# Medical Image Processing for Interventional Applications

## Ultrasound

Online Course – Unit 37
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# Topics

# Historical Remarks

**1942:** Discovery of medical ultrasound by Theodore Dussik

**1984:** First 3-D ultrasound system reported by Kazunori Baba


Figure 1: First applications of sound (echometry due to Aristoteles)

# Generation of Ultrasound Waves

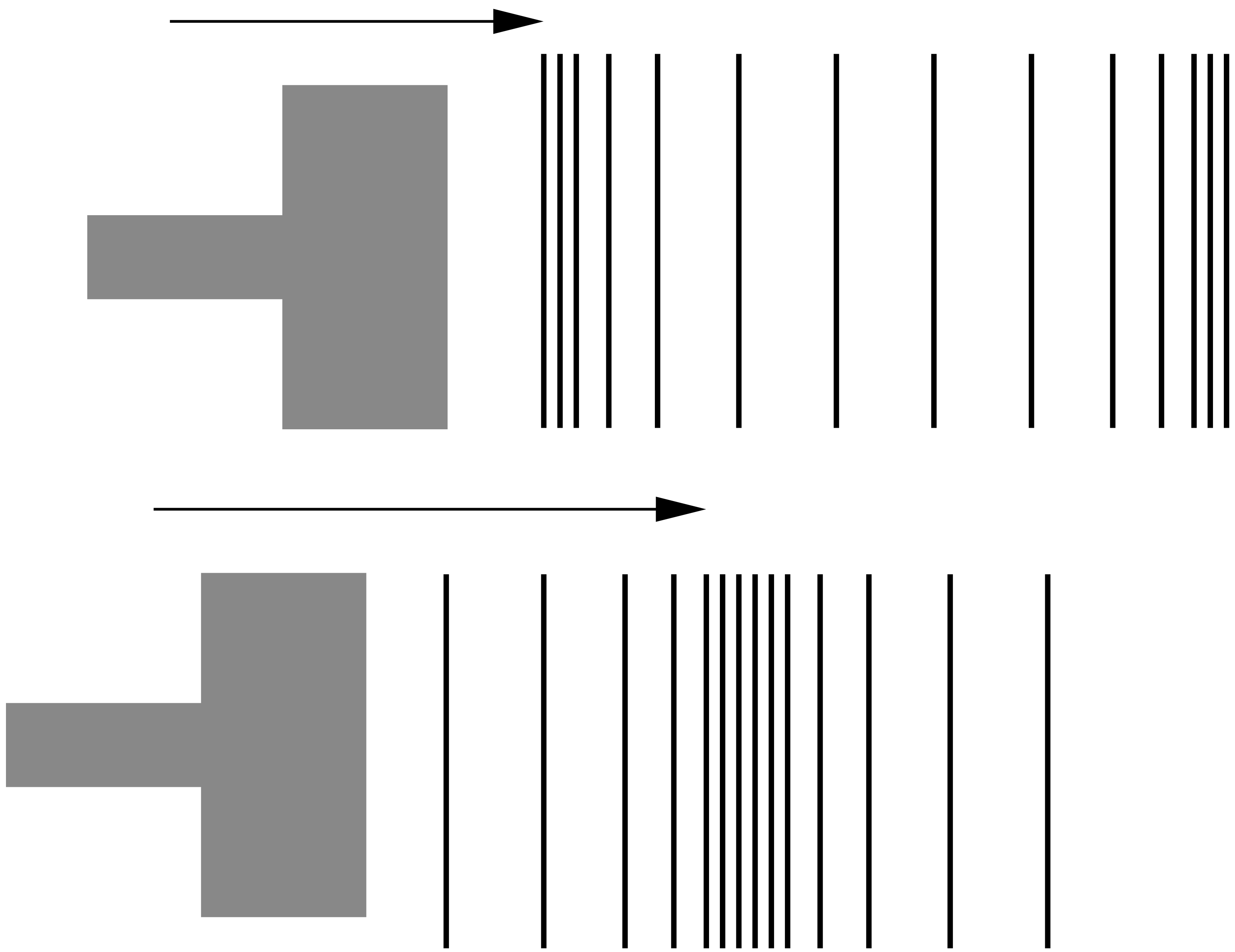

Figure 2: Pressure waves generated by periodic motion

# Properties of Waves

- **Reflection:** At the boundary of two media waves are not transmitted, but reflected.
- **Refraction:** At the boundary of two media waves are bended.
- **Absorption:** Conversion of acoustic energy to heat causes attenuation of waves.

Figure 3: Siemens-ACUSON Aspen Echo System (left), Siemens-ACUSON US CV 70 (right)

# 2-D Ultrasound Images


Figure 4: Portable ultrasound system (Siemens Healthcare)

# 2-D Ultrasound Images

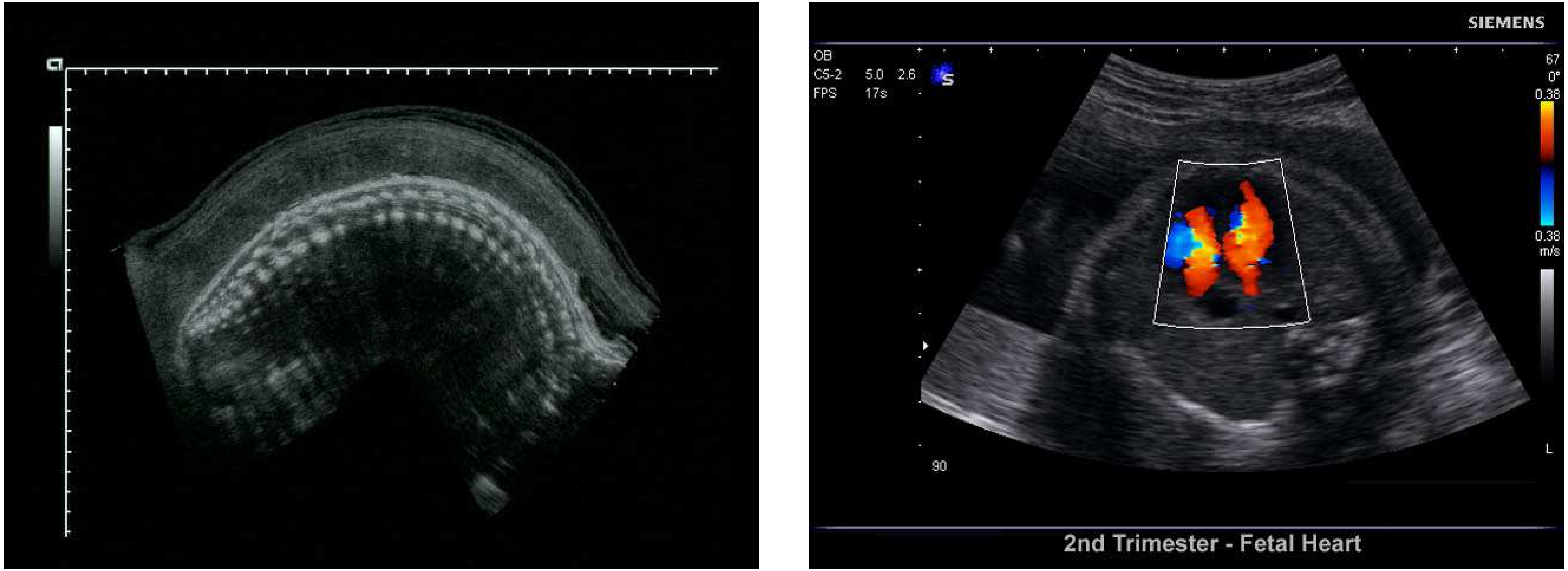


Figure 5: 2-D ultrasound showing a fetal spine and heart (images courtesy of Siemens Healthcare)

# 3-D Ultrasound Images

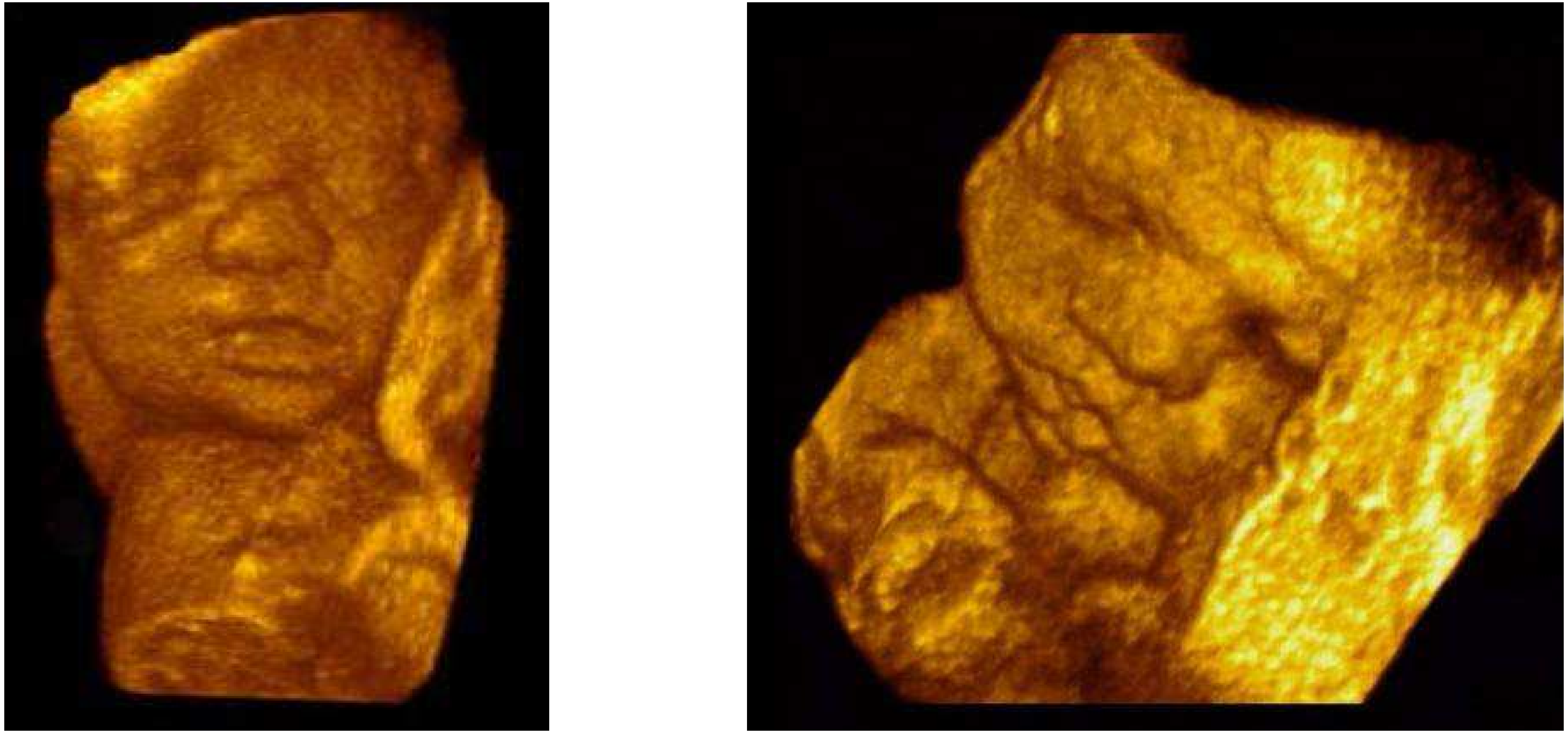

Figure 6: 3-D ultrasound images of a fetus (images courtesy of Siemens Healthcare)

# Carotid Artery

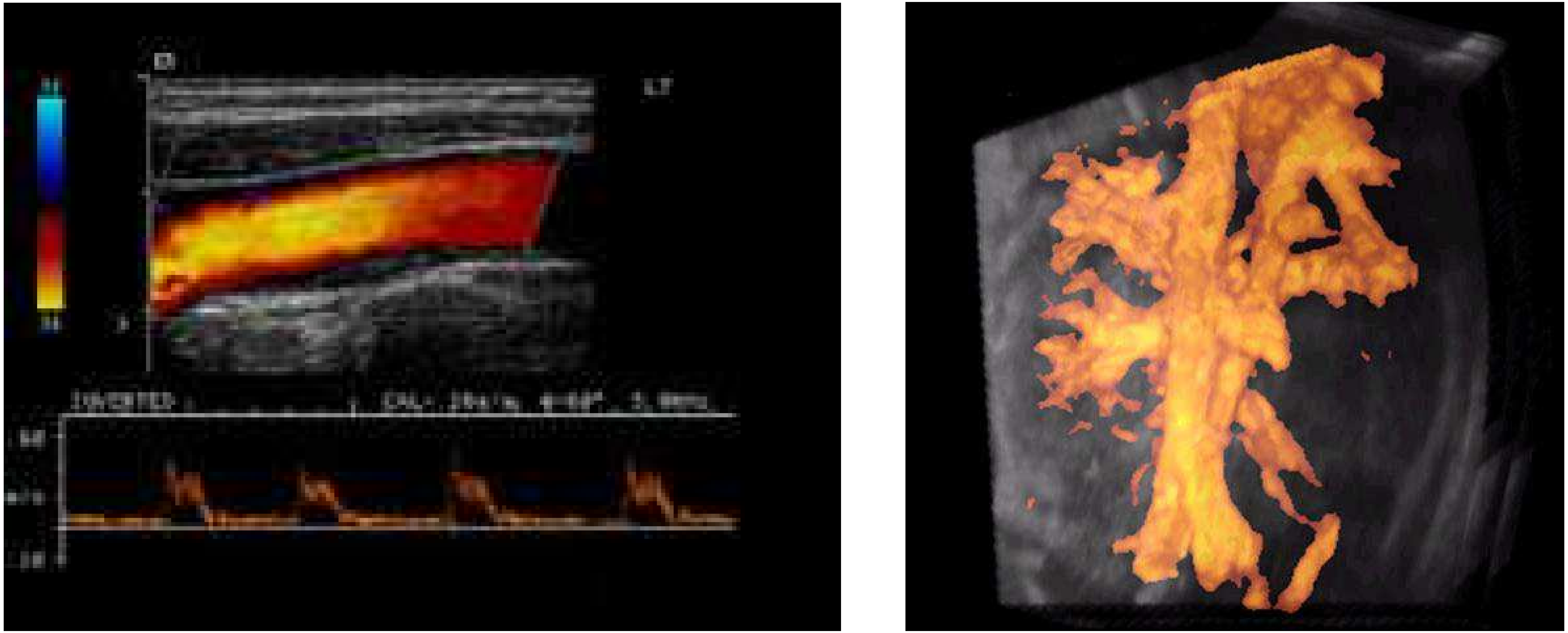

Figure 7: Carotid artery and 3-D ultrasound image of vessels (images courtesy of Siemens Healthcare)

# Basics from Physics

- Physical medium can vibrate and produce sound.
- Sound waves are due to tissue vibrations.
- Sine waves: peak represents the maximum, nadir represents the minimum pressure.
- Characteristics of sound waves: period, frequency, speed, amplitude, power, intensity, wavelength
- Propagation speed in human tissue: $\sim 1500\,\mathrm{m\,s^{-1}}$
- Hearable sound: 20–20000 Hz
- Clinical ultrasound: 1–10 MHz

# Biological Media

| **medium** | $\boldsymbol{c}$ [m s$^{-1}$] | $\boldsymbol{Z}$ [g cm$^{-2}$ s$^{-1}$] | $\boldsymbol{\rho}$ [g cm$^{-3}$] |
|---|---|---|---|
| air | 331 | 430 | 0.013 |
| grease | 1470 | $1.42 \times 10^5$ | 0.97 |
| water | 1492 | $1.48 \times 10^5$ | 0.9982 |
| brain tissue | 1530 | $1.56 \times 10^5$ | 1.02 |
| muscles | 1568 | $1.63 \times 10^5$ | 1.04 |
| bones | 3600 | $6.12 \times 10^5$ | 1.7 |

Table 1: Data of different biological media (speed of sound in the medium, acoustic impedance, density)

# Basics from Physics

**Important observations:**

- Medium determines the speed of sound.
- Sound of different frequencies propagates at the same speed in the same medium.

# Basics from Physics

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## Definition

The ***acoustic impedance*** $Z$ is:

$$Z = \rho \cdot c,$$

where $\rho$ is the density of the medium, and $c$ the speed of sound waves in the medium.

# Basics from Physics

**Reflection at the boundary of two different tissue classes** can be described by:

$$I_R = I_I \frac{1 - \frac{Z_2}{Z_1}}{1 + \frac{Z_2}{Z_1}},$$

where

- $I_I$: intensity of incoming wave,
- $I_R$: intensity of reflected wave,
- $Z_1$: impedance of tissue class 1,
- $Z_2$: impedance of tissue class 2.

# Basics from Physics

The **relationship of speed** $c$**, frequency** $f$ **and wavelength** $\lambda$ is:

$$c = f \cdot \lambda \,.$$

- The denser a medium, the higher the speed of sound through the medium.
  $\rightarrow$ Sound propagates faster through bones than liquids.
- The higher the frequency, the lower the wavelength.
  $\rightarrow$ Echocardiographic imaging: Higher image resolution due to smaller wavelength; deeper penetration results from larger wavelength.

# Basics from Physics

The **distance between ultrasound source and boundary** can be computed as

$$d = \frac{1}{2} c t \,,$$

where

- $d$: distance between source and tissue boundary,
- $t$: runtime of signal,
- $c$: speed of sound.

**Note:** Factor 0.5 results from the fact that the signal moves from the source to the tissue boundary and back.

# Topics

Ultrasound

- Historical Remarks
- Facts on Ultrasound

Summary

- Take Home Messages
- Further Readings

# Take Home Messages

- Ultrasound is using sound waves to generate images. This is possible due to different acoustic characteristics of the tissue materials.
- There are various medical applications and, in contrast to X-ray imaging, US does not depend on possibly harmful radiation.

# Further Readings


- Carlo Tomasi and Takeo Kanade. "Shape and Motion from Image Streams Under Orthography: A Factorization Method". In: *International Journal of Computer Vision* 9.2 (Nov. 1992), pp. 137–154. DOI: 10.1007/BF00129684
- C. J. Poelman and T. Kanade. "A Paraperspective Factorization Method for Shape and Motion Recovery". In: *IEEE Transactions on Pattern Analysis and Machine Intelligence* 19.3 (Mar. 1997), pp. 206–218. DOI: 10.1109/34.584098
- Mei Han and Takeo Kanade. "A Perspective Factorization Method for Euclidean Reconstruction with Uncalibrated Cameras". In: *The Journal of Visualization and Computer Animation* 13.4 (2002), pp. 211–223. DOI: 10.1002/vis.290
- Peter Sturm and Bill Triggs. "A Factorization Based Algorithm for Multi-Image Projective Structure and Motion". In: *Computer Vision — ECCV '96: 4th European Conference on Computer Vision Cambridge, UK, April 15–18, 1996 Proceedings Volume II*. ed. by Bernard Buxton and Roberto Cipolla. Vol. 1065. Lecture Notes in Computer Science. Berlin, Heidelberg: Springer Berlin Heidelberg, 1996, pp. 709–720. DOI: 10.1007/3-540-61123-1_183