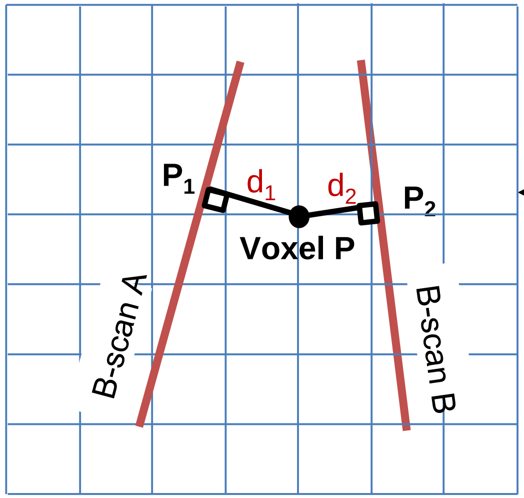
(III) ***Hub*** was used to deliver tracking data to the host computer wirelessly via a *RF/USB* module *(IV)*

(I) Source generates the electromagnetic (EM) field to track ***sensor***

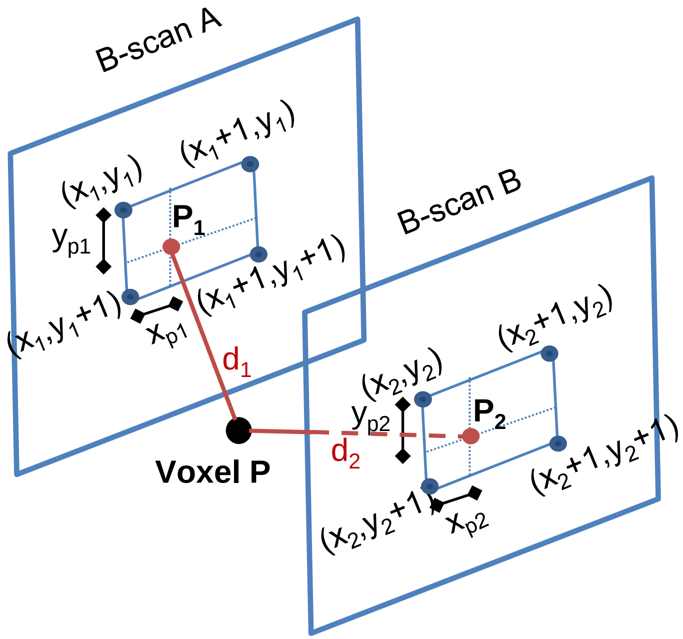
Fig. Portable 3D ultrasound imaging system

3D Reconstruction

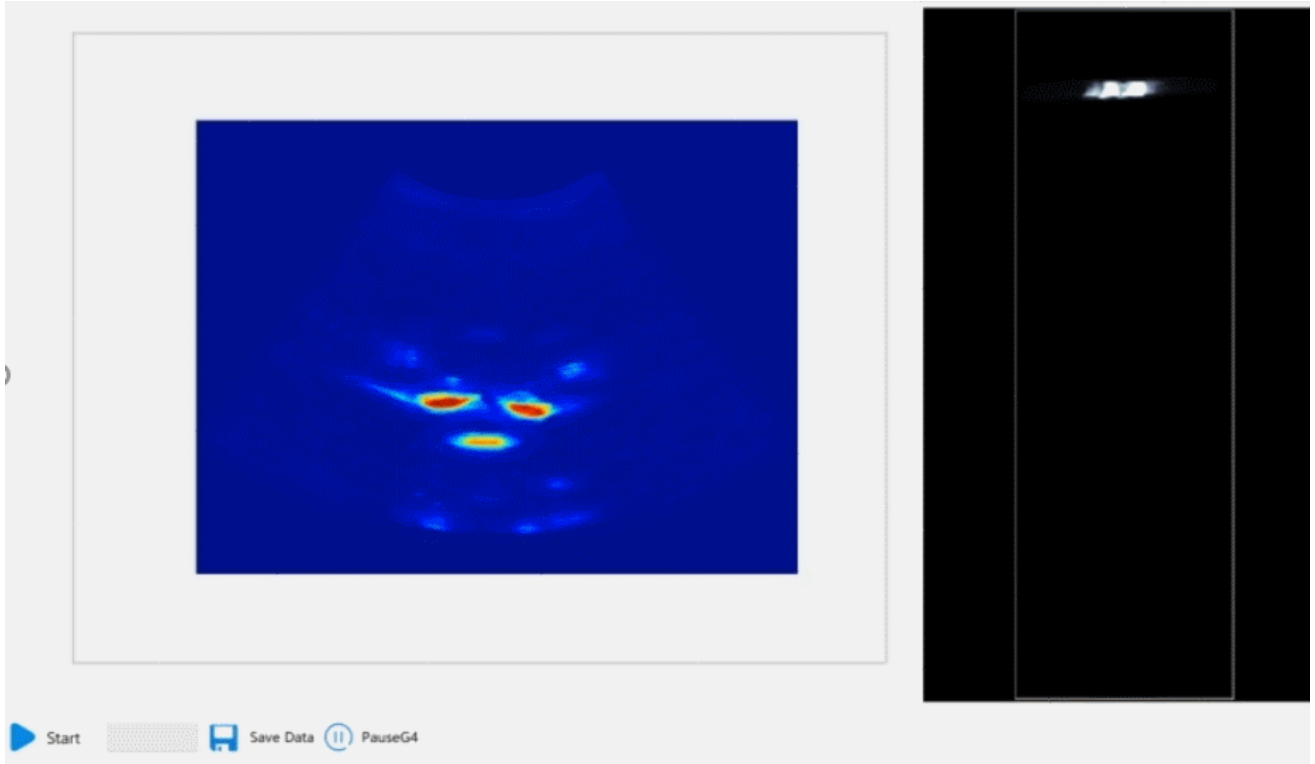




$$P = \frac{P_1 \cdot \frac{1}{d_1} + P_2 \cdot \frac{1}{d_2}}{\frac{1}{d_1} + \frac{1}{d_2}}$$

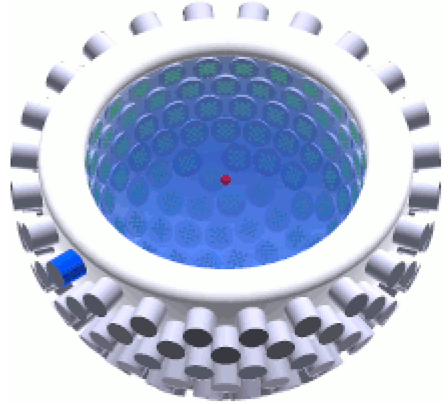


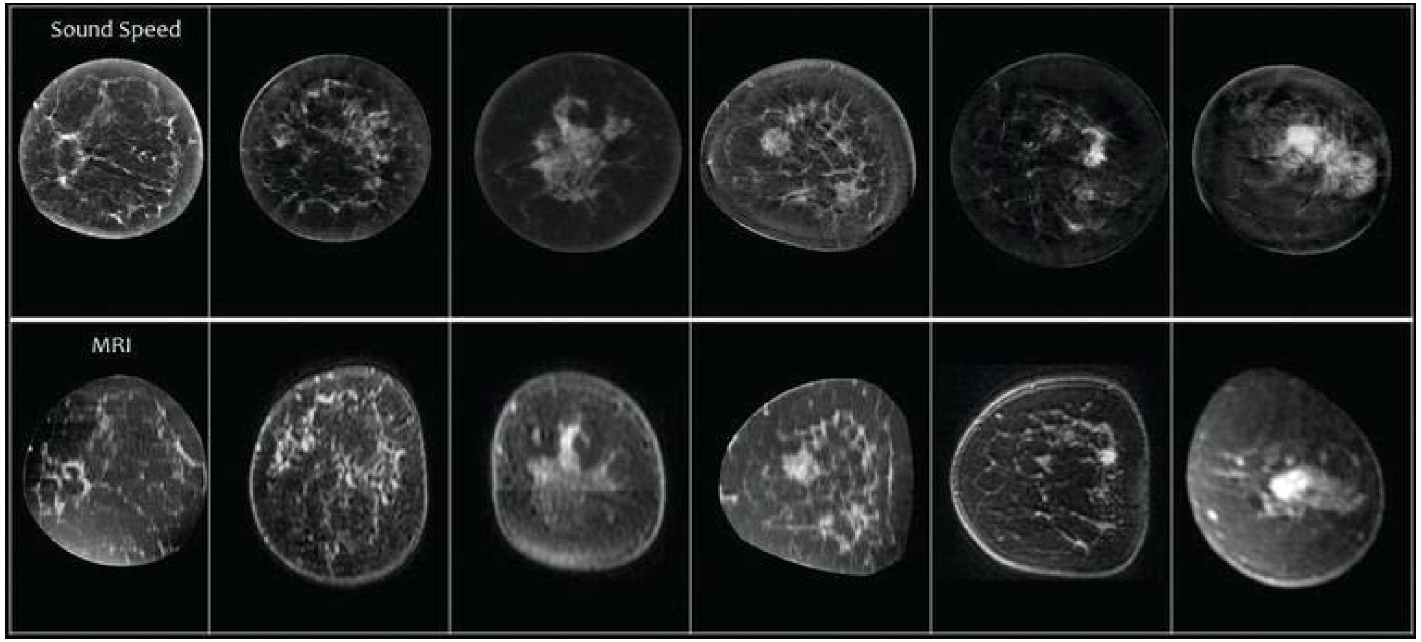
3D Ultrasound Imaging



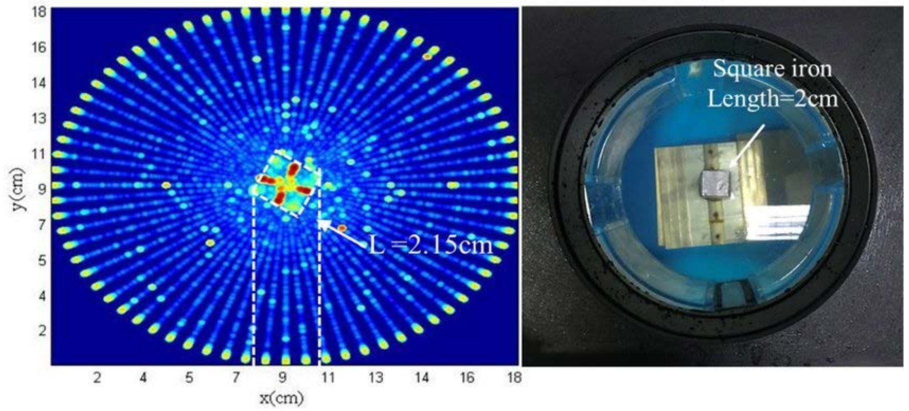
Ultrasound Tomography

- Circular scanning using the ring system;
- Currently most used for breast cancer;
- More complex algorithm based on wave equation and inverse problem;





Top: Coronal UST sound speed images for six different patients.
Bottom: Corresponding fat subtracted contrast-enhanced MR images



Endoscopic Ultrasound

Endoscopic Ultrasound (EUS, 内窥镜超声)

- a minimally invasive procedure to assessing digestive (gastrointestinal) and lung diseases;
- high-frequency ultrasound
- detailed images of the lining and walls of digestive tract and chest, nearby organs such as the pancreas and liver, and lymph nodes;
- combined with fine-needle aspiration (细针抽吸活检)

https://www.youtube.com/watch?v=DLjKze7a6Y8&list=PL08eXrSEzsLbI-mcLwho0n3vY7TfZ8tIg&index=1

Elastography

Elasticity Imaging (Elastography, 弹性成像)

- Mapping the elastic properties and stiffness of soft tissue;
- Ultrasound elastographic techniques
  - Quasistatic elastography / strain imaging;
  - Acoustic radiation force impulse imaging (ARFI)
  - Shear-wave elasticity imaging (SWEI)

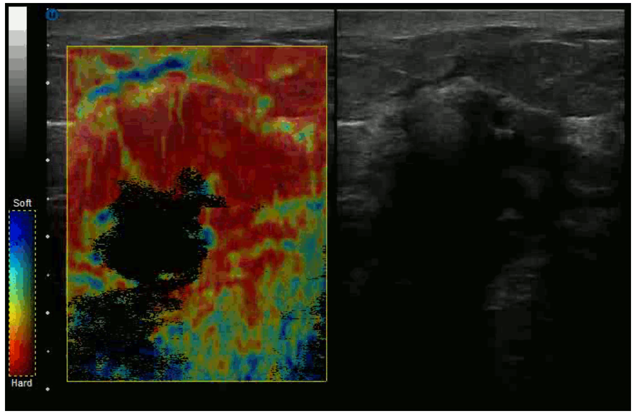


Fig. Manual compression (quasistatic) elastography of invasive ductal carcinoma, a breast cancer.

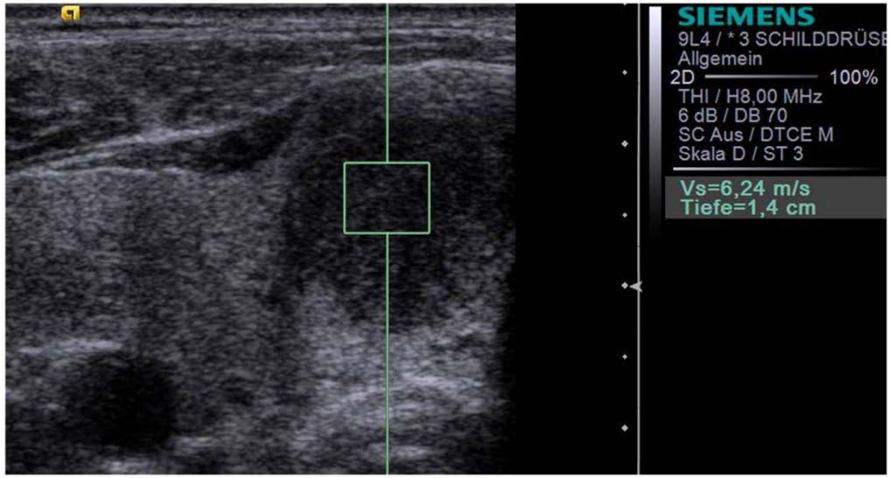


Fig. An ARFI image of a thyroid nodule in the right thyroid lobe. The shear wave speed inside the box is 6.24 m/s, which is reflective of a high stiffness. Histology revealed papillary carcinoma.

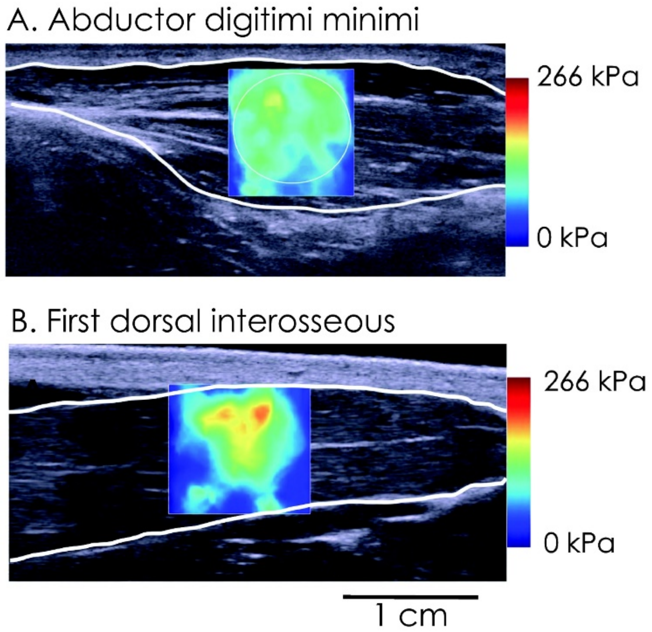
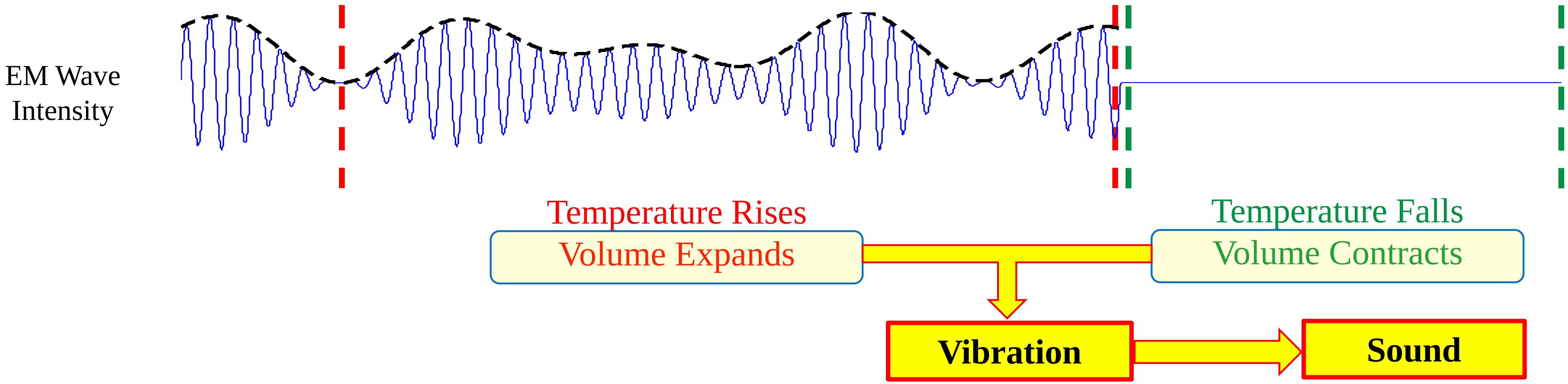


Fig. Supersonic shear imaging of the stiffness during contraction of the hand muscles abductor digiti minimi (A) and first dorsal interosseous (B). The scale is in kPa of shear modulus.

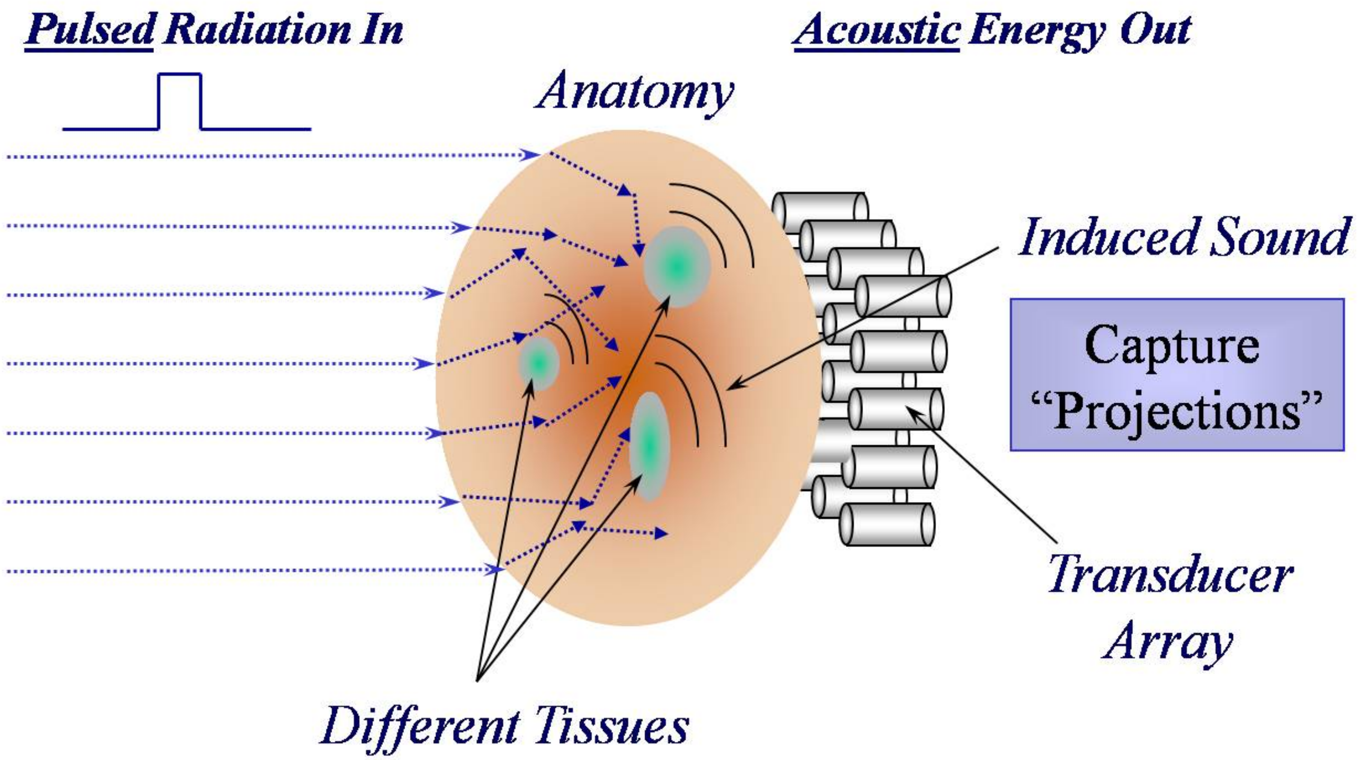
EM wave induced imaging

- Audible sound could be created by illuminating an intermittent beam of sunlight onto a rubber sheet. --- by A. G. Bell in 1880
- Hybrid imaging techniques: electromagnetic-to-acoustic energy conversion
- Radio, microwave (Thermoacoustic, TA), terahertz, optical (Photoacoustic, PA)



EM wave induced imaging

- Using microwave to image biological samples was proposed by T. Bowen in 1981, microwave-induced thermoacoustic imaging (TAI);
- Using Laser to image biological tissues from 1980s, photoacoustic imaging
- Incident electromagnetic wave intensity must be modulated or usually in the form of a pulse;
- EM energy absorption is closely associated with physiological properties of tissues.

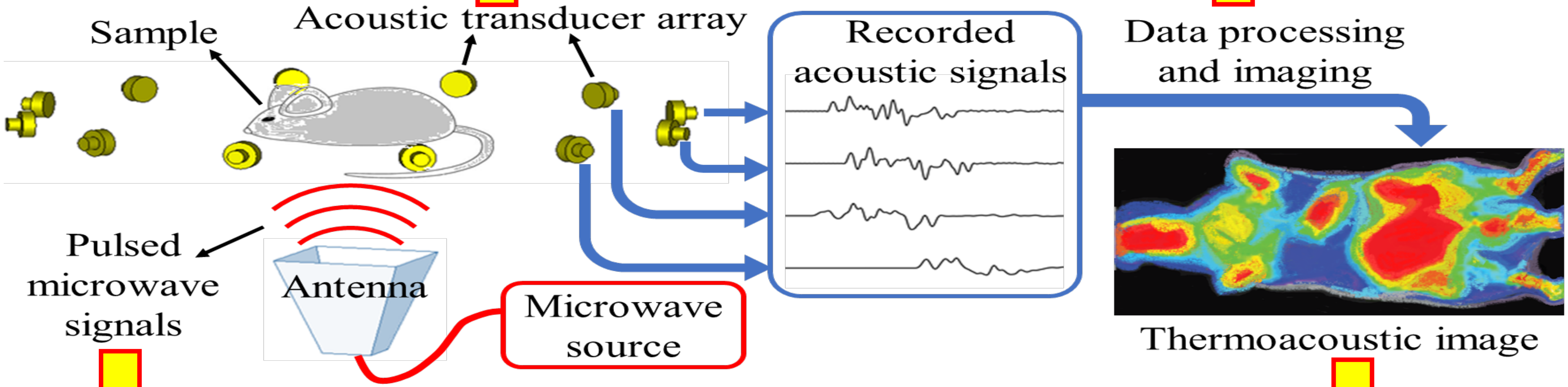


Thermoacoustic Imaging

Basic Setup

- Acoustic signal frequency: kHz – MHz

- Imaging algorithm: back-projection, delay and sum, compressive sensing

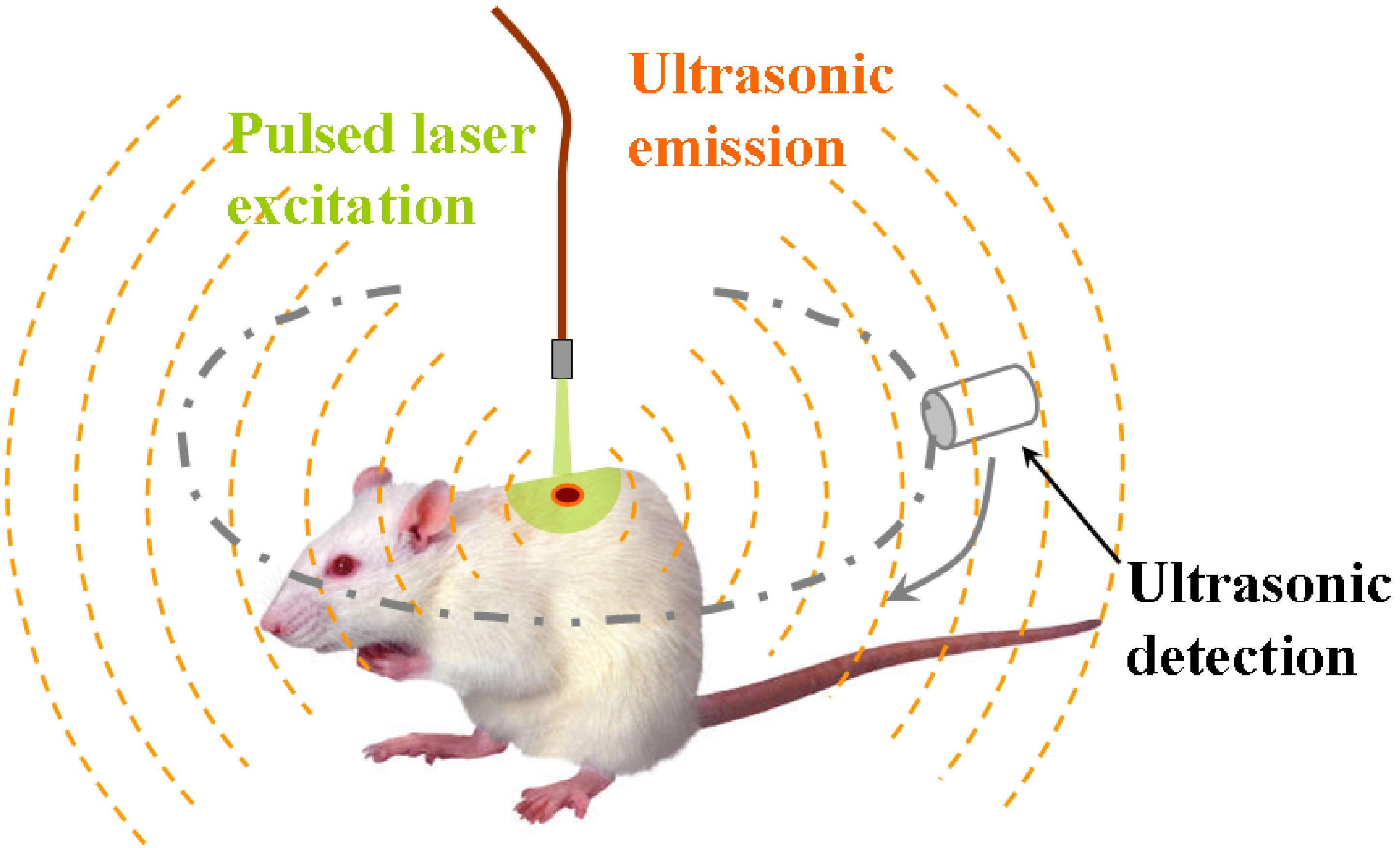


- Pulse width: ns – μs
- Frequency: below 10 GHz
- Peak power: kW

Advantages:
- Non-ionizing and noninvasive
- High contrast (microwave imaging)
- High resolution ~mm (ultrasound imaging)
- Low cost and compact
- Easy imaging procedure (<10% acoustic heterogeneity)

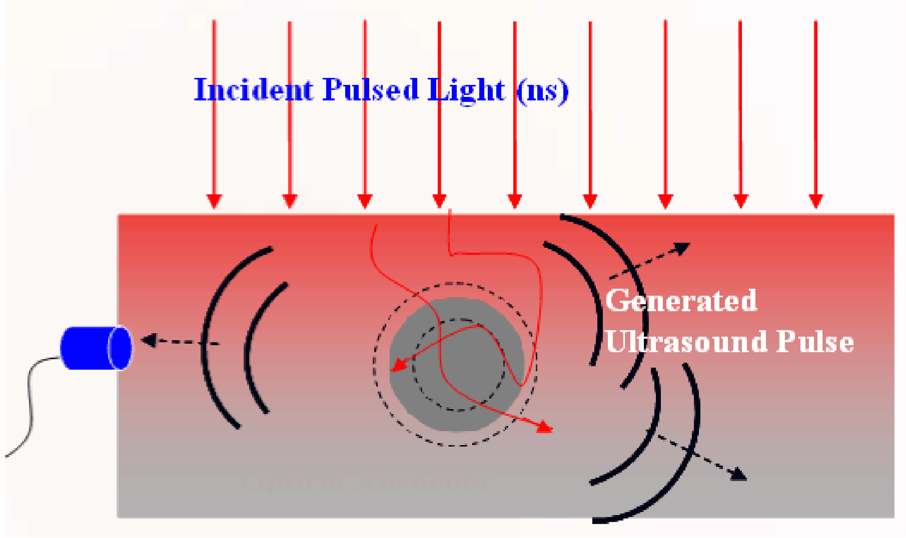
Applications:
- Breast cancer, brain cancer, prostate cancer
- Foreign body, renal calculi, explosive
- Temperature monitoring

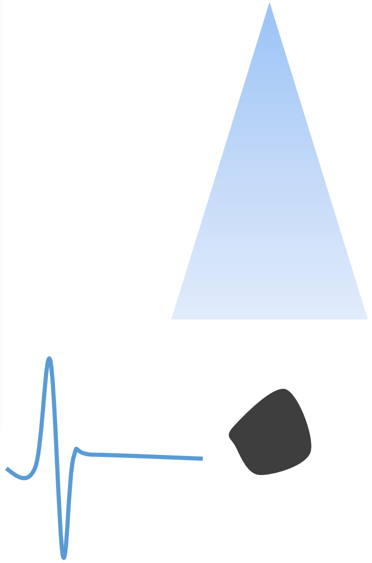
Photoacoustic imaging



Laser/ RF pulse	→	Absorption	→	Thermal expansion	→	Acoustic waves	→	Ultrasonic detection	→	Image formation

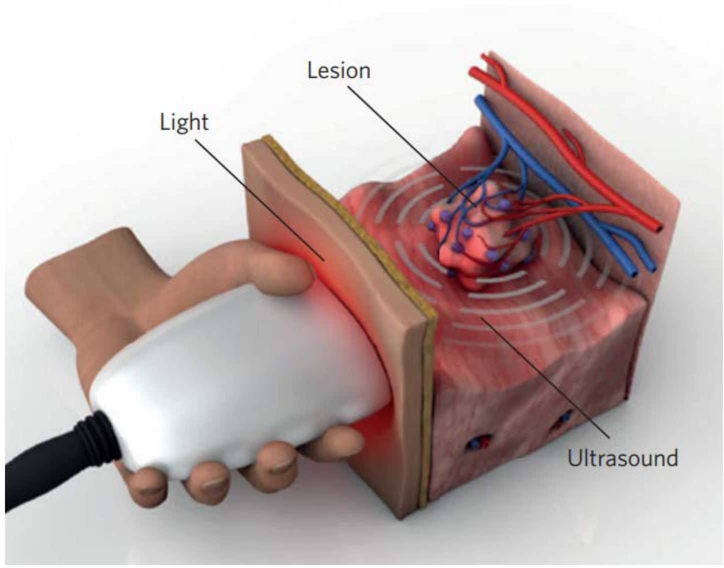
Photoacoustic imaging

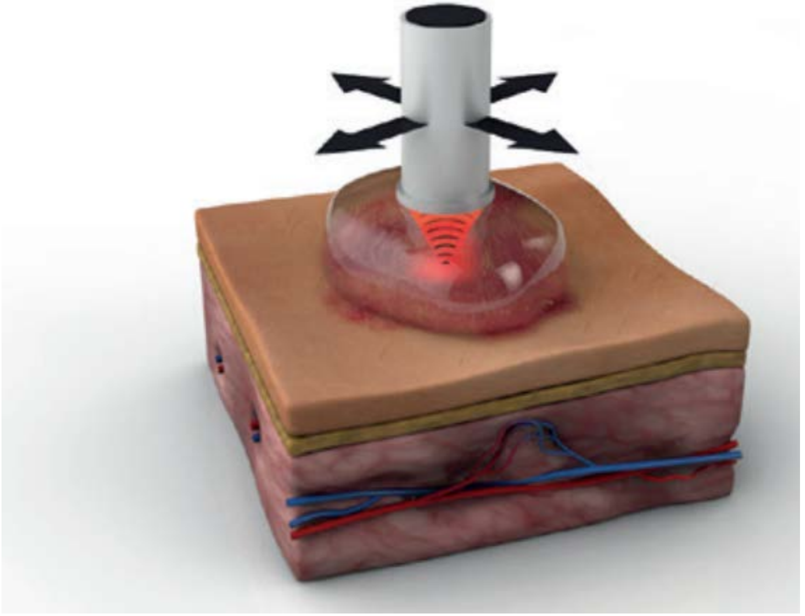




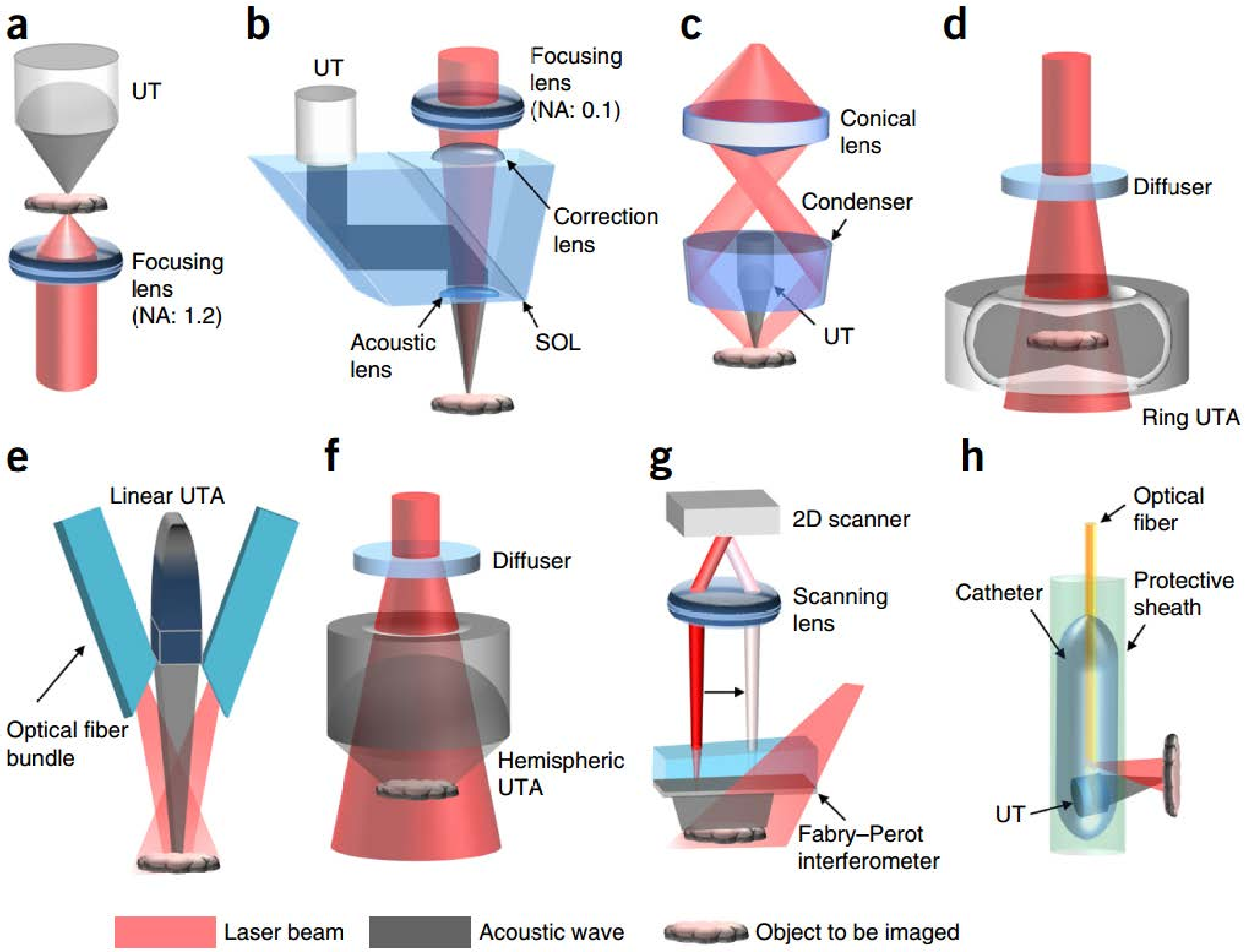
combining light and sound

>> Pulsed light illumination
>> Transit light absorption
>> Heating
>> thermoelastic expansion
>> acoustic emission

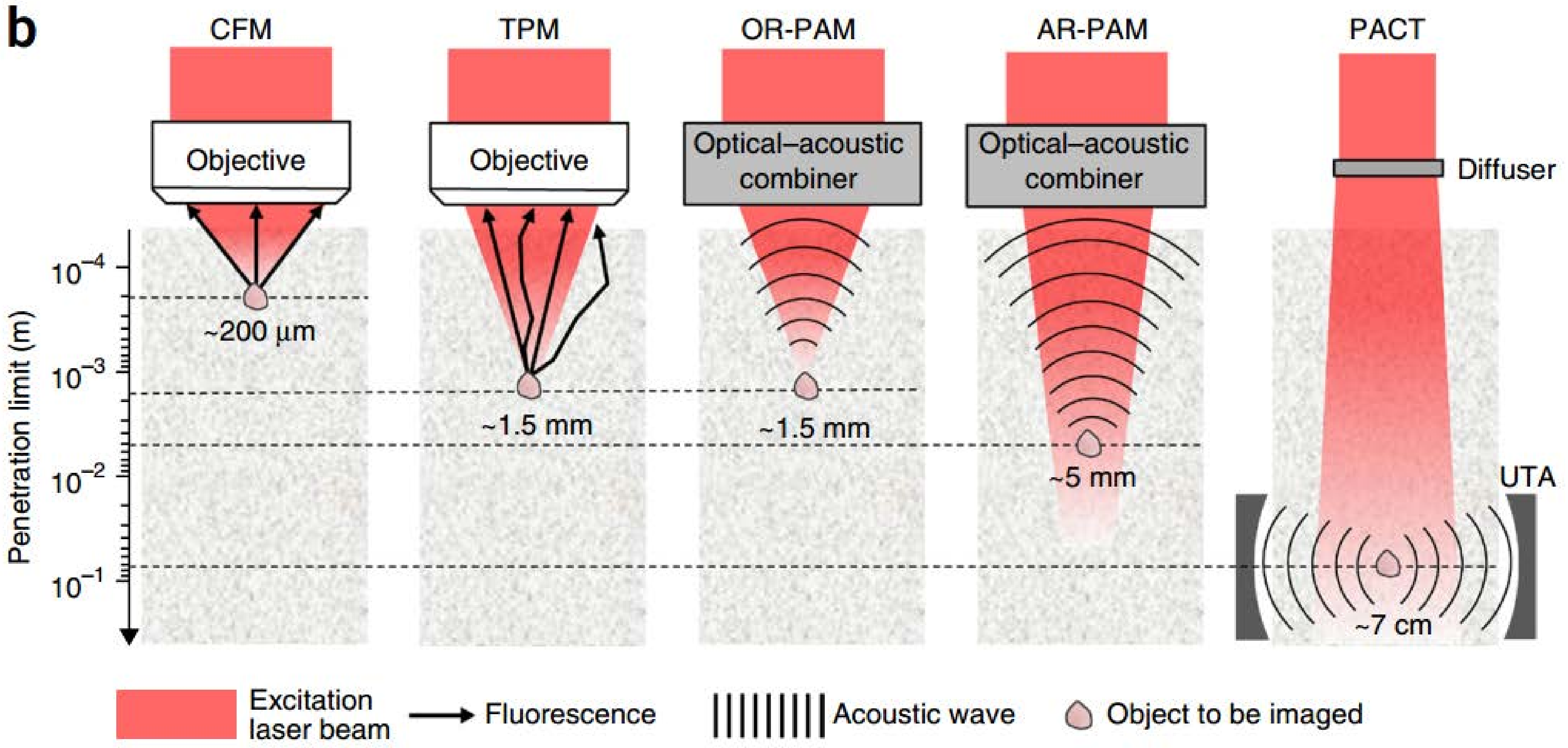




Representative implementations



PAT in different imaging scales



Benchmark table

Imaging modality	Optical imaging	Ultrasound imaging	PA imaging
Contrast	Optical scattering and absorption	Mechanical impedance	***Optical absorption***
Spatial resolution	Optical diffraction limit (sub um)	Ultrasound diffraction limit (sub mm)	***Scalable (sub um ~ sub mm)***
Imaging depth	< 1 mm	> 1 cm	***> 1 cm***
Applications	Anatomical, functional and molecular imaging	Anatomical imaging	***Anatomical, functional and molecular imaging***