Physics of Ultrasound

Fourth lecture

Interaction of Ultrasound with Matter II

Dr. Nasma Adnan

Third Stage

Department of medical physics

Al-Mustaqbal University-College

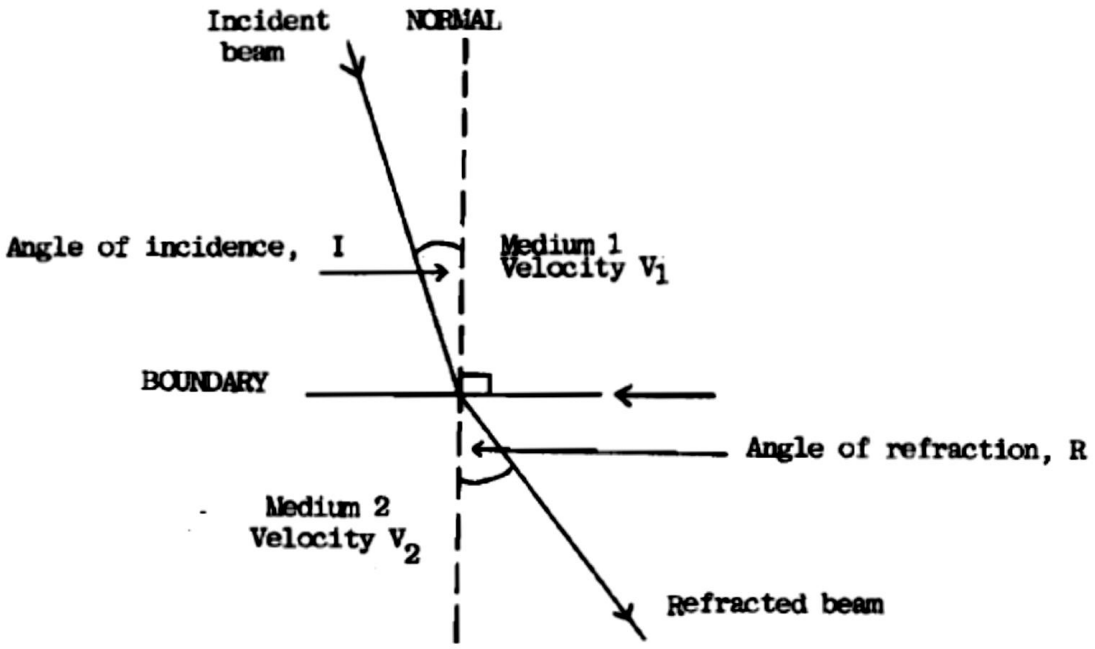
2021- 2022

1. *Refraction of ultrasound*

- Refraction is a change of beam direction at a boundary between two media in which ultrasound travels at different velocities.
- It is caused by a change of wavelength as the ultrasound crosses from the first medium to the second while the beam frequency remains unchanged.

Velocity = frequency x wavelength

When velocity changes but frequency remains the same, the wavelength must undergo change.



- The phenomenon of refraction occurs when the angle of incidence at the boundary is not zero.
- In the case of normal incidence, part of the beam energy is reflected directly backwards, and the remaining energy is transmitted into the second medium without directional change.
- At any other angle of incidence, the transmitted beam is deviated from the original direction of the incident beam, either towards or away from

the normal, depending on the relative velocities of ultrasound in the two media.

- The relationship between the angle of incidence and the angle of refraction is governed by Snell's law as in optics:

$$\frac{\text{Sin I}}{\text{Sin R}} = \frac{V_1}{V_2} \qquad \text{(Snell's law)}$$

I = angle of incidence

R = angle of refraction

V_1 = velocity of ultrasound in medium 1

V_2 = velocity of ultrasound in medium 2

  - ✓ Refraction does not contribute usefully to the process of image formation.
  - ✓ The deviation of ultrasonic energy into new directions contributes to loss of beam intensity.

2. *Absorption of ultrasound*

- Absorption is the process by which energy in the ultrasound beam is transferred to the propagating medium, where it is transformed into a different form of energy, mostly heat.
- The medium is said to absorb energy from the beam. The extent of absorption in a medium is affected by three main variables. These are:
  - (i) The viscosity of the medium.
  - (ii) The relaxation time of the medium
  - (iii) The beam frequency.
- Viscosity is a measure of the frictional forces between particles of the medium as they move past one another. The greater these frictional forces the more heat generated by the vibrating particles. Therefore, absorption of ultrasound increases with increasing viscosity.

- Relaxation time is a measure of the time taken by medium particles to revert to their original mean positions within the medium following displacement by an ultrasound pulse.
- When the relaxation time is short, vibrating particles are able to revert to their original positions before the next disturbing pulse, but when it is long, the next pulse may encounter the particles en route before they are fully relaxed.
- The new compression and the particles may then be moving in opposing directions, thus resulting in additional dissipation of energy from the beam.
- Therefore, the longer the relaxations time of a medium, the higher the absorption of ultrasound.
- The frequency of vibrations affects the amount of heat generated through both the viscous drag and the relaxation process.
- Higher frequency means that medium particles move past each other at an increased rate, thus generating more frictional heat.
- Increased frequency also reduces the probability that, following an ultrasonic pulse, vibrating particles will have reverted to their equilibrium positions before the next disturbance, thereby increasing energy absorption as the new wave moves in opposition to the relaxing particles.
- We conclude that absorption of ultrasound increases with increasing beam frequency.
- In soft tissues, absorption of ultrasound increases in direct proportion to the beam frequency.
- Among materials of biological interest, bone absorbs ultrasound much more strongly than the soft tissues.

4. *Beam divergence and interference*

- ✓ Divergence of an ultrasound beam describes the spreading out of the beam energy as it moves away from the source.
- ✓ Interference refers to the manner in which different parts of the wave (called wave fronts) interact with each other.
- ✓ The theoretical explanation for the spreading out of beam energy is provided by Huygens ' Principle of wavelets.
- ✓ Divergence affects the intensity of the beam both axially (along the beam direction) and laterally (perpendicularly to the beam direction).
- ✓ Interference can result in either a strengthening or a weakening of the wave, depending on the phases (positions in the wave cycle) of the interacting wave fronts.
- ✓ In diagnostic ultrasound the dimensions of the ultrasound beam, and the manner, in which it diverges, has a great influence on image resolution, and on the tissue depths that can be investigated using the beam.

5. *Attenuation of ultrasound in tissues*

- Attenuation refers to the total propagation losses that result in a reduction of the beam intensity.
- These losses include those due to reflection, scattering, refraction, and absorption.

Ultrasonic half value thickness (HVT)

- The extent of beam attenuation depends on both the beam frequency and the properties of the propagating medium.
- The attenuation in a specified medium may be quantified in terms of the ultrasonic half value thickness (HVT).

- The HVT of a beam of ultrasound in a specified medium is the distance within that medium which reduces the intensity of the beam to one half of its original value

Acoustic windows and acoustic barriers

- ☒ The HVT values for water (and for other liquids) are large, whereas those for bone and gas are very low.
- ☒ This means that ultrasound can travel long distances in liquids.
- ☒ The reason for this is that clear liquids are acoustically homogeneous - there are no acoustic boundaries within them.
- ☒ This eliminates those attenuation processes which depend on changes at boundaries (including reflection and refraction).
- ☒ Overall attenuation is therefore low.
- ☒ Compartments which allow ultrasound to pass readily through them are referred to as acoustic windows.
- ☒ Liquid cavities within the body, containing bile, urine, amniotic fluid, cerebrospinal fluid, and so on, fit this description.
- ☒ On ultrasonic images, they appear as clear, echo-free zones.
- ☒ The bone and gas impede the flow of ultrasound. Bone absorbs heavily, while gas boundaries reflect almost totally. The presence of fat also impedes the transmission of ultrasonic energy, for a variety of complex reasons. Such materials are referred to as acoustic barriers.

Effect of beam frequency

- ✓ Attenuation of ultrasound increases rapidly with increasing beam frequency.
- ✓ This is because the process of absorption increases approximately in direct proportion to frequency.

- ✓ While the probability for beam scattering increases even more rapidly with increasing frequency.
- ✓ In ultrasonic imaging, the rapid increase in attenuation as the beam frequency is increased implies that very high frequencies cannot be employed to examine long distances in tissue.
- ✓ High frequencies reduce beam penetration. For reasons of improved image quality use of high frequencies would be desirable, but reduced beam penetration sets the upper limits of frequencies used in diagnostic ultrasound at about 15 MHz.