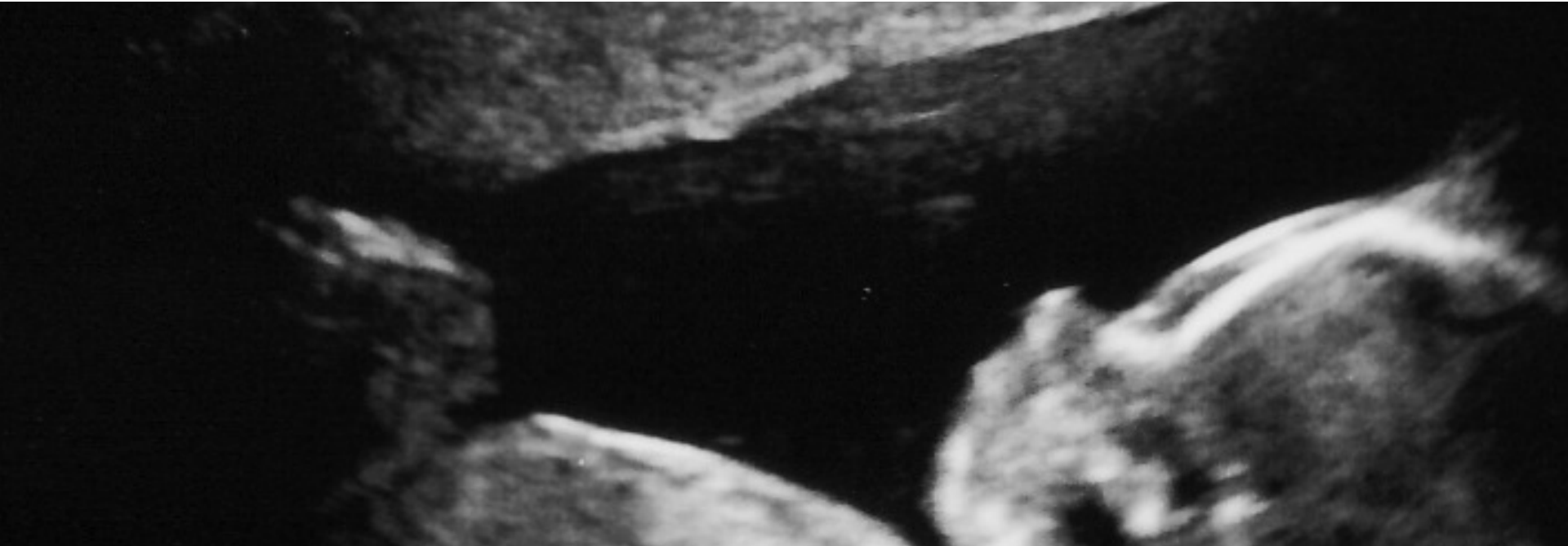


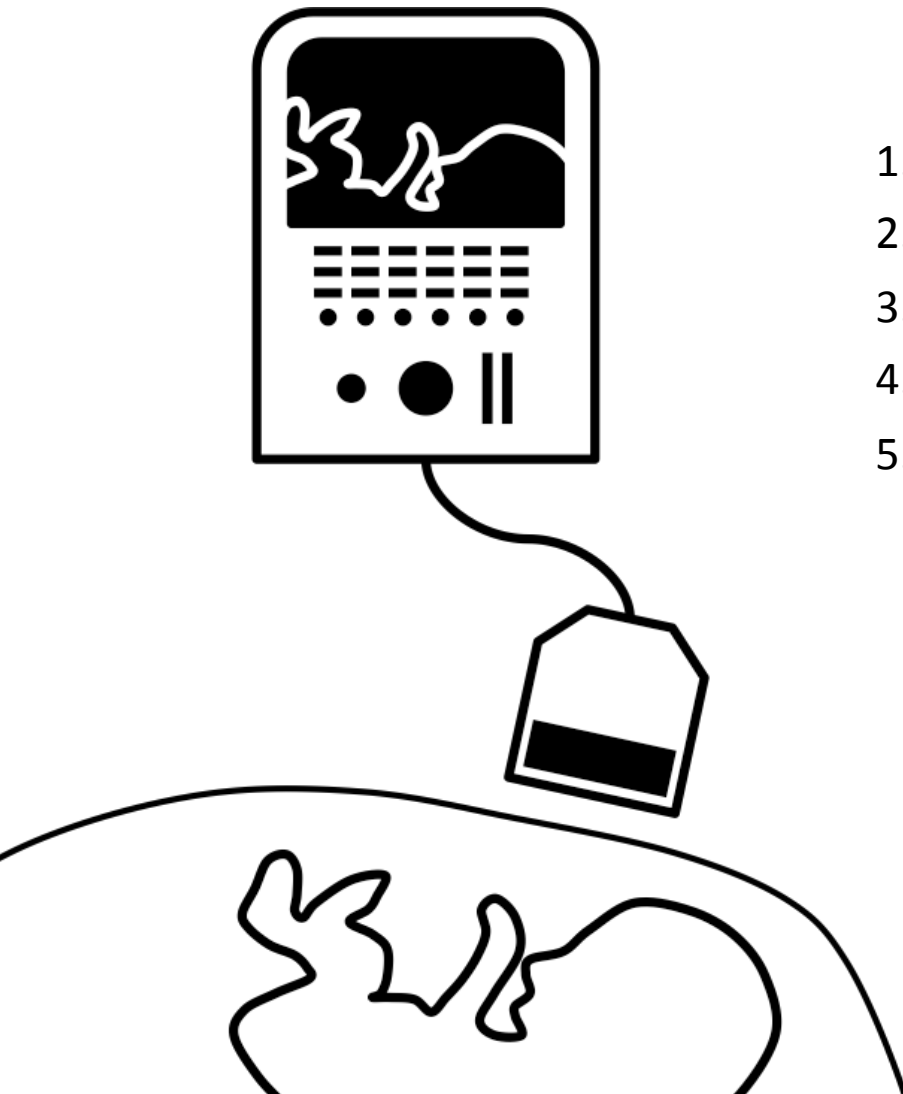
Ultrasound Physics (BWHRR.US)

1. Fundamentals of Acoustics



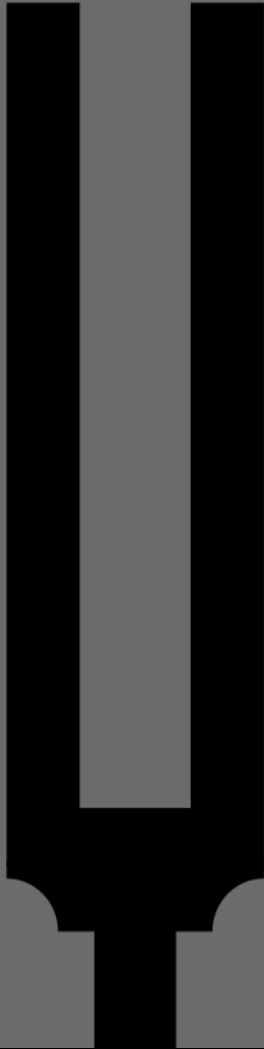
Phillip Jason White, Ph.D.
Department of Radiology
Brigham and Women's Hospital | Harvard Medical School
221 Longwood Avenue | EBRC 521
Boston, MA 02115

Contact: (617) 525-7465, white@bwh.harvard.edu

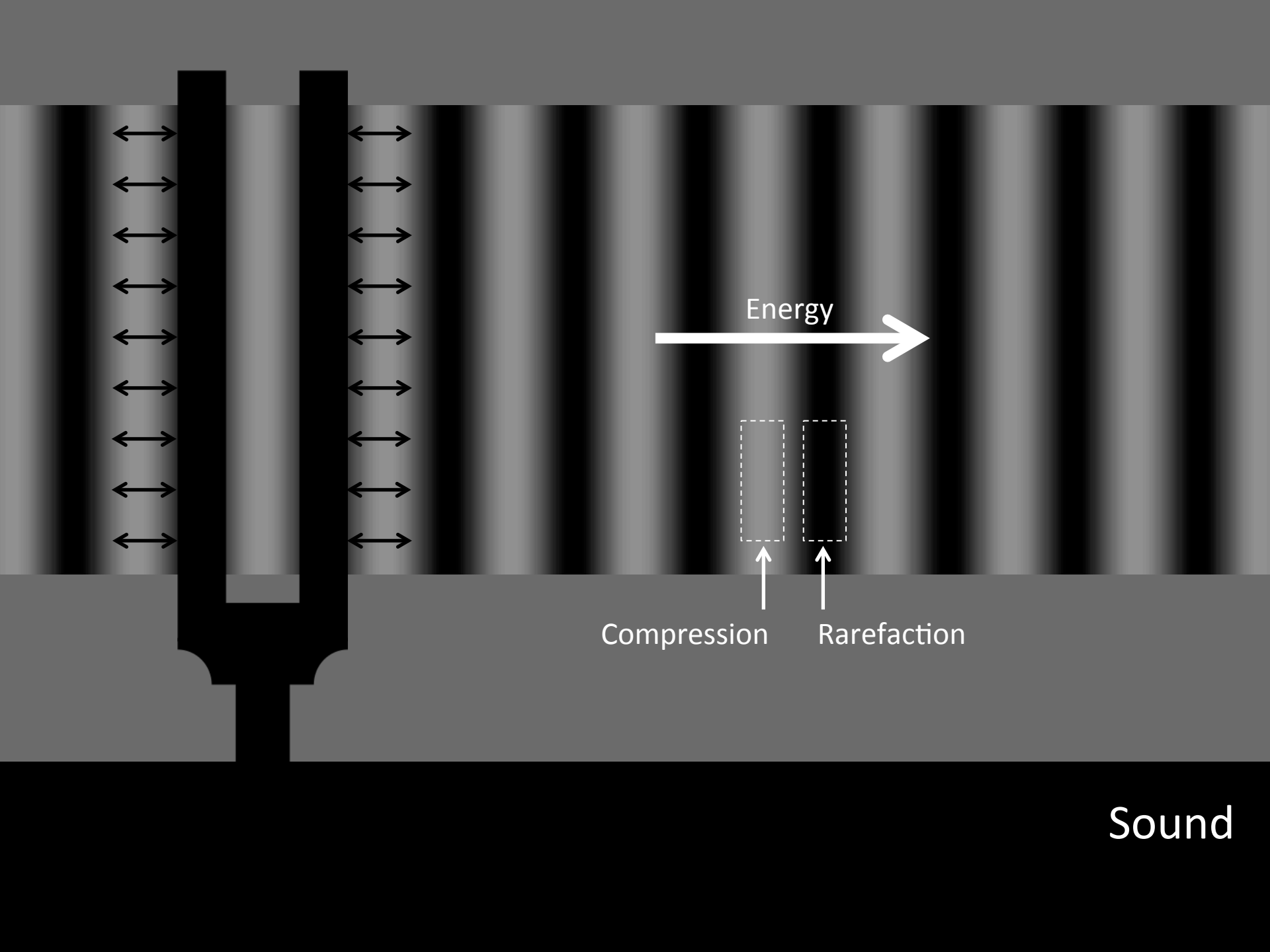


1. Fundamentals of Acoustics
2. Transduction and Beamforming
3. Ultrasound Imaging and Artifacts
4. Advanced Imaging Methods
5. Ultrasound Safety and QA

Overview



Sound

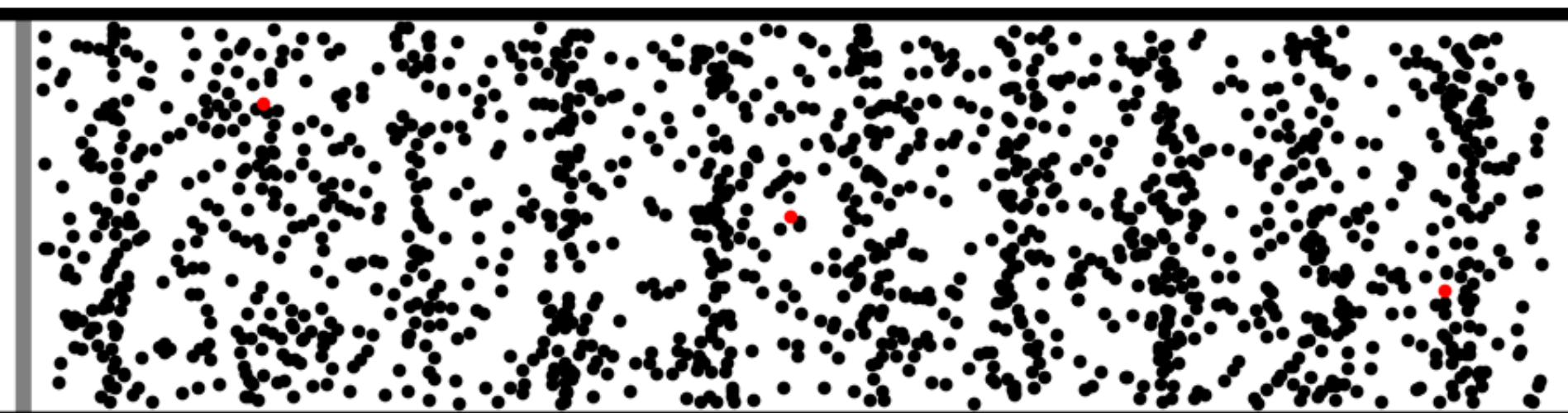


Energy

Compression

Rarefaction

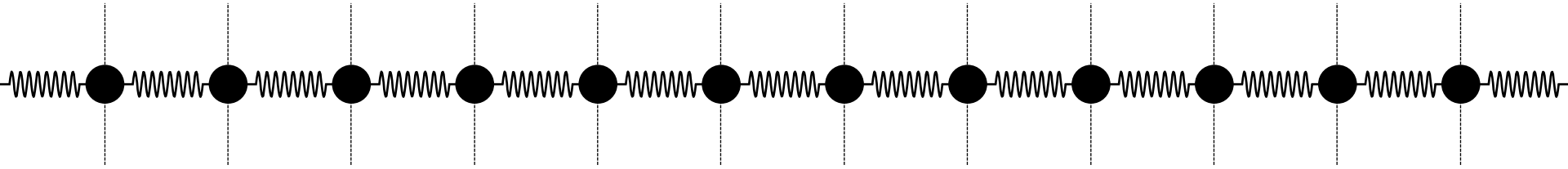
Sound



©2011. Dan Russell

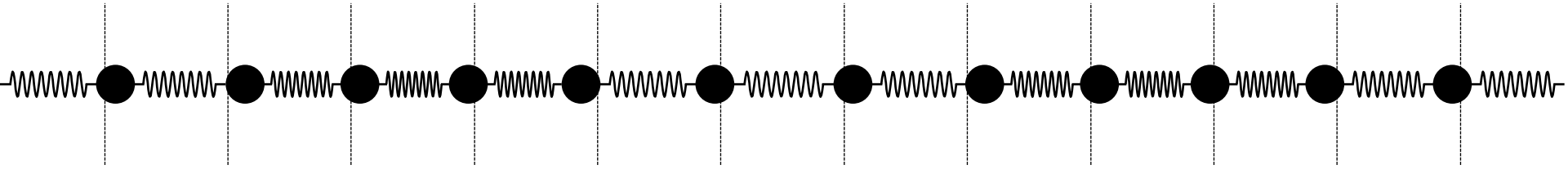
Sound

Longitudinal (Pressure)



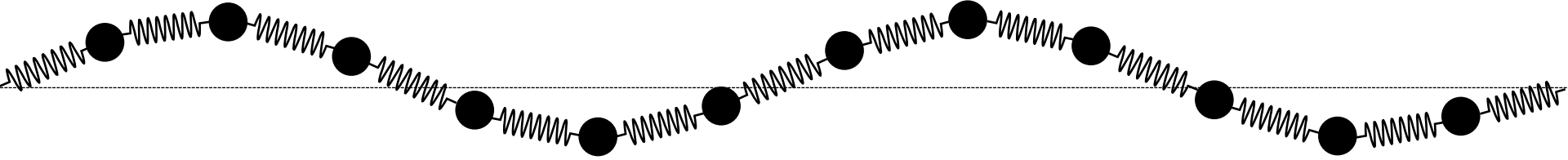
Transverse and Longitudinal Waves

Longitudinal (Pressure)



Transverse and Longitudinal Waves

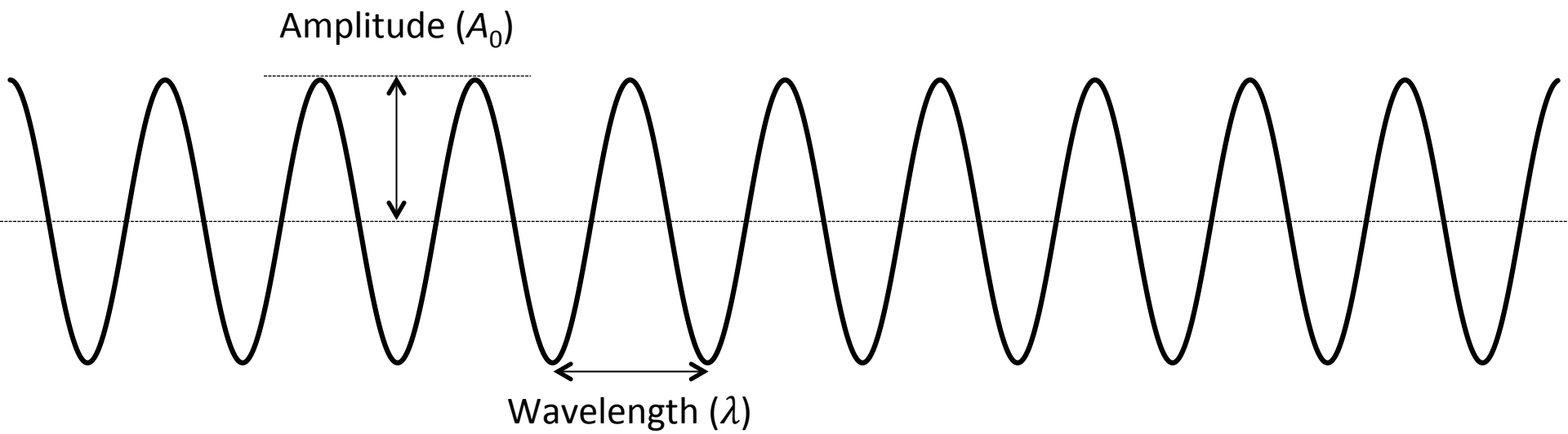
Transverse (Shear)



Energy



Transverse and Longitudinal Waves

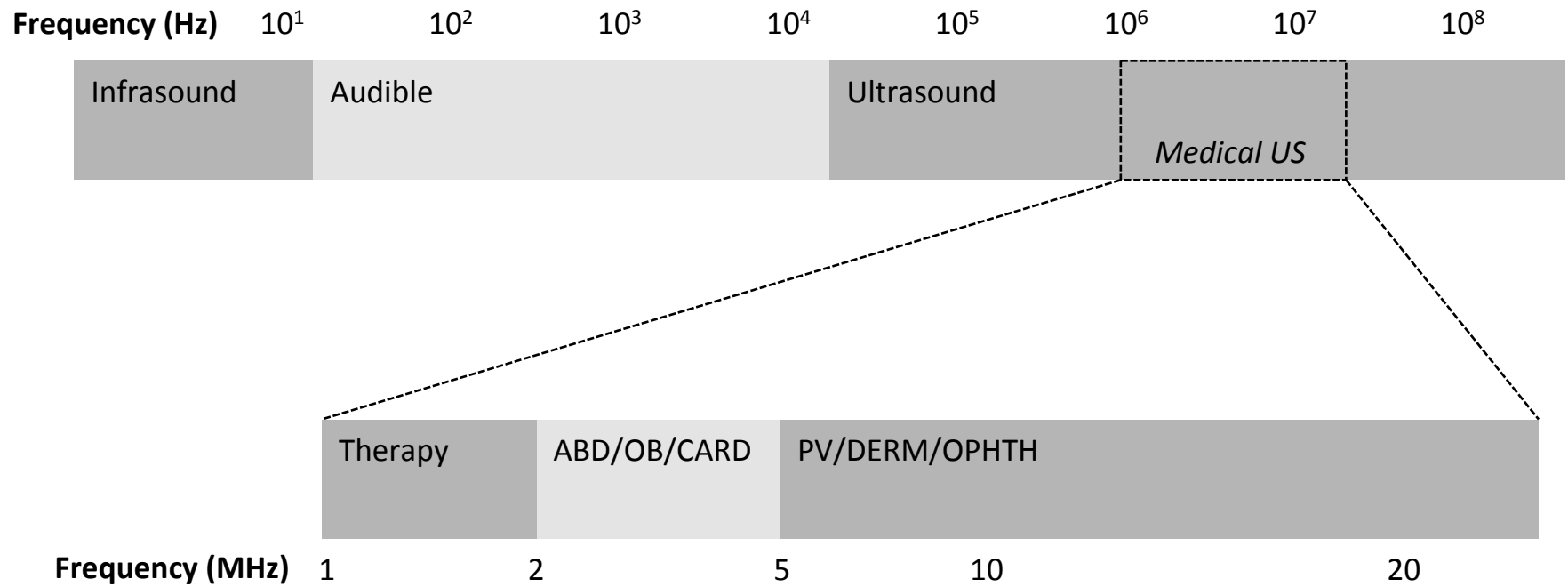


Velocity (c)



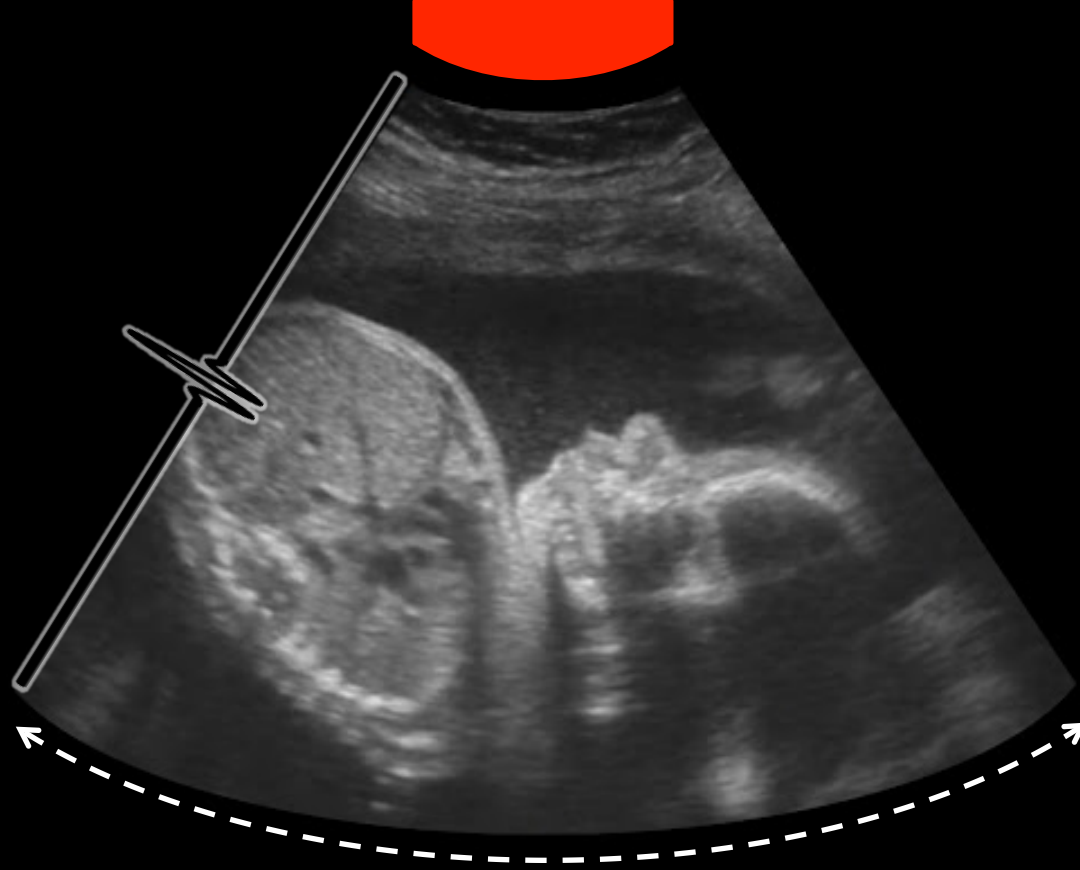
$$f = \frac{c}{\lambda}$$

Wave Mechanics



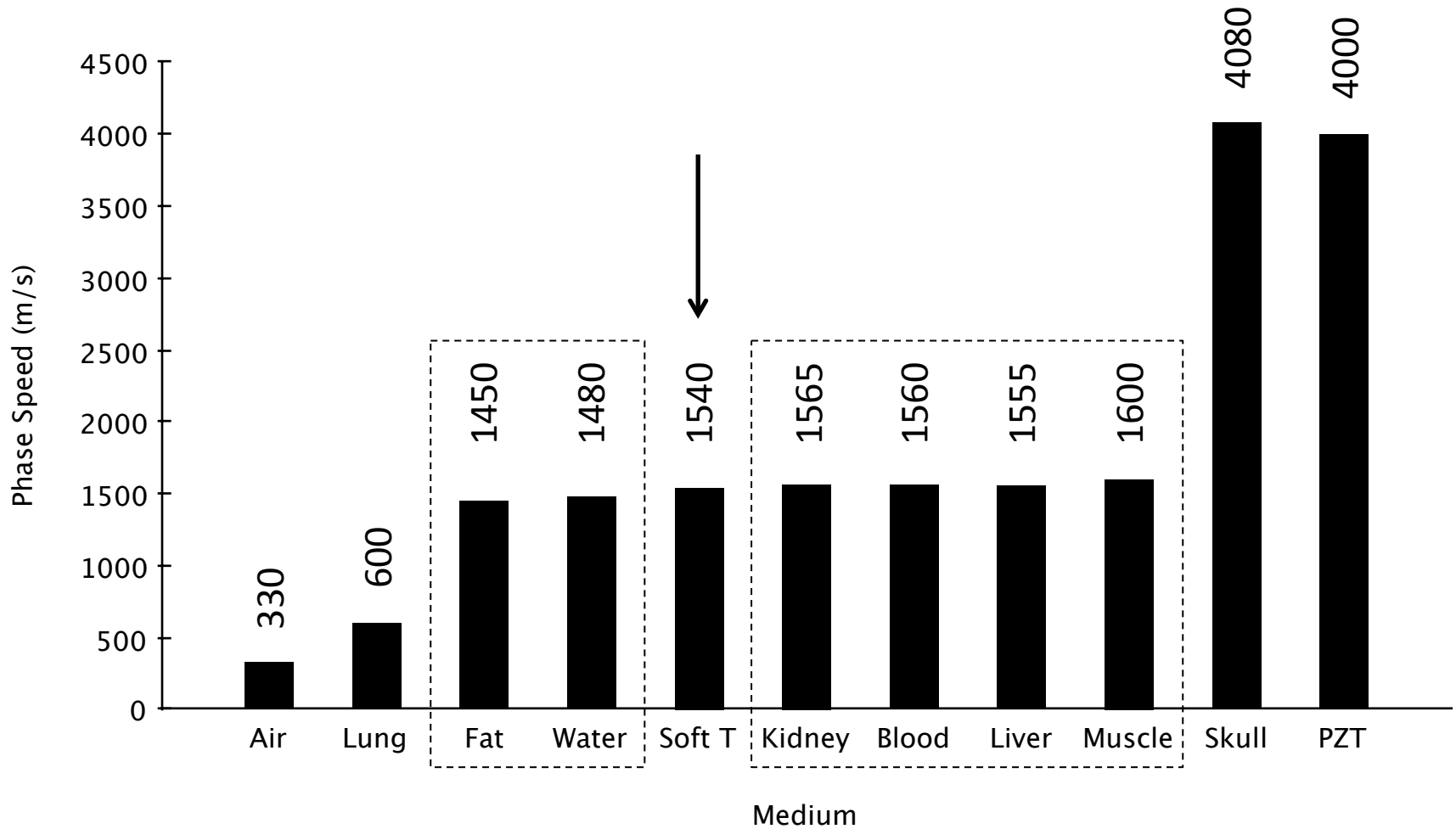
$$f = \frac{c}{\lambda}$$

Acoustic Spectrum

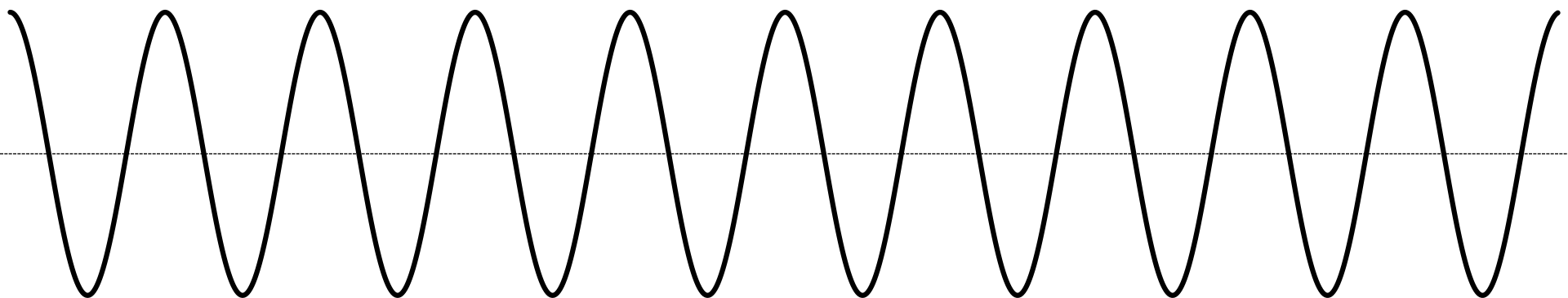


$$f = \frac{c}{\lambda}$$

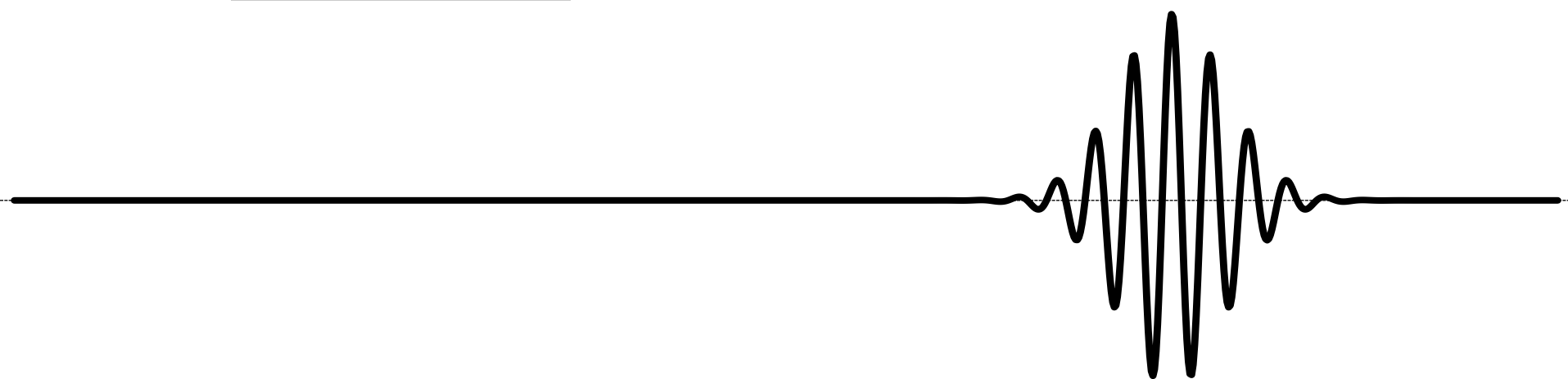
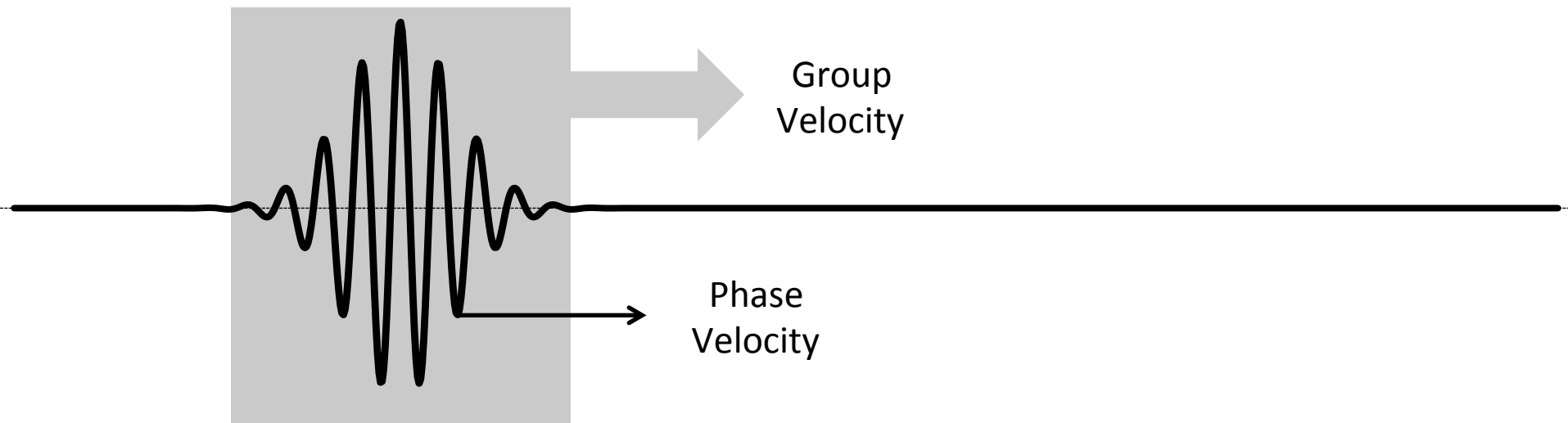
Ultrasound Velocity



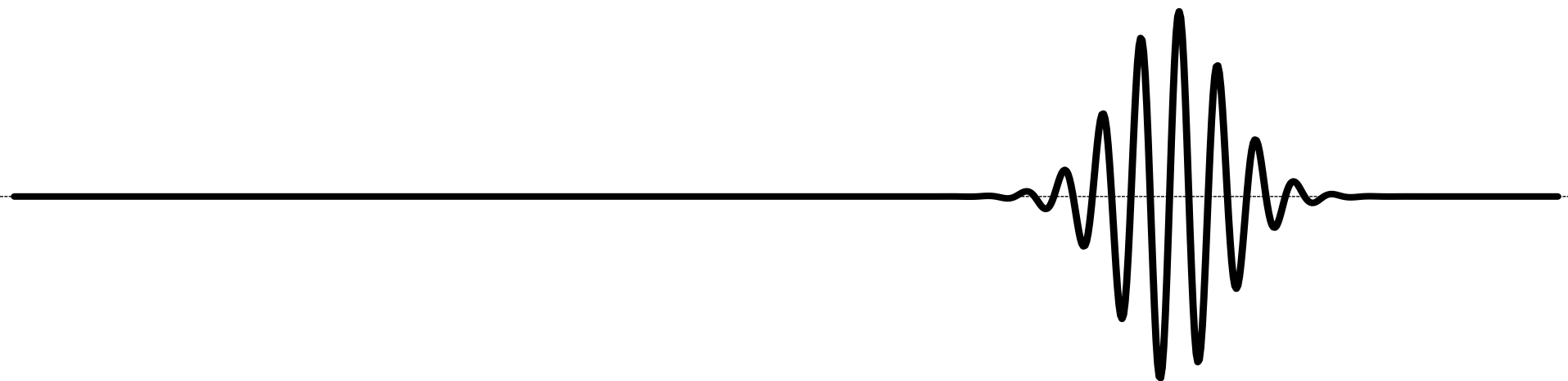
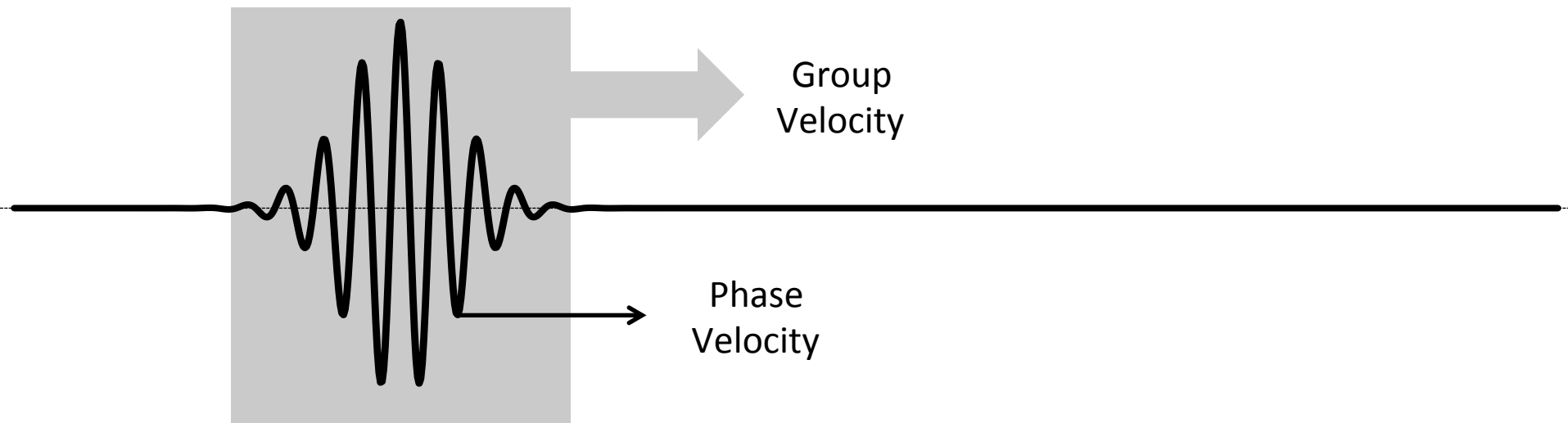
Ultrasound Velocity



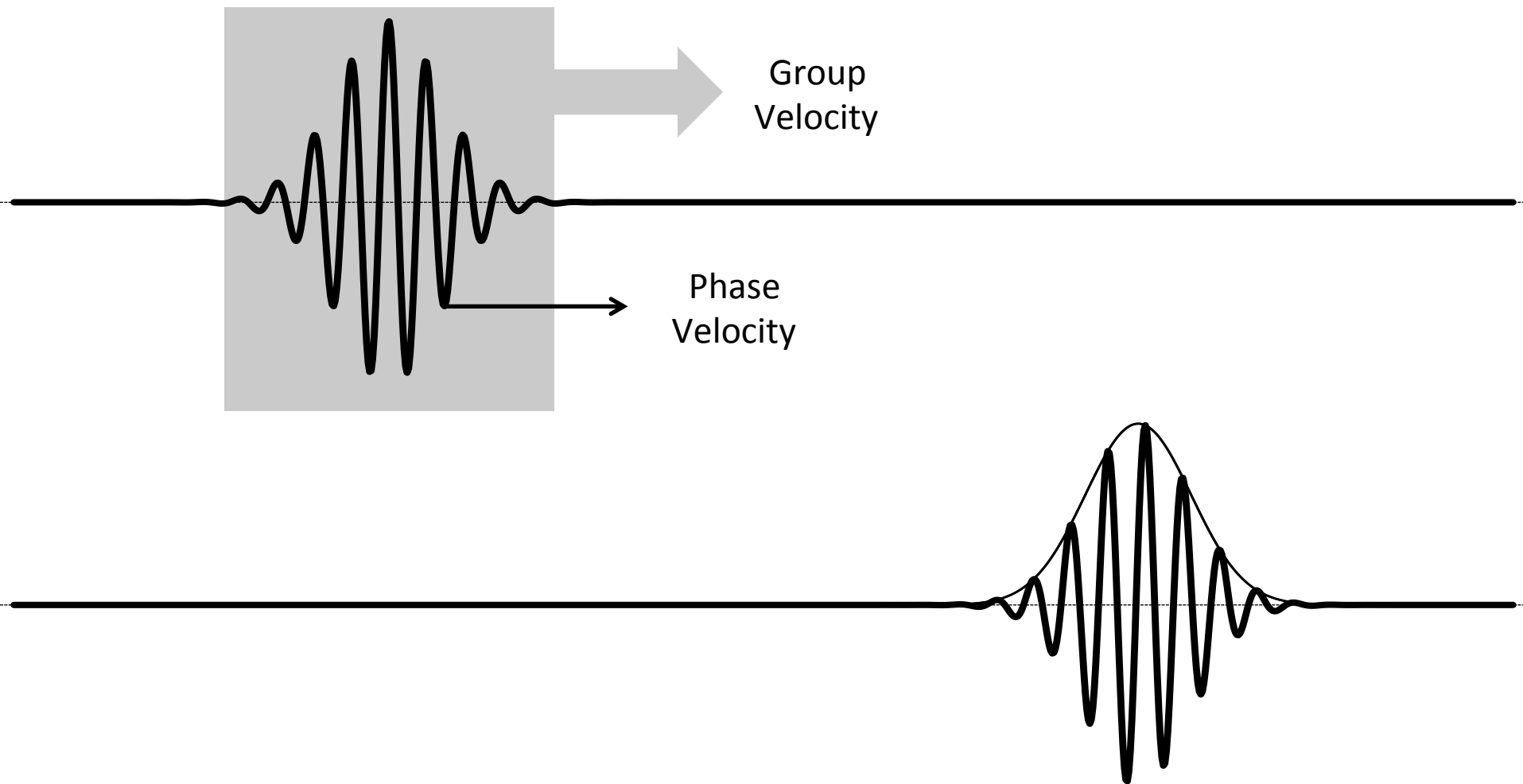
Ultrasound Velocity



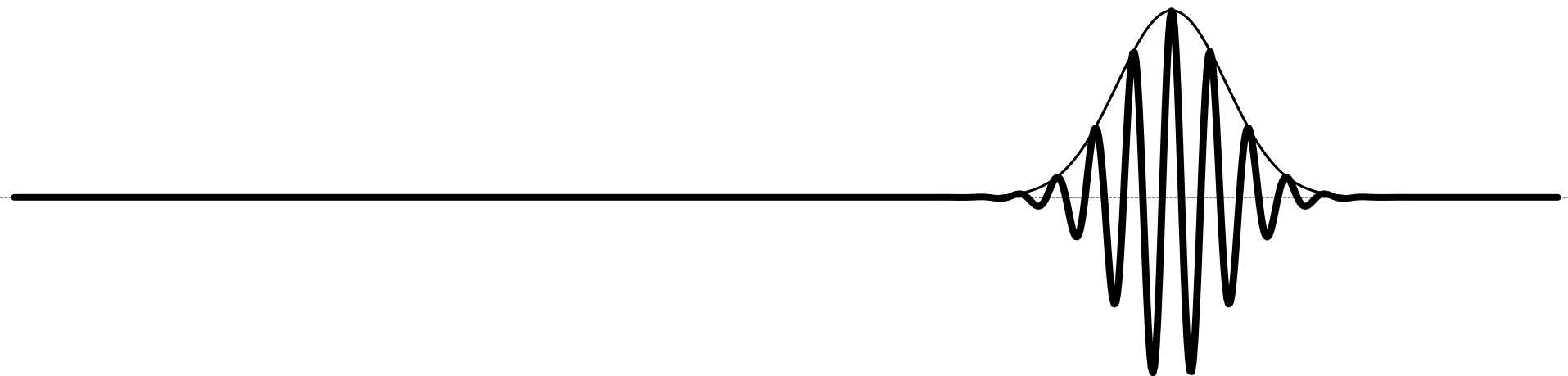
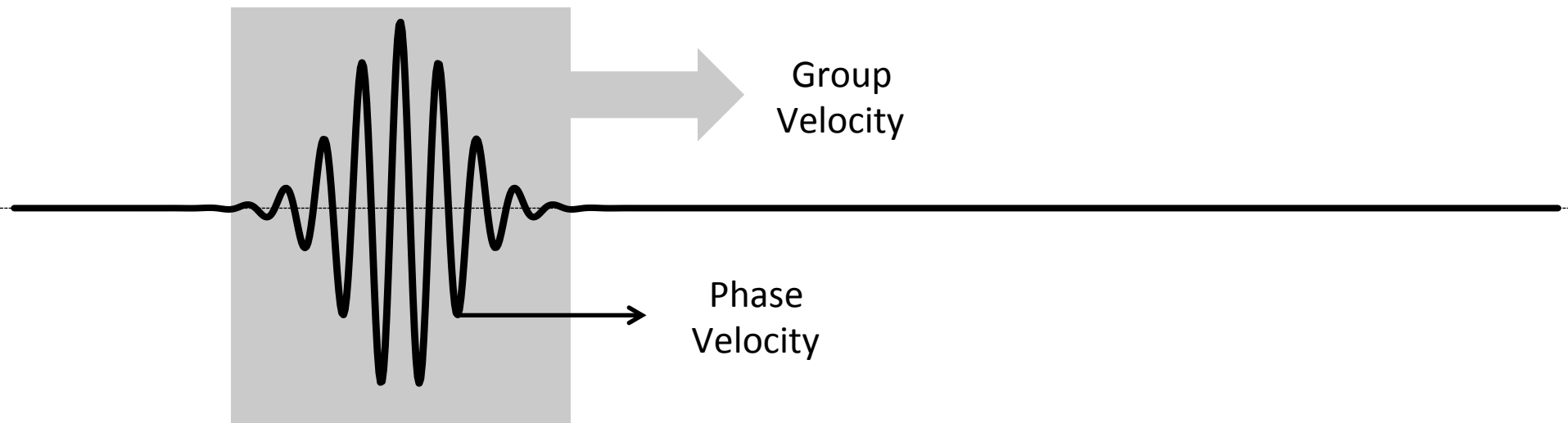
Ultrasound Velocity



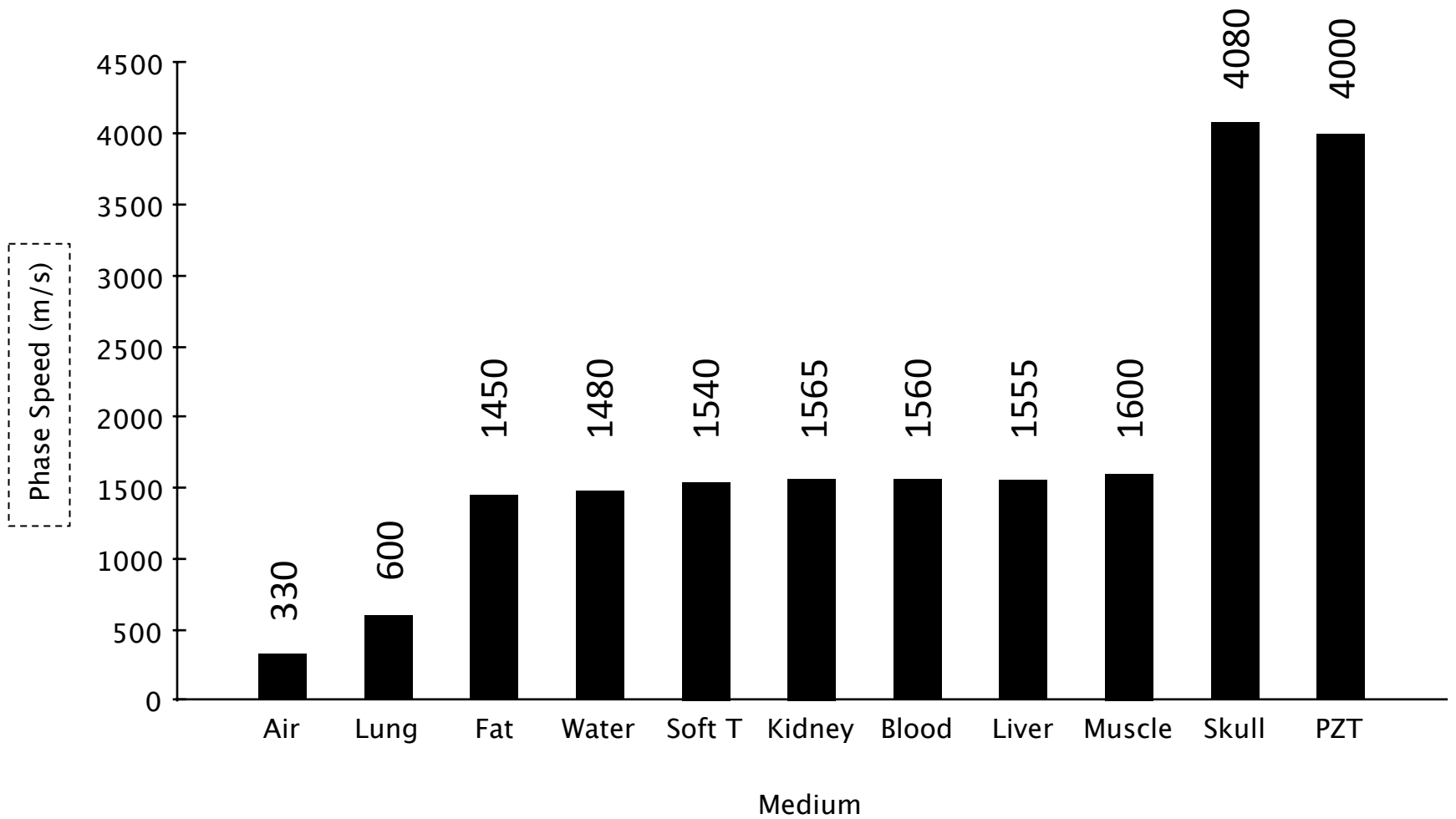
Ultrasound Velocity



Ultrasound Velocity

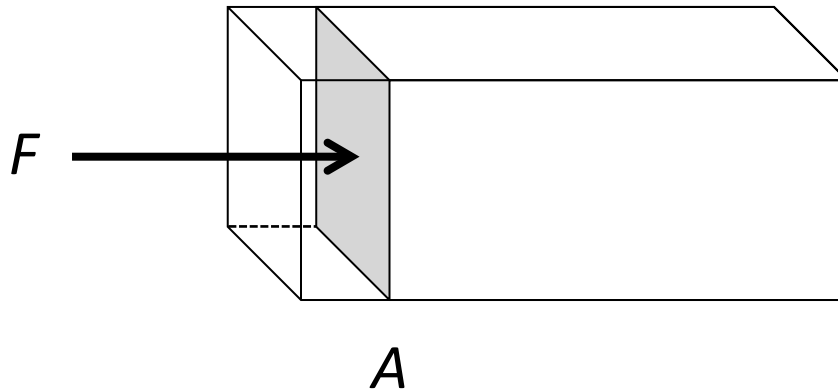


Ultrasound Velocity



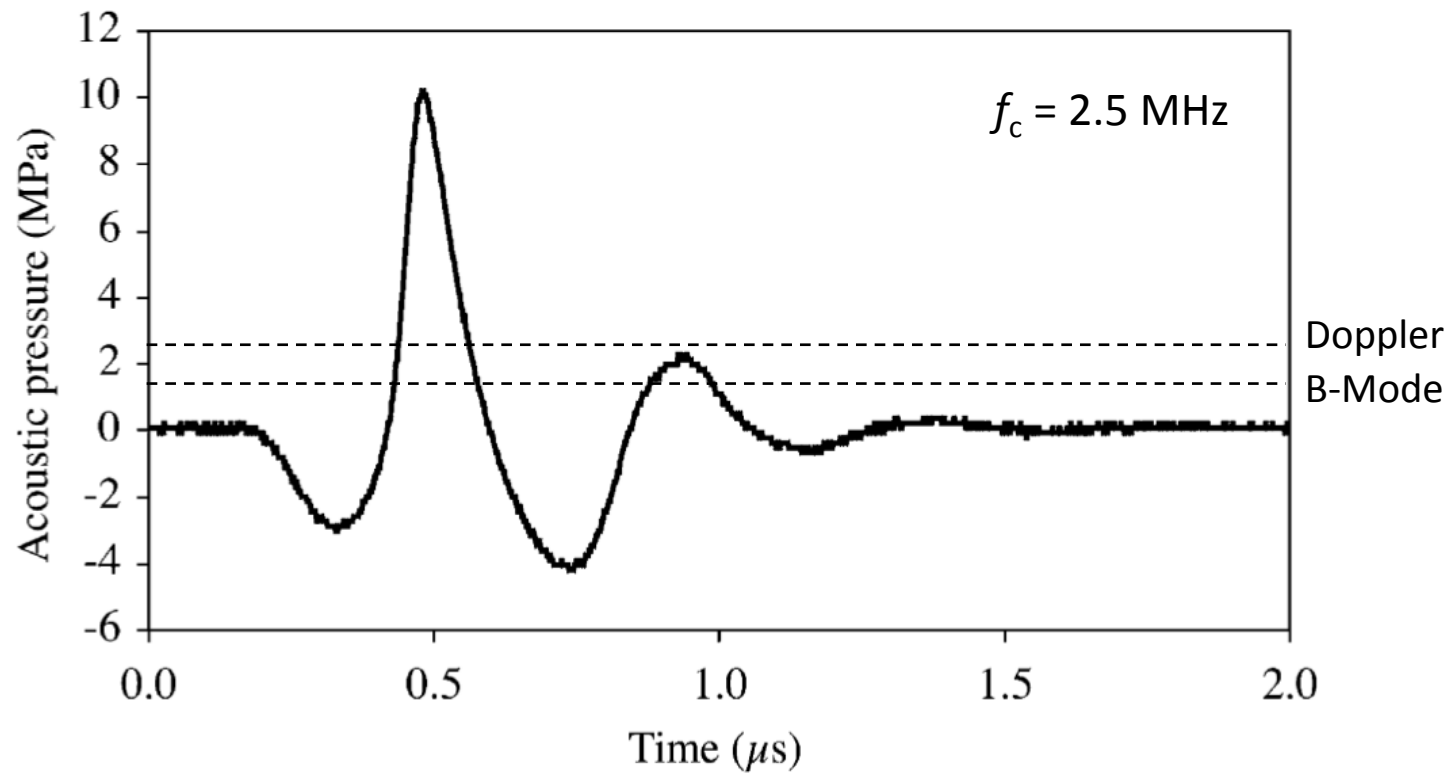
Ultrasound Velocity

$$p = \frac{F}{A}$$

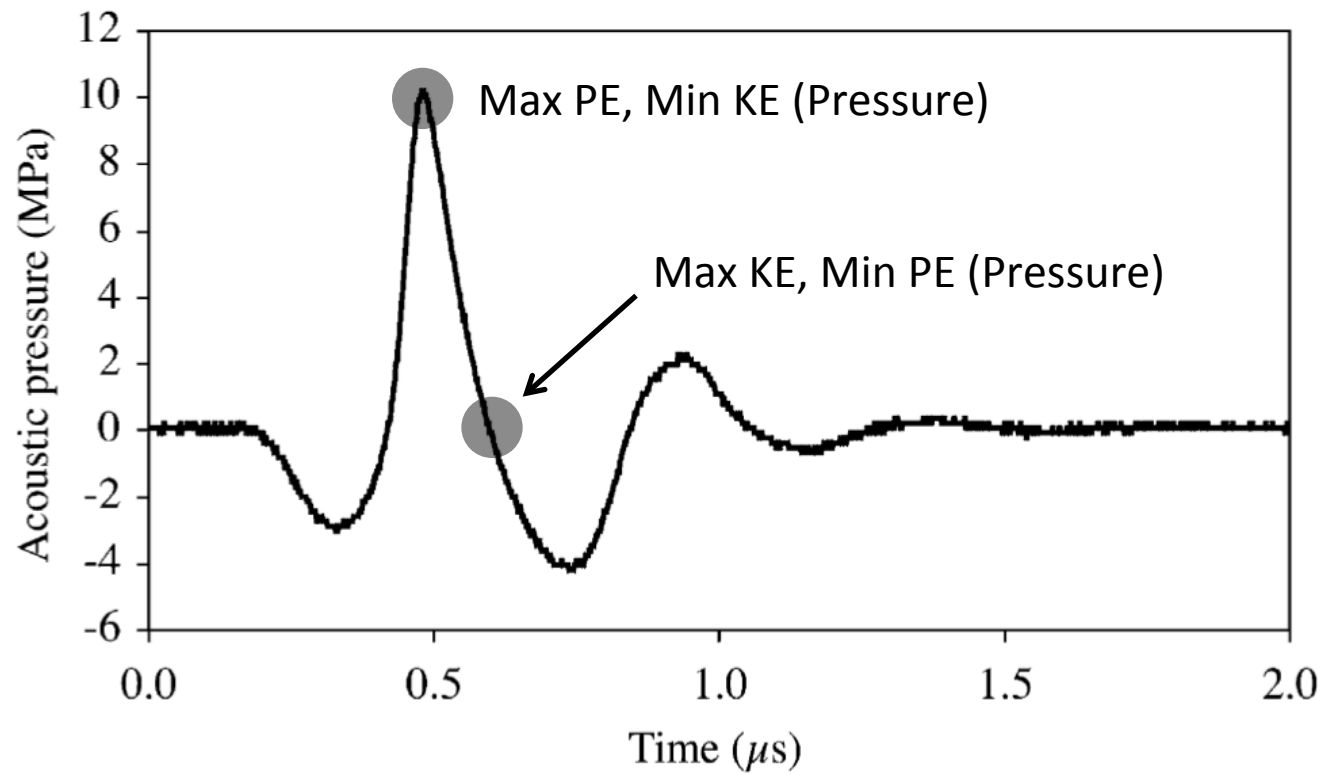


Unit	SI Equivalent (Pa)
Pa	= 1 N/m ²
bar	1.00×10 ⁵
atm	1.01×10 ⁵
psi	6.89×10 ³
mmHg	133.3
cmH ₂ O	98.1

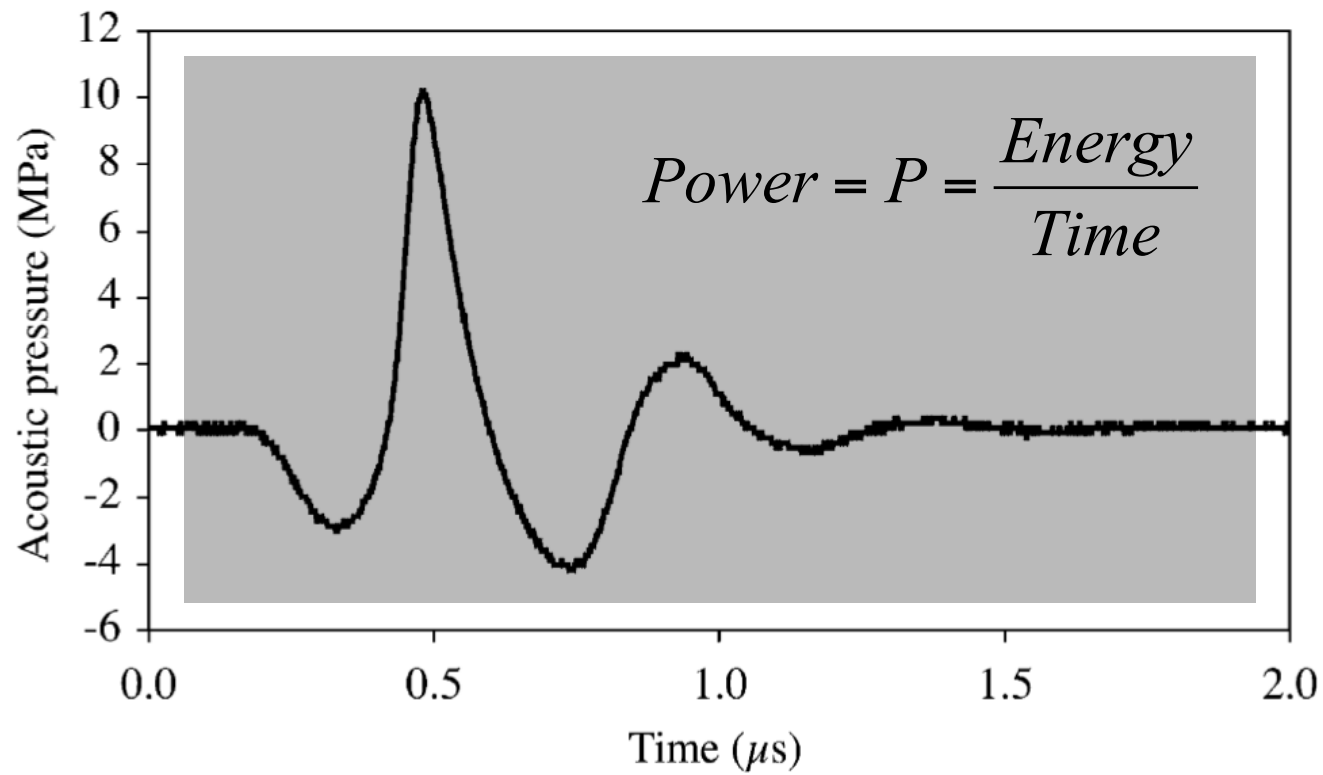
Pressure



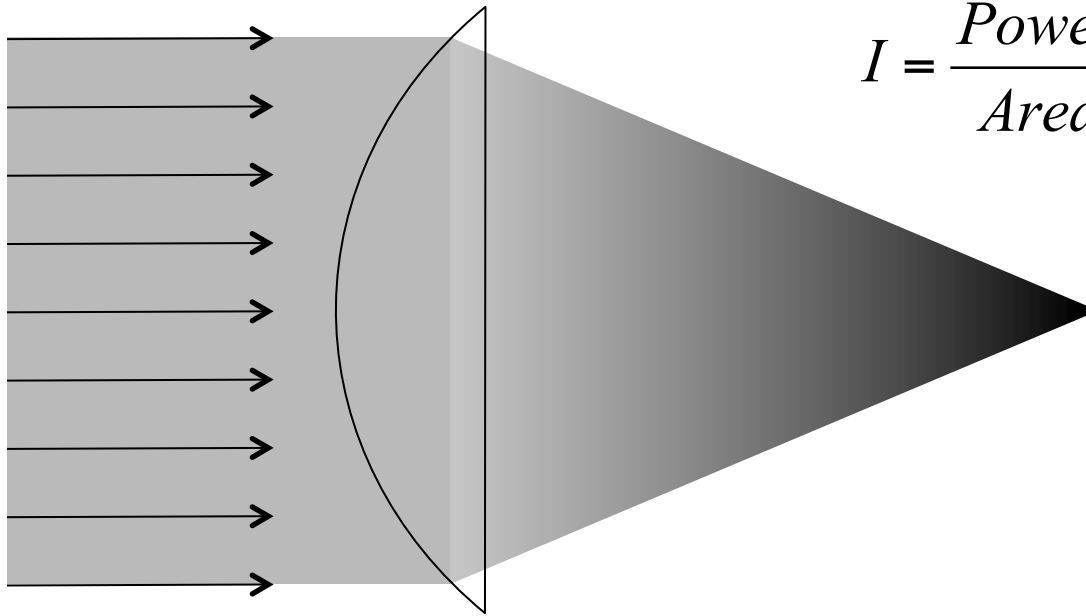
Pressure



Energy



Power



$$I = \frac{\text{Power}}{\text{Area}} = \frac{\text{Energy}}{\text{Time} \cdot \text{Area}}$$

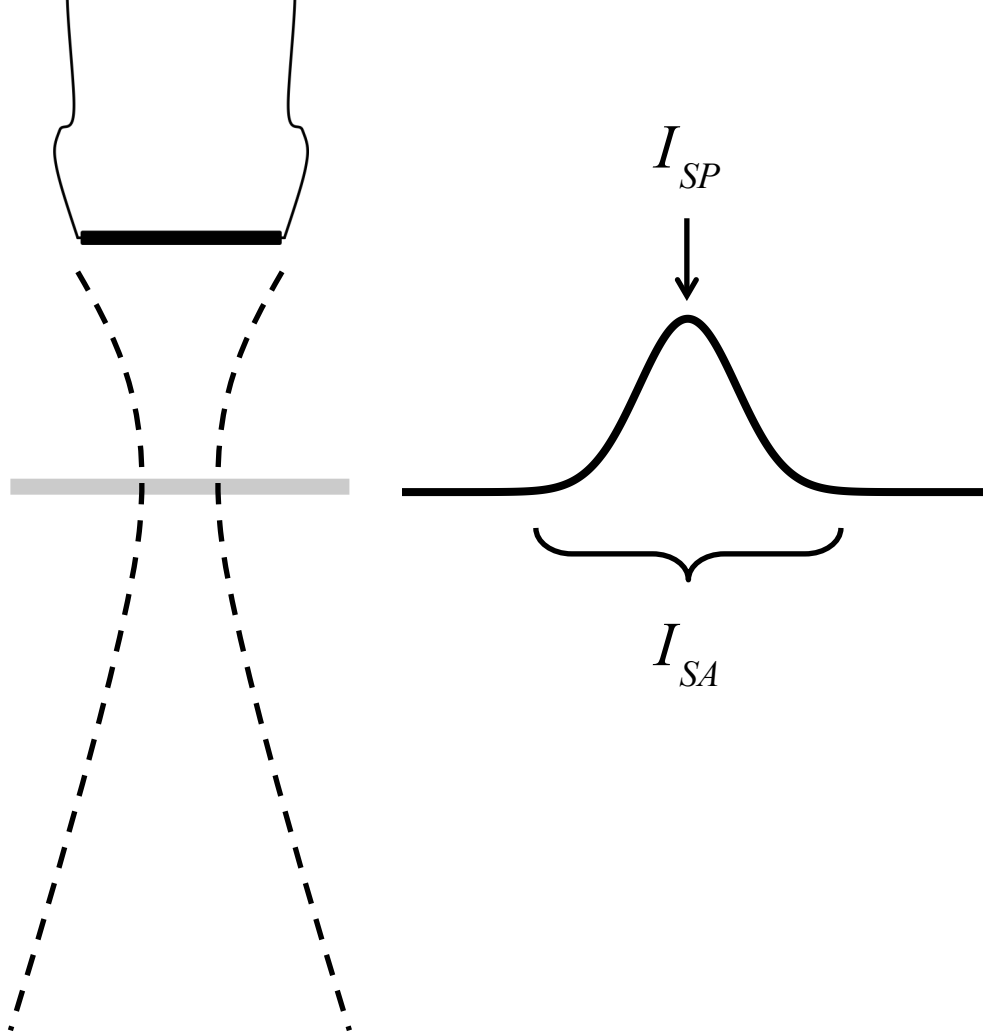
1

2

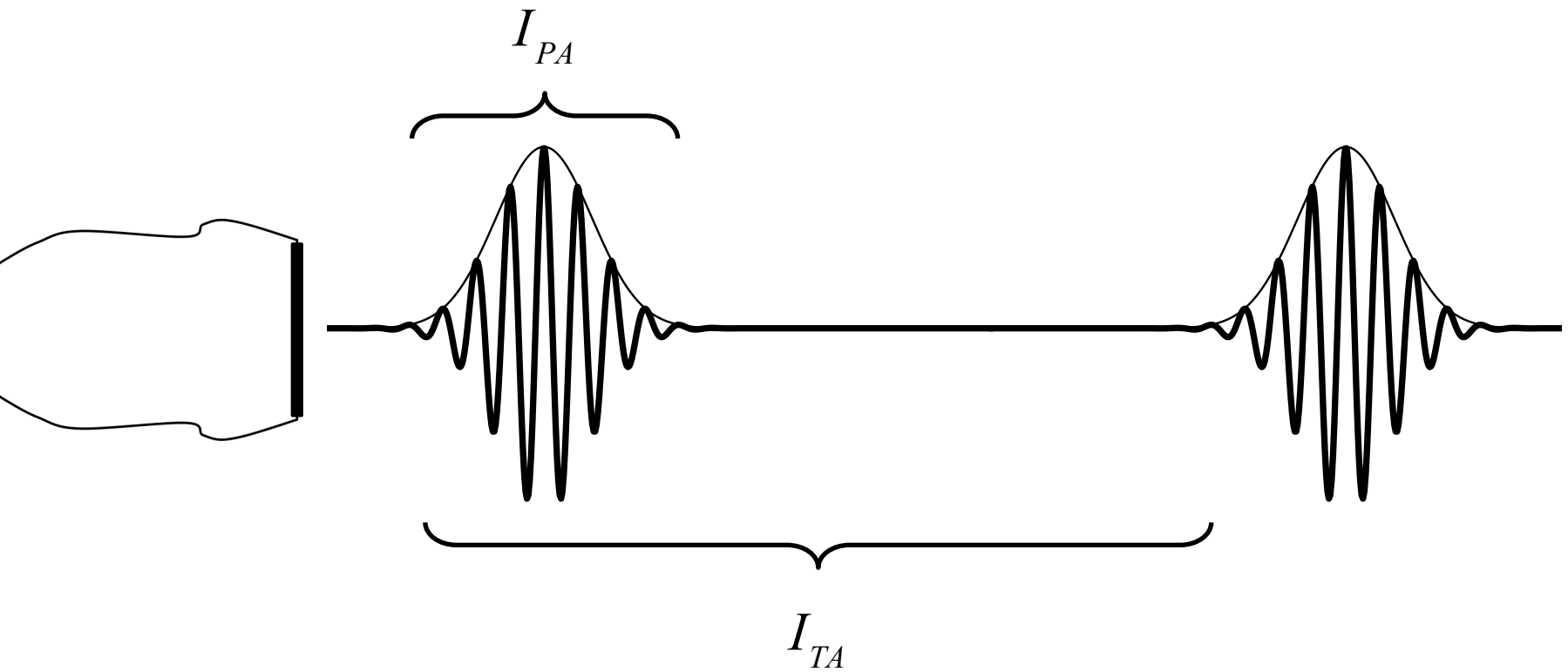
$$P_1 = P_2$$

$$I_1 < I_2$$

Intensity



Intensity



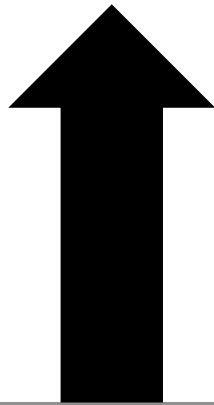
Intensity

Mode	Pressure (MPa)	Power (mW)	I_{SPTA} (mW/cm ²)	I_{SPPA} (mW/cm ²)
B-Mode	1.68	18	19	174,000
M-Mode	1.68	4	73	174,000
Pulsed Doppler	2.48	31	1,140	288,000
Color Flow	2.59	81	234	325,000

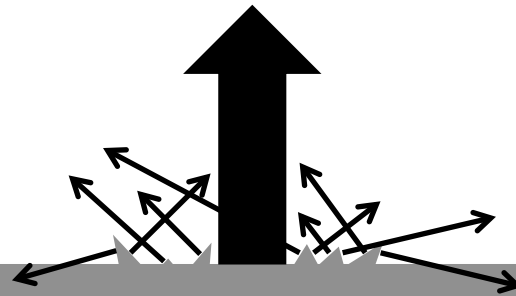
Ultrasound Safety



Ultrasound Contrast



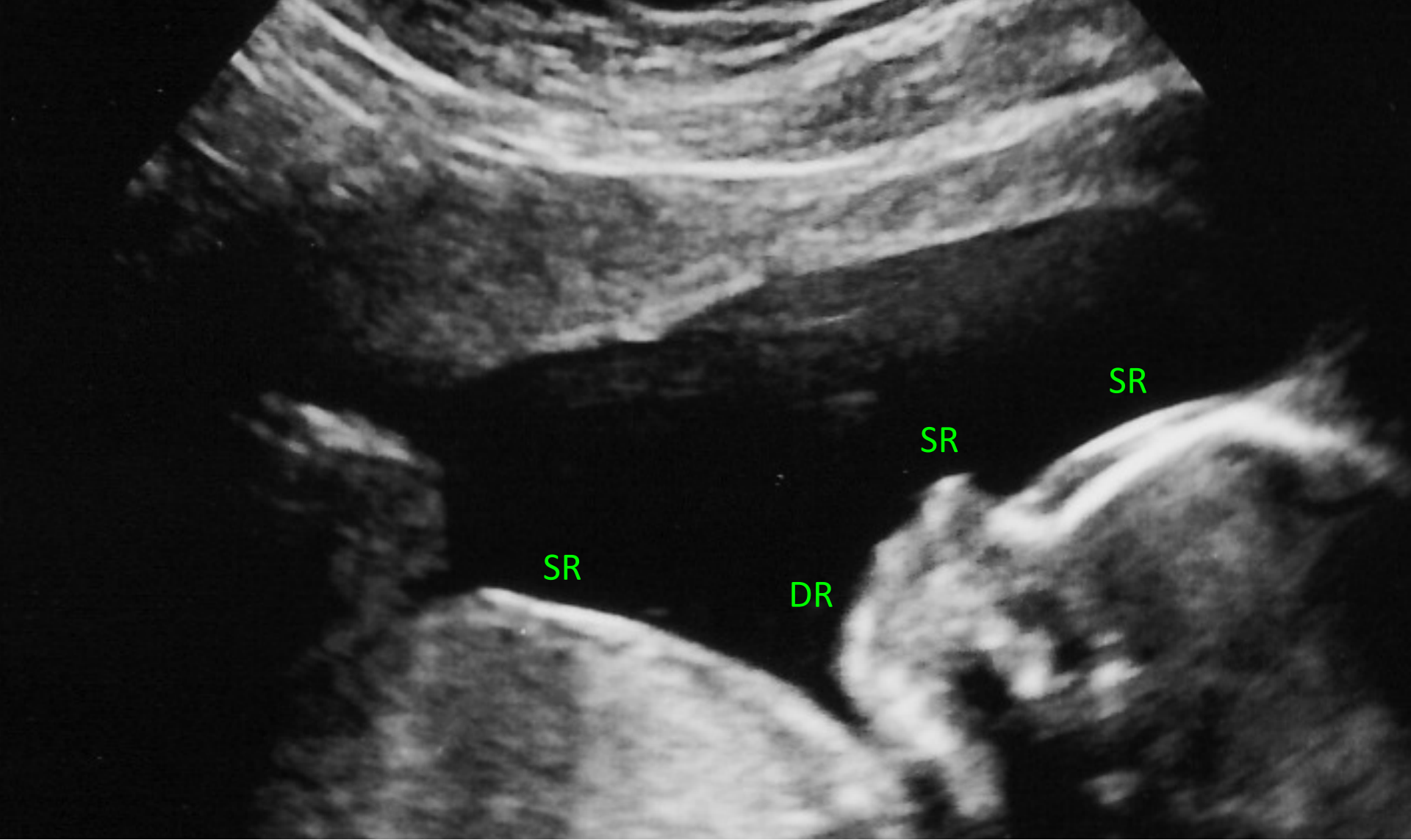
Specular
Reflection



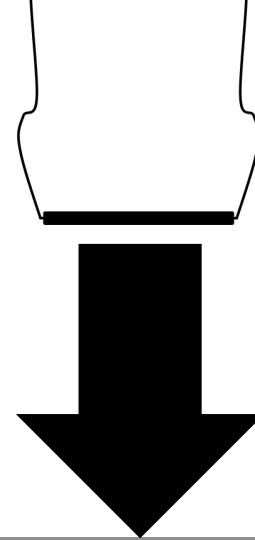
Diffuse
Reflection



Scattering



Scattering

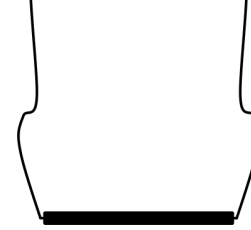


$$Z_1 = \rho_1 c_1$$

$$Z_2 = \rho_2 c_2$$

$$Z_1 = Z_2$$

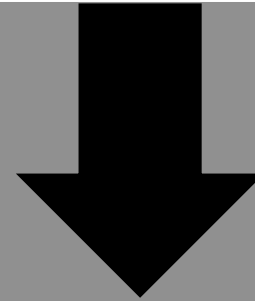
Reflection and Transmission



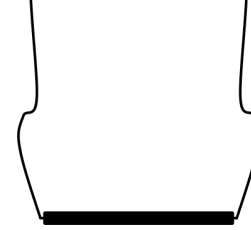
$$Z_1 = \rho_1 c_1$$

$$Z_2 = \rho_2 c_2$$

$$Z_1 = Z_2$$



Reflection and Transmission



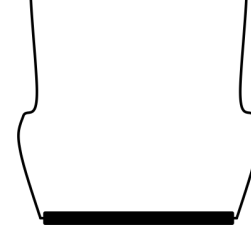
$$Z_1 = \rho_1 c_1$$

$$Z_2 = \rho_2 c_2$$

$$Z_1 \cong Z_2$$



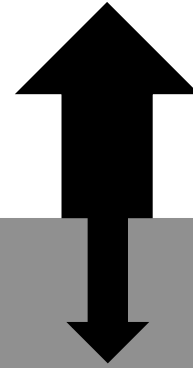
Reflection and Transmission



$$Z_1 = \rho_1 c_1$$

$$Z_2 = \rho_2 c_2$$

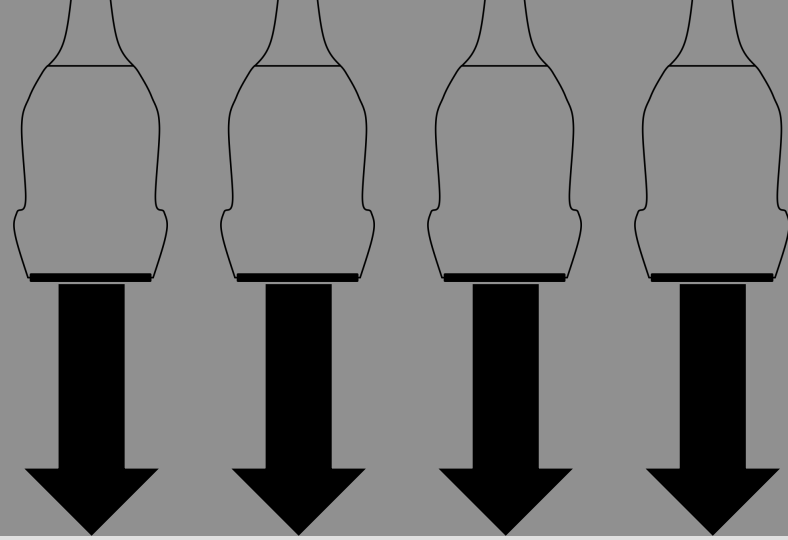
$$Z_1 \neq Z_2$$



Reflection and Transmission

Muscle

1.7
MRayl



Fat

1.3
MRayl

Bone

7.8
MRayl

Lung

0.2
MRayl

Air

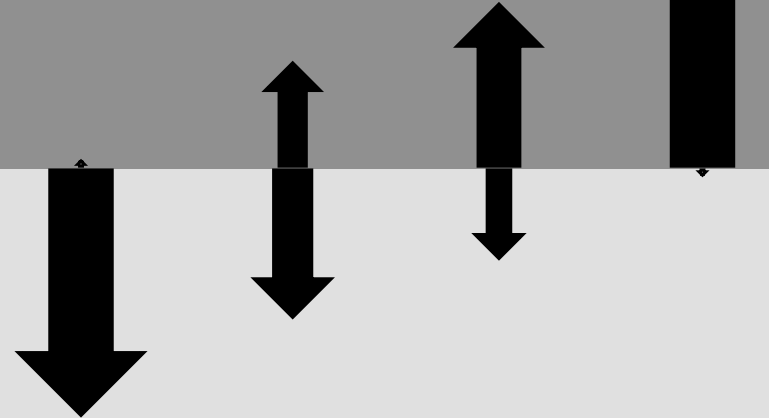
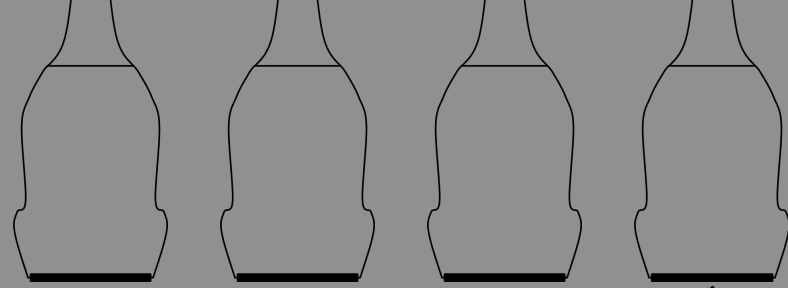
0.0004
MRayl

(Cobbold 2007)

Reflection and Transmission

Muscle

1.7
MRayl



Fat

Bone

Lung

Air

1.3
MRayl

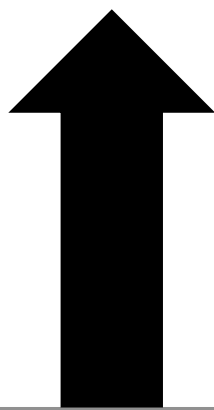
7.8
MRayl

0.2
MRayl

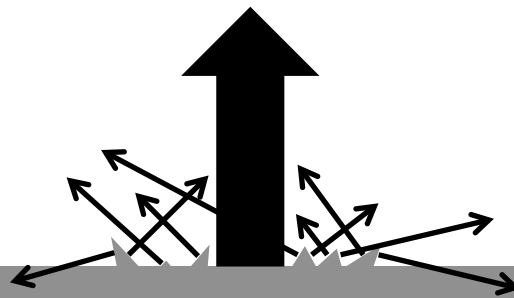
0.0004
MRayl

(Cobbold 2007)

Reflection and Transmission



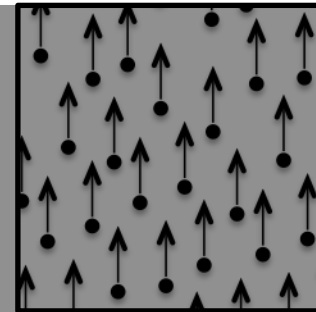
Specular
Reflection



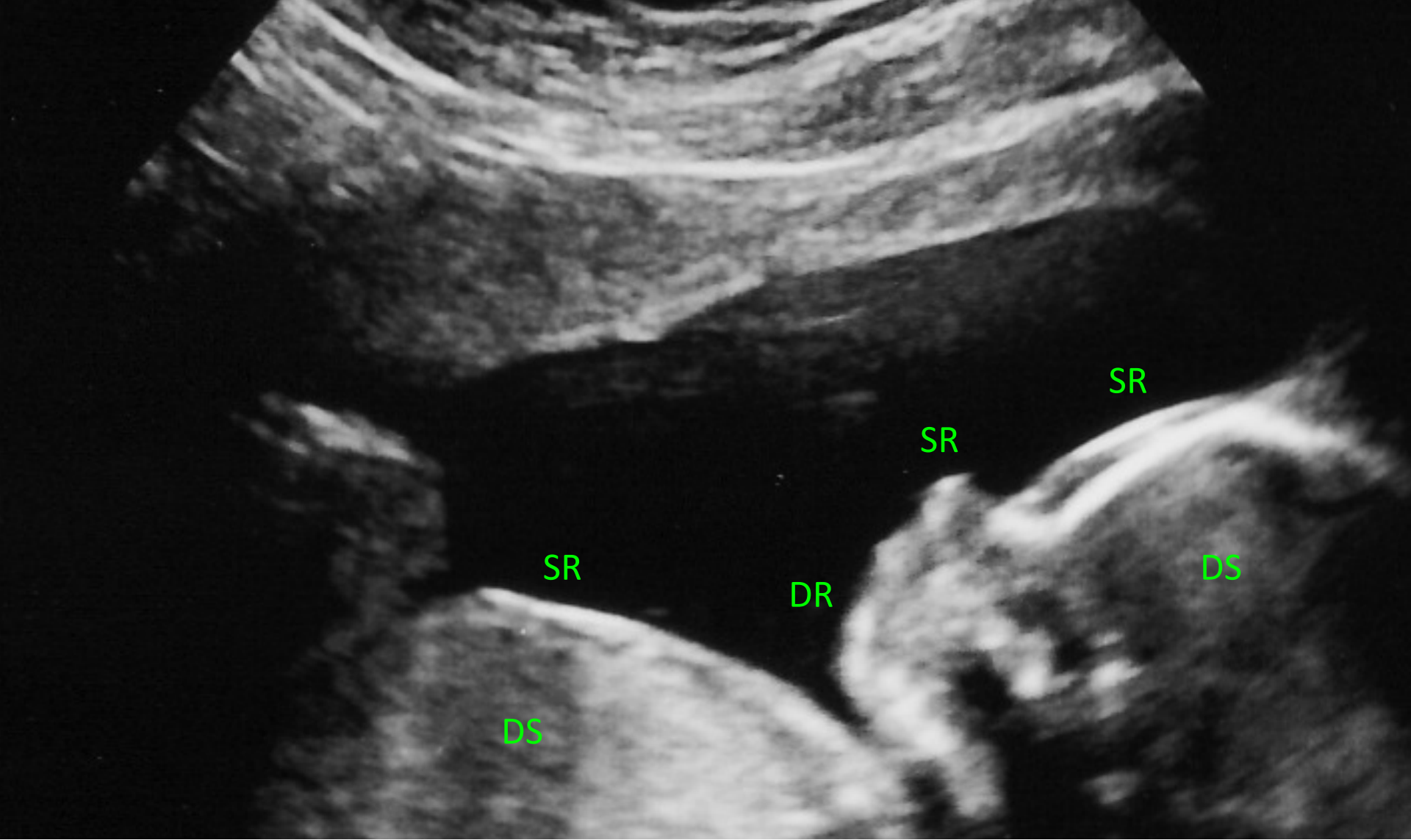
Diffuse
Reflection



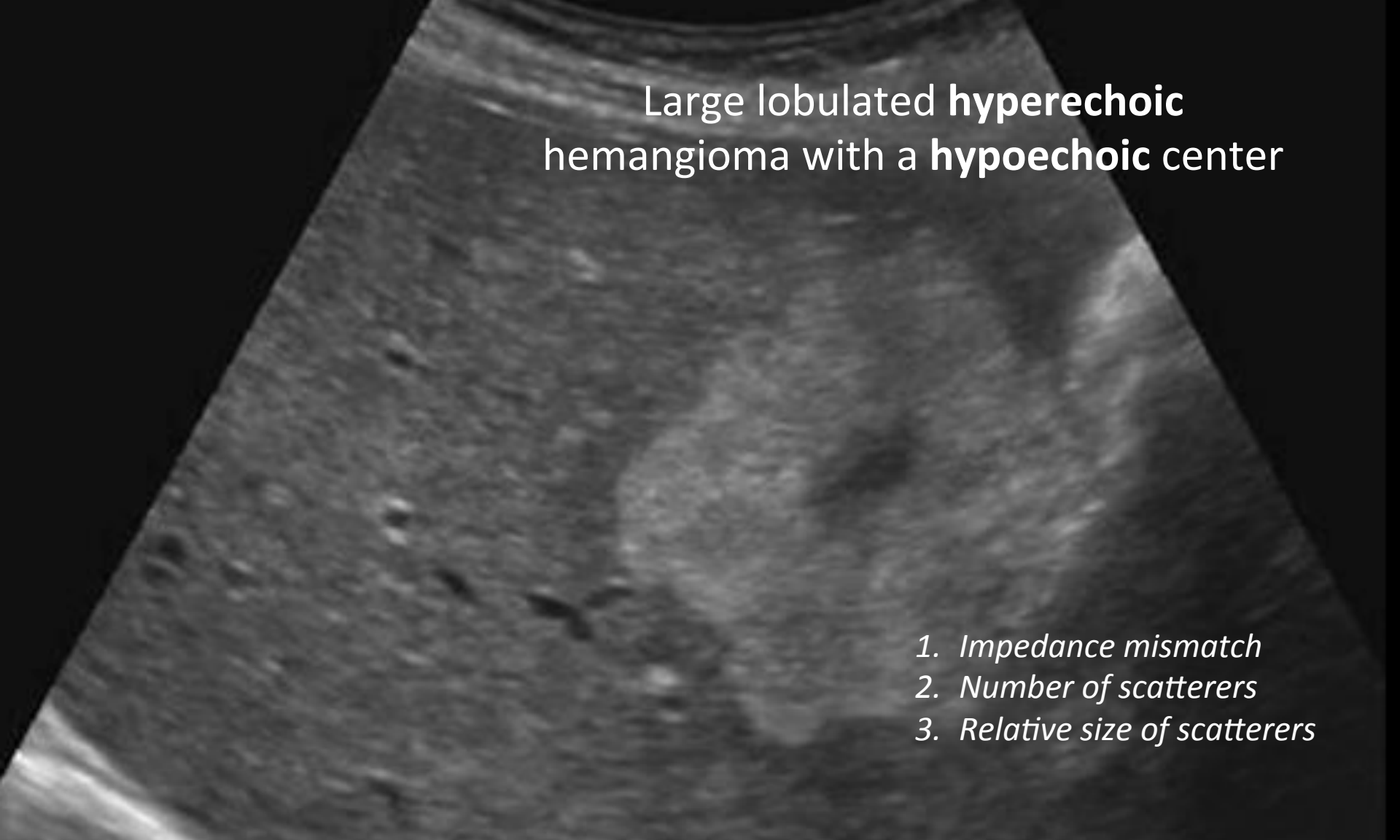
Diffuse
Scattering



Echogenicity



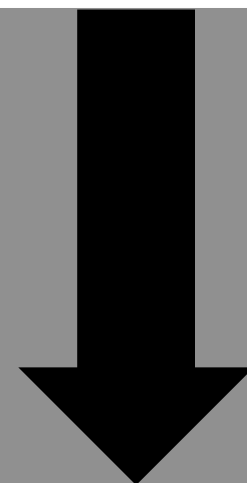
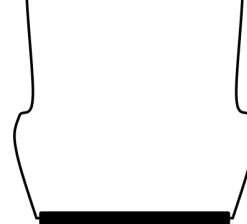
Echogenicity



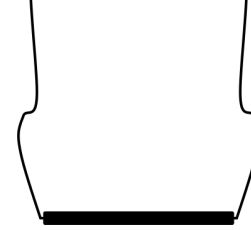
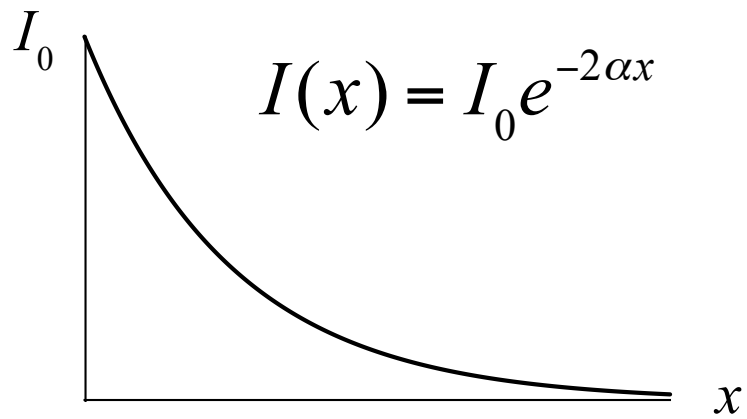
Large lobulated **hyperechoic**
hemangioma with a **hypoechoic** center

1. *Impedance mismatch*
2. *Number of scatterers*
3. *Relative size of scatterers*

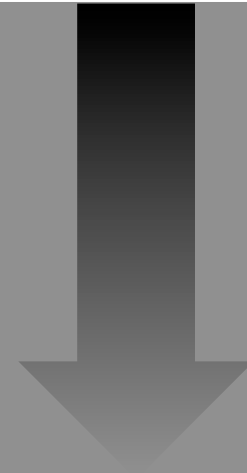
Echogenicity



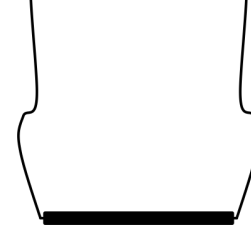
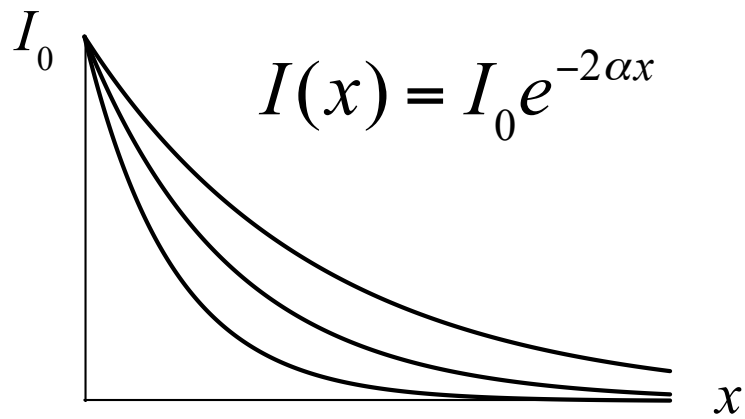
Attenuation



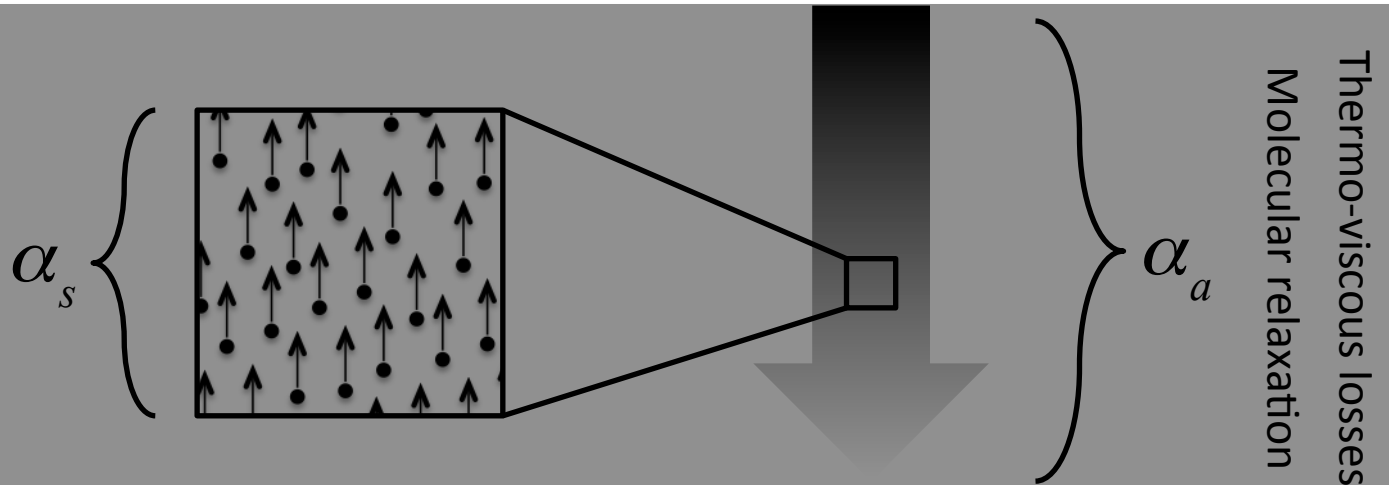
$$\alpha = \alpha_s + \alpha_a$$



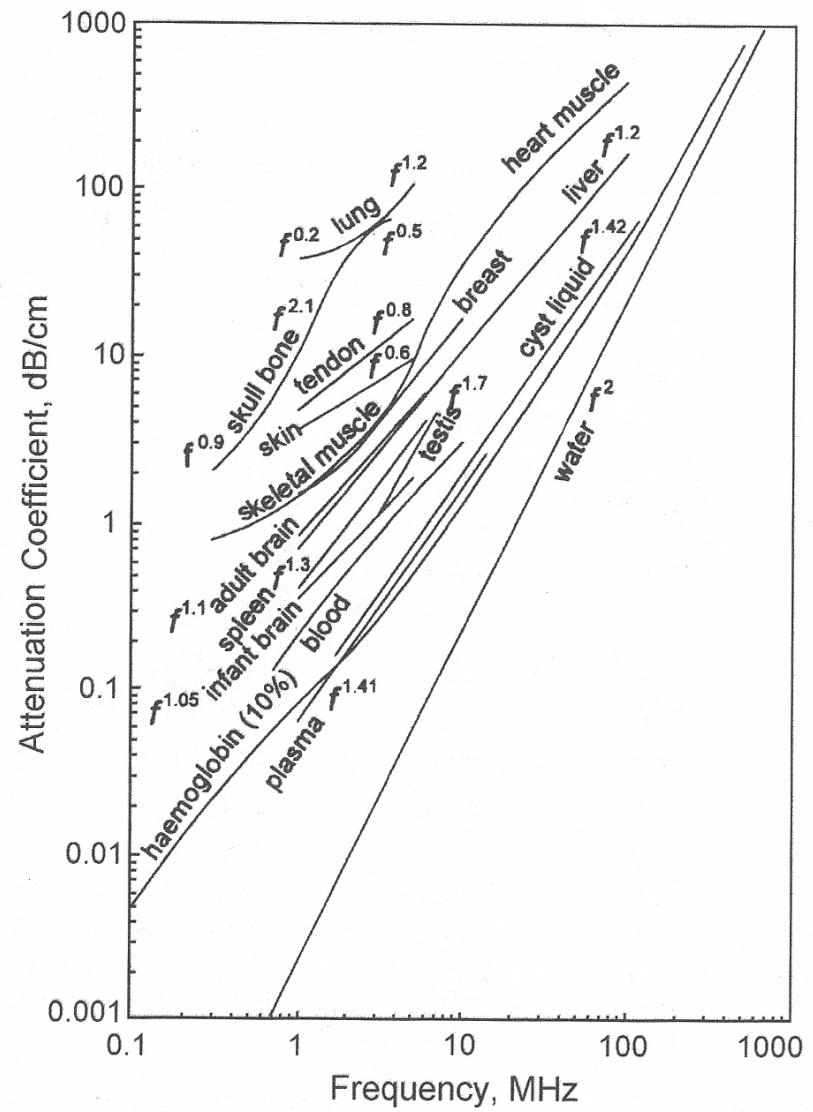
Attenuation



$$\alpha = \alpha_s + \alpha_a$$



Attenuation



(Cobbold 2007)

Attenuation



Time-Gain Compensation (TGC)

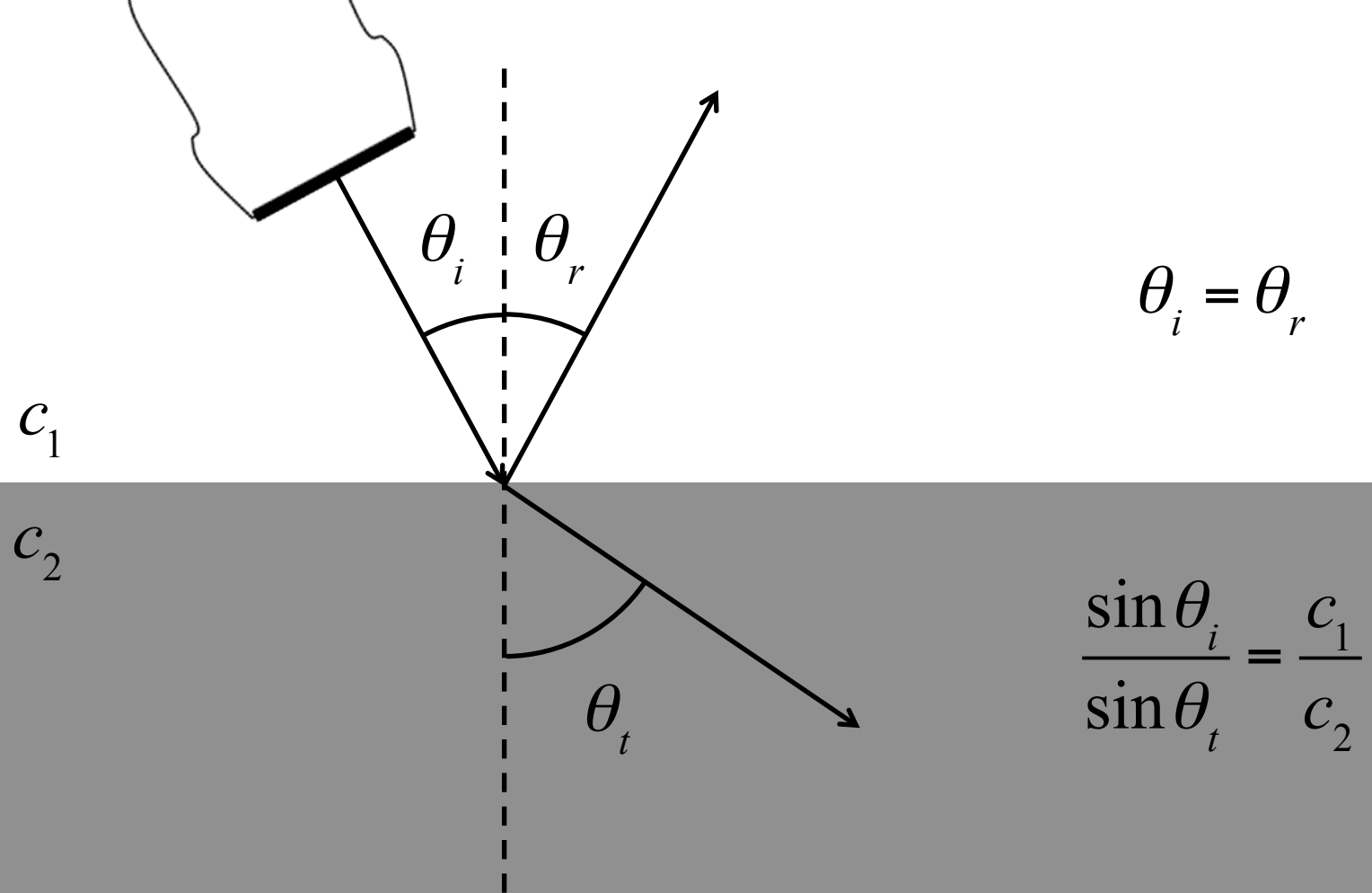


Time-Gain Compensation (TGC)

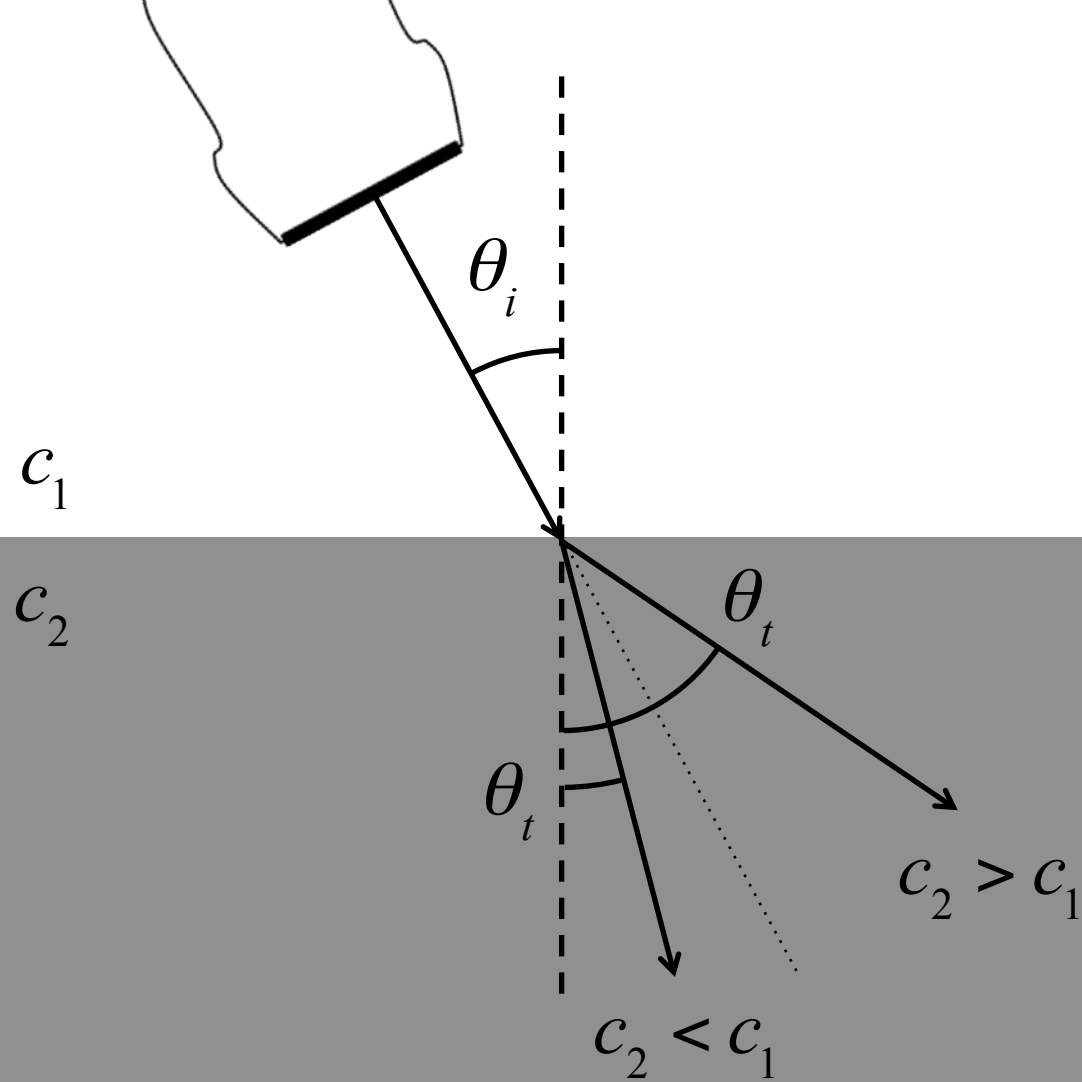
Tissue	α_0 [dB/(cm·MHz ^y)]	y
Water	0.0022	2
Blood	0.2	1.21
Fat	0.48	1
→ Soft Tissue	0.5	1
Liver	0.5	1.05
Cardiac	0.52	1
Brain	0.6	1.3
Breast	0.75	1.5
Bone (Cortical)	6.9	0.9
Bone (Trabecular)	9.9	0.9

(Cobbold 2007, Cox 2013)

Attenuation



Refraction



$$\frac{\sin \theta_i}{\sin \theta_t} = \frac{c_1}{c_2}$$

Refraction

Ultrasound Basics

Frequency

Amplitude

Wavelength

Velocity

Pressure

Energy, Power, and Intensity

Ultrasound Contrast

Scattering

Echogenicity

Reflection and Transmission

Characteristic Impedance

Attenuation

Refraction

Summary