Ministry of Higher Education and Scientific Research
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Radiological Physics

Al-Mustaqbal University College

3rd

Radiology Techniques Department

By

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Lecture 5: Interactions of Ultrasound with Tissue

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Characteristic Acoustic Impedance of a Medium

The acoustic impedance of a medium z is a measure of the response of the particles of the medium in terms of their velocity, to a wave of a given pressure. It is analogous to electrical impedance (or resistance R)

$$Z = \sqrt{\rho k}$$

By combining this equation with that for the speed of sound given earlier, it can be shown also that:

$$Z = \rho c$$

Acoustic impedance z has units of kg.m^{-2} s $^{-1}$, but the term rayl (after Lord Rayleigh) is oft en used to express this unit.

Material	z (kg m^{-2} s^{-1})
Liver	1.66×10^6
Kidney	1.64×10^6
Blood	1.67×10^6
Fat	1.33×10^6
Water	1.48×10^6
Air	430
Bone	6.47×10^6

The amount of reflection or backscatter is determined by the difference in the acoustic impedances of the materials forming the interface

For example, ultrasound beams are reflected strongly at air–tissue and air–water interfaces because the impedance of air is much less than that of tissue or water

- Acoustic impedances high values : solids
- intermediate values: liquids and soft tissues
- low values: of gases

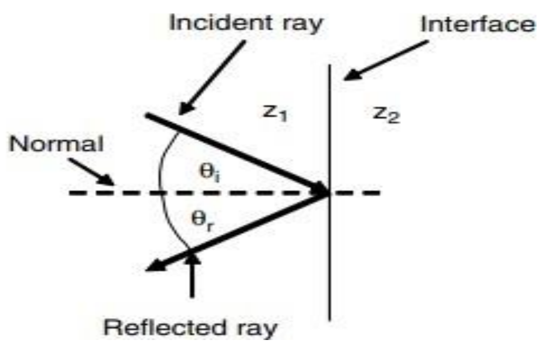
Therefore, Acoustic impedance is the opposition of a tissue to the passage of ultrasound waves.

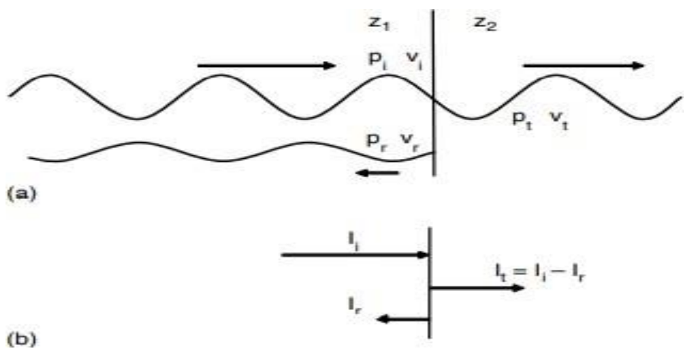
Reflection

The amplitudes of the transmitted and reflected waves depend on the change in acoustic impedance.

The angle of incidence (θi) = angle of reflection (θr), and it obeys Snell's law

$$\frac{sin\emptyset_i}{sin\emptyset_r} = \frac{C_1}{C_2}$$

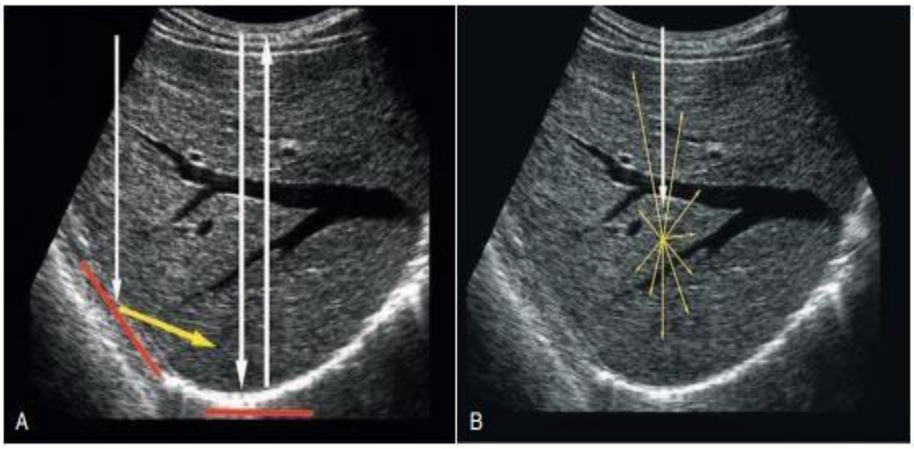




The way ultrasound is reflected when it strikes an acoustic interface is determined by the size and surface features of the interface.

Specular or Diffuse Reflection

- Specular reflectors are large, smooth surfaces, such as bone
- If large and relatively smooth, the interface reflects sound much as a mirror reelects light. Such interfaces are called **specular reflectors**.
- The acoustic interfaces involve structures with individual dimensions much smaller than the wavelength of the incident sound. the echoes from these interfaces are scattered in all directions. Such reflectors are called **diffuse reflectors**



Soft tissue is classified as a diffuse reflector, where adjoining cells create an uneven surface causing the reflections to return in various directions in relation to the transmitted beam

- If a specular reflector is perpendicular to the incident sound beam, the amount of energy reflected (i.e., **the reflection coefficient R**) is determined by the following relationship:

$$\frac{I_r}{I_i} = R = R^2 = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2$$

ΔZ large ⟶ High reflection and low transmisson ⟶ mismatching

The fraction of the incident energy that is transmitted across an interface is described by the **transmission coefficient T**, where

$$T = \frac{I_t}{I_i} = \frac{4Z_1 Z_2}{(Z_1 + Z_2)^2}$$

Obviously T+ R=1.

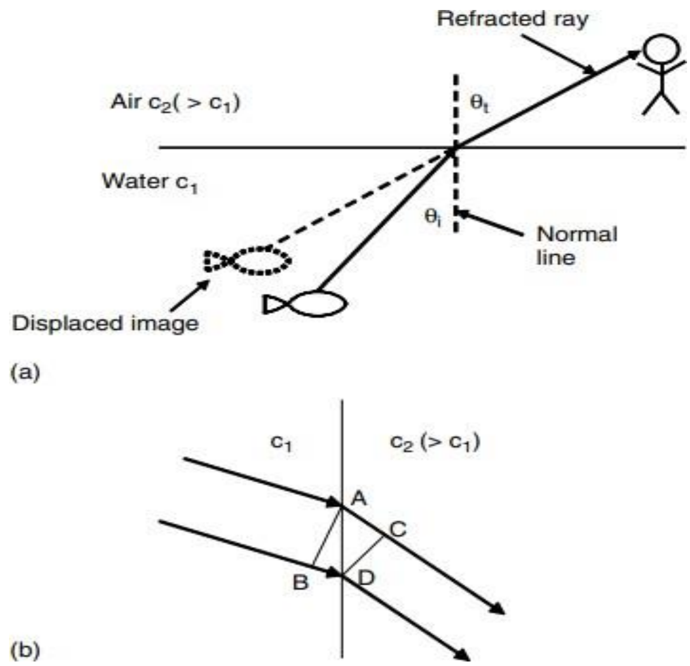
Example: At a "liver–air" interface, $Z_1 = 1.65\times 10^6$ Rayl and $Z_2 = 0.0004\times 10^6$ Rayl calculate the coefficient of reflection and transmission

$$R = \left(\frac{1.65 - 0.0004}{1.65 + 0.0004}\right)^2 = 0.9995$$

T+ R=1 ⟶ T=1− R ⟶ T=1− 0.9995 , T= 0.0005

Refraction

When sound passes from a tissue with one acoustic propagation velocity to a tissue with a higher or lower sound velocity, there is a change in the direction of the sound wave. This change in direction of propagation is called refraction and is governed by Snell law



The relationship between the angles θ_i , θ_r , C_1 and C_2 is described by Snell's law:

$$\frac{sin\emptyset_i}{sin\emptyset_r} = \frac{C_1}{C_2}$$

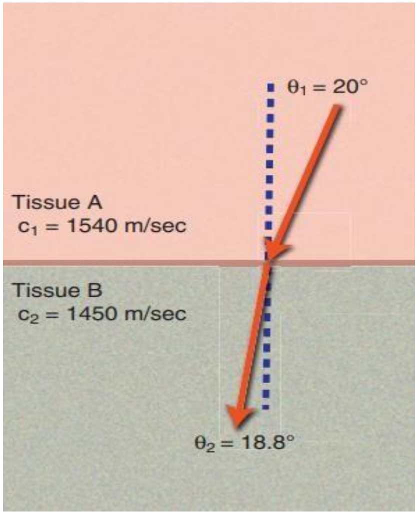
- Refraction of ultrasound waves at boundaries where the speed of sound changes can also cause displacement of the image of a target from its true relative position in the patient

When the wave crosses an interface where the speed of sound increases, the angle to the normal also increases.

If $C_1 < C_2$

Conversely, when the wave experiences a reduction in the speed of sound as it crosses the interface, the angle to the normal also decreases.

If $C_1 > C_2$



Refraction is important because it is one cause of misregistration of a structure in an ultrasound image.

- Refraction is a principal cause of artifacts in clinical ultrasound images.