Medical physics

Lecture:

Ch12 (p2): Sound & Ultrasound in medicine

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- **The plan for lecture:**

1. Ultrasound’s interaction with the tissue .
2. Ultrasound Images.
3. The uses of medical ultrasound as:

   a. diagnostics

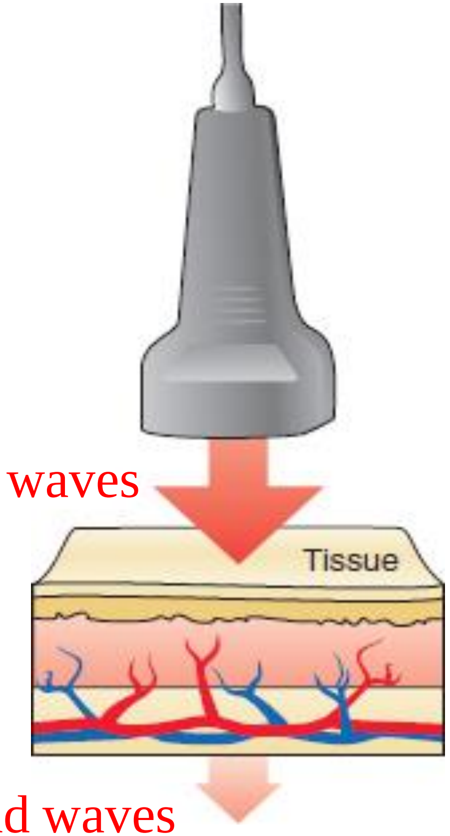
   b. therapeutics

4. Disadvantage of Ultrasound

Ultrasound's interaction with the tissue :

The figure show the attenuation of the incident Ultrasound waves (red arrow) as it travels through living tissue. The continuing propagating Ultrasound wave is smaller due to the interactions as reflection, refraction, and absorption of portions of the incident Ultrasound wave.

Incident Ultrasound waves



propagation Ultrasound waves

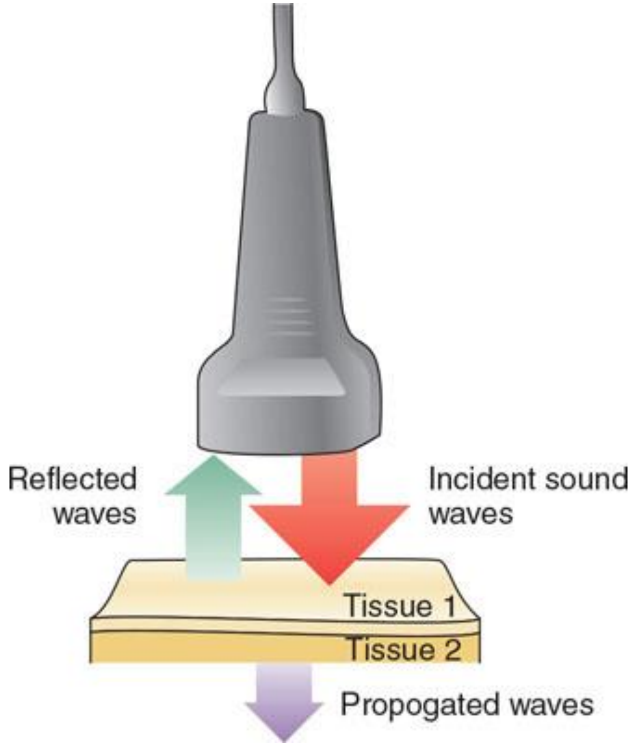
Ultrasound’s interaction with the tissue :

The main interaction of US waves in tissue :

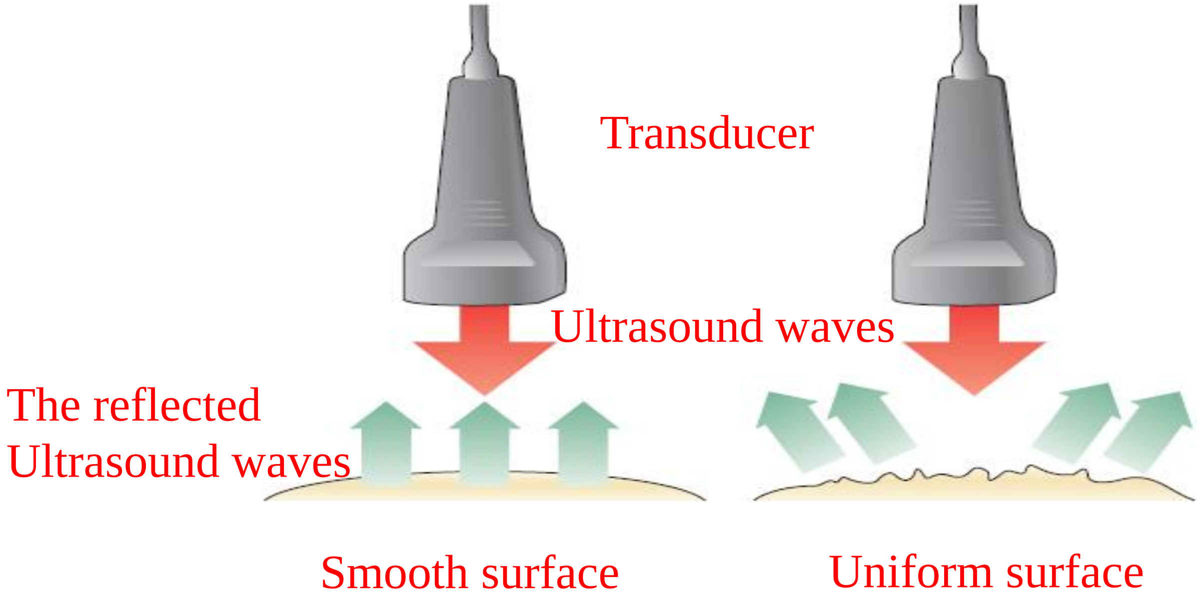
1) Reflection:

Reflection occurs when ultrasound waves hits the soft tissue and bounces back to the transducer (probe) and is used to generate the ultrasound image.

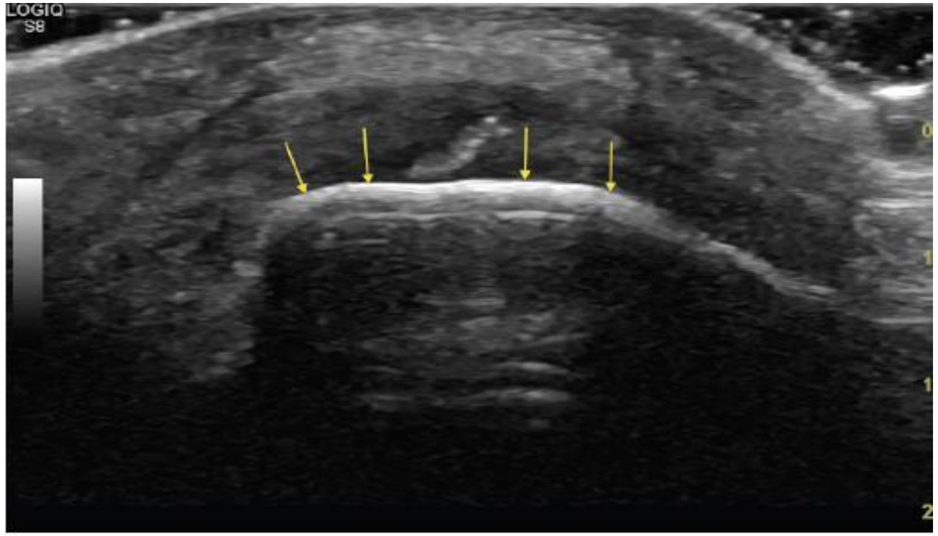
- Not all sound wave is reflected, some it continue deeper into the tissue and will reflect from deeper tissues in the body.
- The amount of ultrasound reflection depends on differences in acoustic impedance (z) between tissue boundaries (tissues with different properties such as fat, muscle and blood) .



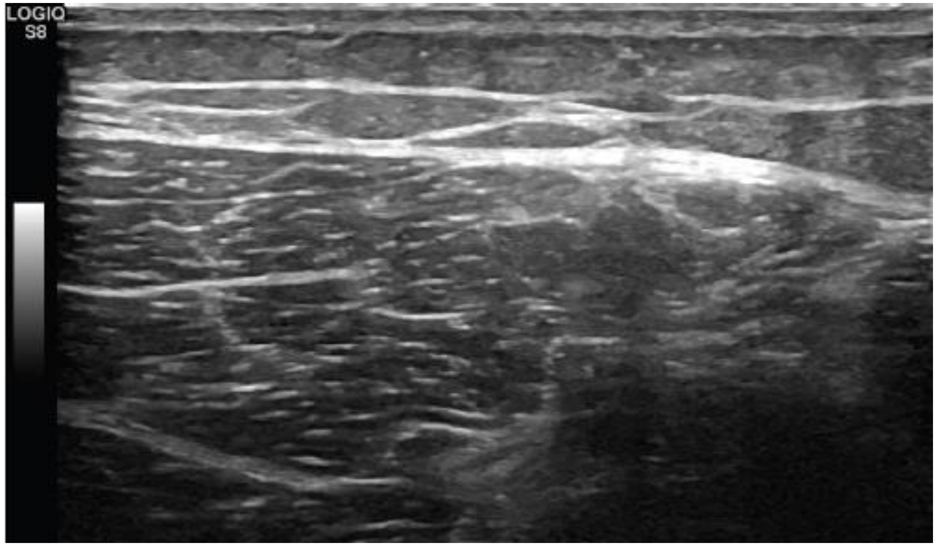
The smooth surface reflection results in more return of the reflected Ultrasound waves to the transducer (green arrows) creating a more hyperechoic (brighter) image. The less uniform tissue reflection results in less return of the reflected Ultrasound waves and a more hypoechoic (darker) image.



For example:



Note that the large smooth surface of the bone (yellow arrows) leads to a bright signal due to the significant impedance difference between it and the surrounding tissue

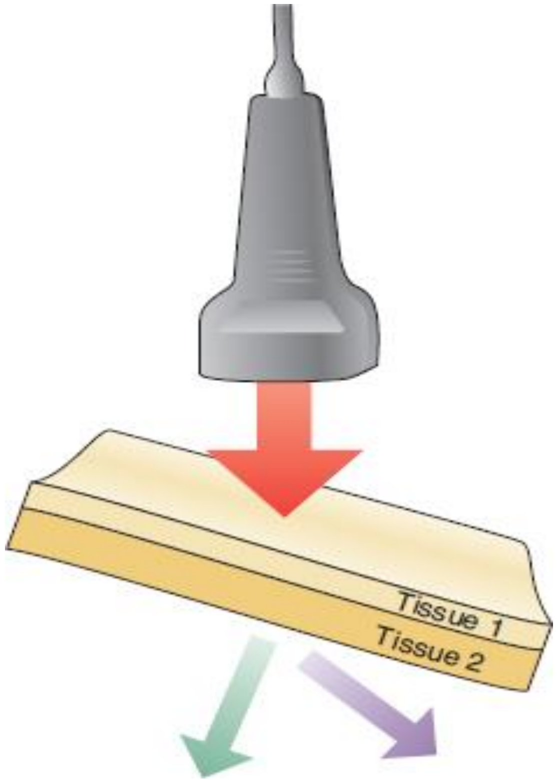


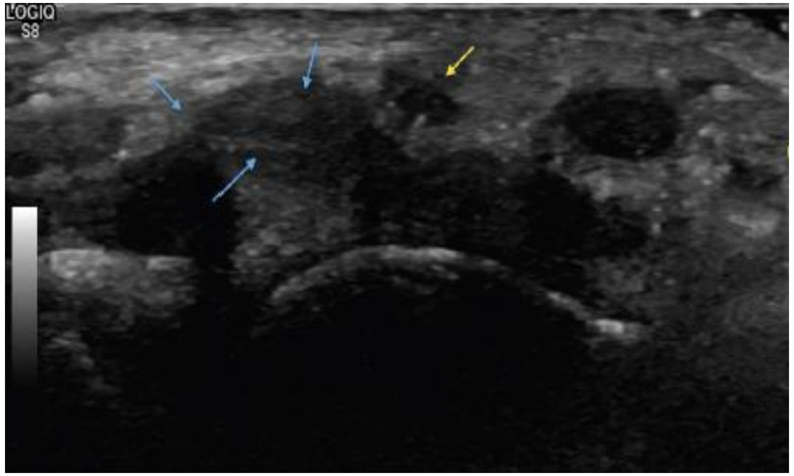
Ultrasound image showing the appearance of more diffuse reflection in muscle tissue. Note that the smaller differences in acoustic impedance reflect various shades of gray rather than the bright signal noted with the interface of bone.

Ultrasound’s interaction with the tissue :

2) Refraction

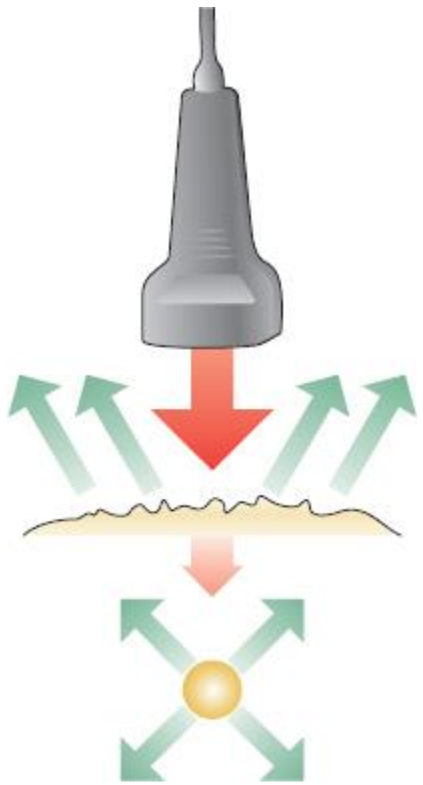
- Refraction is the alteration of direction of the Ultrasound wave after it hits the interface of different tissue with different impedances. If the Ultrasound wave propagation velocity is faster in the first tissue (less impedance in tissue 1) then the refraction occurs toward the center (perpendicular to the interface) (green arrow). If the velocity is greater in the second tissue (less impedance in tissue 2) then the refraction is away from the incident beam (purple arrow).
- Refraction occurs when ultrasound wave as it hits at the interface of tissue surface at an oblique angle from the transducer, it’s deviated.
- Ultrasound waves are refracted at a different medium interface of different acoustic impedance.
- Refraction can result in ultrasound image artifacts.





Ultrasound image artifact with darkening of the structures

Ultrasound’s interaction with the tissue :



3) Scattering : Ultrasound wave dispersed in all direction.

Scattering occurs when ultrasound wave hits the tissue and then it split up in all directions and scattered, by interaction with rough surface and irregularly shaped of tissue (e.g. RBCs).

This allows some of the reflected ultrasound waves to return to the transducer and be used to generate an image.

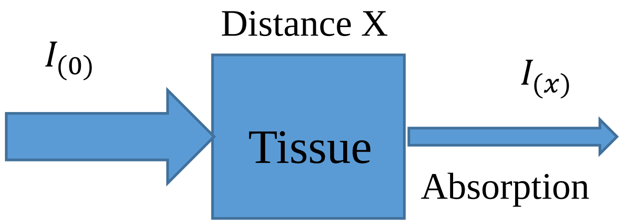
4) Another source of attenuation of the propagating Ultrasound wave is through absorption.

This occurs when the Ultrasound wave energy is given off as heat. As a result, none of this energy returns to the transducer to contribute to the creation of the electrical signal.

This occurs when the Ultrasound waves travel through tissues, producing heat and loss of wave energy due to friction. The loss of this energy increases with the increase in depth. As a result, none of this energy returns to the transducer to contribute to the creation of the electrical signal.

As Ultrasound waves travel through tissue, there is a progressive reduction in the intensity of the wave. This process is known as attenuation. The property of the degree of Ultrasound wave attenuation in specific tissue is known as that tissue's attenuation coefficient.

This formula (1) is described by exponential law with some factors to consider in the exponent;
Where; $I_{(0)}$ is the initial intensity, $I_{(x)}$ is the intensity as a function of distance (this intensity decreases exponentially), the attenuation coefficient alpha ($\propto$) is given in unit [dB/ cm /MHz] (decibels per centimeter per megahertz). The intensity is given in watt/cm2.
For example: The average rate of attenuation in soft tissue (0.5 dB/ cm /MHz).



$$I_{(x)} = I_{(0)}\, e^{-\propto x} \quad \ldots\ldots (1)$$

Notes:

- The decibel is the unit for describing the difference between ultrasound intensities.
- The attenuation (decrease in ultrasound intensity (I)) occurs as a result of four processes: *reflection*, *refraction*, scattering and *absorption*

Notes:

- Tissues more water content is low absorption rate (fat). (Muscles absorb twice as much as fat)
- Tissues more protein content is high absorption rate (nerve and bone).

Attenuation of ultrasound energy depends on the several factors are:

a. Frequency of ultrasound (higher frequency, more attenuation).

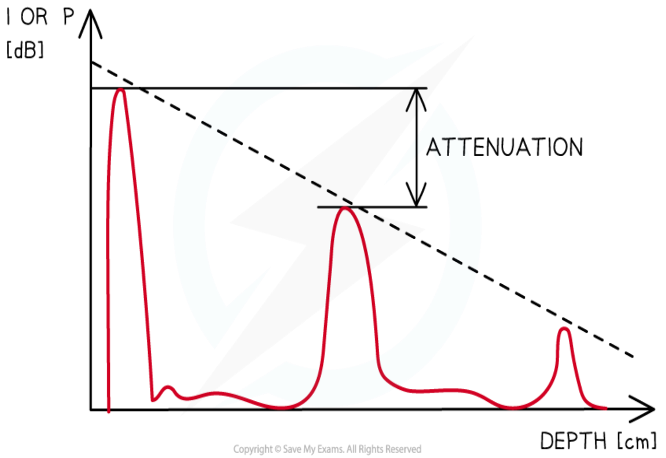
b. Density of tissue (tissues have differing densities (ρ); the greater density the slower speed sound

c. Propagation velocity of sound (velocity of propagation (υ); the greater the stiffness / faster the sound (ex: bone > muscle> liver> fat> lung) .

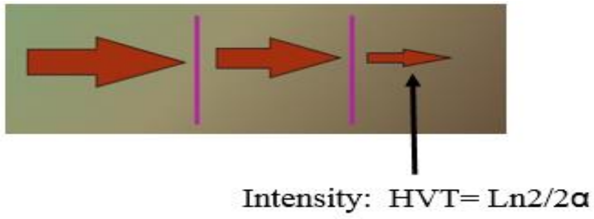
speed of sound in human tissue is 1540 m/s

d. Acoustic impedance (z) of the tissue. (Acoustic impedance is the resistance to the propagation of ultrasound in a tissue).

$$z = \rho \upsilon$$



The distance that ultrasound travels in order for the intensity to decrease to half the original value is called; half value thickness (HVT) or half value depth. Half value thickness decreases as the frequency increases.



Ultrasound Penetration:

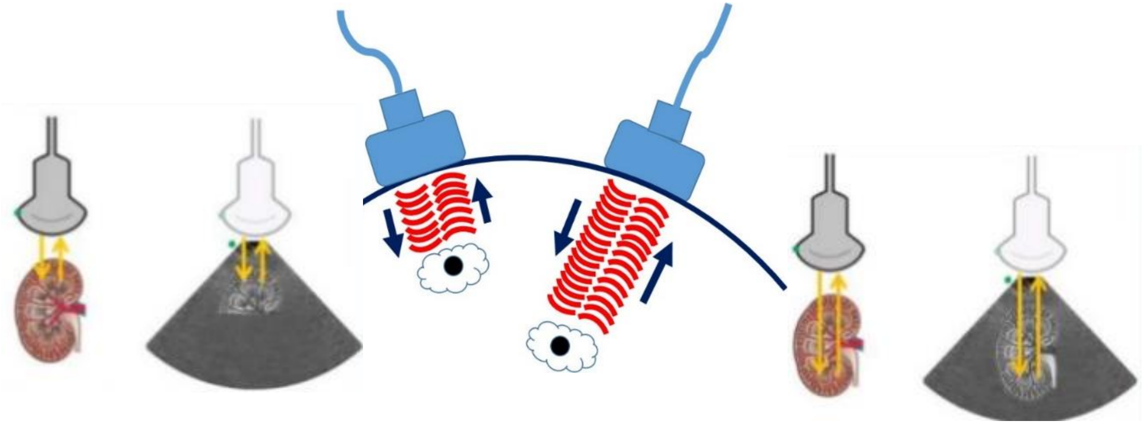
How far ultrasound waves can travel ?

US frequency vs Resolution and penetration:

For example;

The figure show the difference between high-frequency and low-frequency ultrasound wave

High frequency image = 5 MHz   Low frequency image = 2 MHz



- Tissues closer appear on top (superficial structure)
- Provide high resolution
- and faster the waves return

- Tissues further appear at the bottom (Note that the low-frequency wave penetrates deeper in the same tissue
- lower resolution
- and slower the waves return

Ultrasound images:

US is used to image organs and structures inside of the body, helping to diagnosis medical in frequency range from 1 to 10 MHz.

How ultrasound image is generated ?

- The ultrasound beam enters the patient and is bounced to the transducer to deform again and produce an electrical signal that is converted into an image displayed on the monitor.
- The information in an ultrasound image is influenced by physical processes underlying scattering, reflection, refraction, absorption of ultrasound waves in tissue.

How is an image formed on the monitor?

- The amplitude of each reflected wave is represented by a dot.
- The position of the dot represents the depth from which the echo is received.
- The brightness of the dot represents the strength of the returning echo.
- These dots are combined to form a complete image.

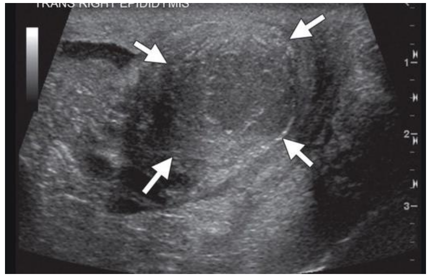
To obtain good-quality images,

- Must know what type and size of transducer to use
- How to use the transducer of ultrasound .
- And selection of the appropriate of the transducer depends on the location of structures to be imaged and the size of the patient

The uses of medical ultrasound:

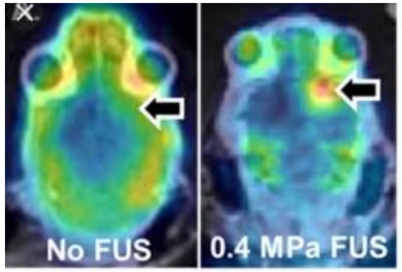
a) as medical diagnostics: ultrasound has a wide range of medical application as follow:

1. Evaluate and identify the source of the pain, swelling, infections and affect blood flow.



2. Cardiac and vascular imaging.

3. Detect tumors.



4. Detect brain abnormalities in newborn.

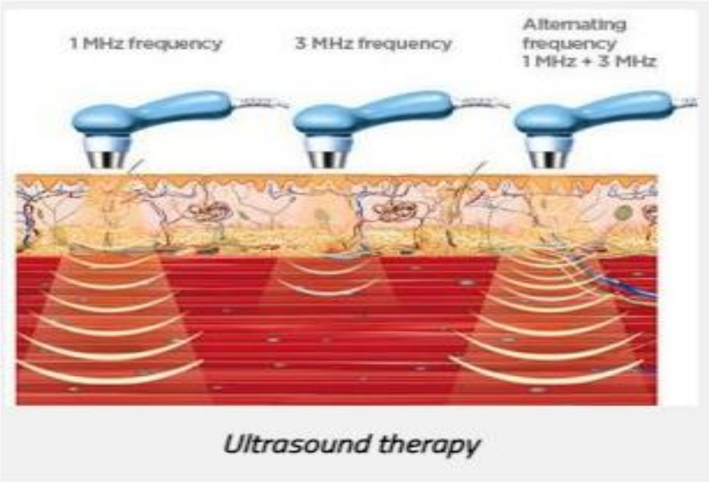
5. Imaging of the abdominal organs

6. In utero imaging of the developing fetus

7. ophthalmology

b) The uses of ultrasound as medical therapeutics:

- Ultrasound→carries energy that can be absorbed by the medium, producing biological effects that vary with intensity, frequency, exposure time and Tissue absorption coefficient, these Effects are: a) thermal and b) nonthermal



a) Thermal effects : The energy of US in tissue converted to thermal energy (heating), pressure variation in the tissue.

- At focused to intensities of **10^3 to 10^5 W/cm^2**: Can be used to shatter gallstone or pulverize cancerous tissue in surgical procedures.
- 10^3 to 10^4 W/cm^2 are commonly used for deep heat treatments called US diathermy. Ultrasound diathermy products used in physical therapy equipment produce high-frequency sound waves that travel deep into tissue and create therapeutic heat. Ultrasound diathermy is intended to generate deep heat within body tissues for the treatment of selected medical conditions such as pain, muscle spasms and joint contractures, but not for the treatment of malignancies.

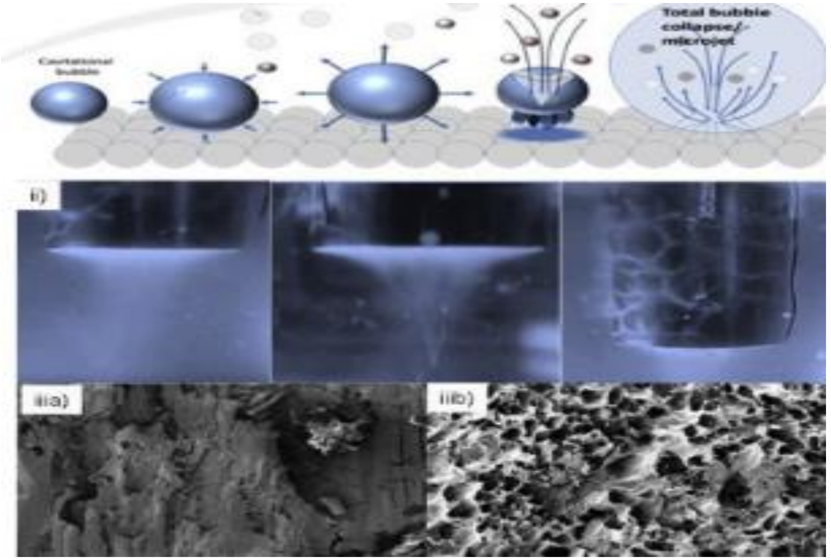
Summary of the uses of thermal effects:

1. It is due to the preferential heating of collagen tissue and to deeply placed structures.
2. Heating fibrous tissue structures such as joint capsules, ligaments, tendons, joint stiffness.
3. Reducing pain and muscle spasm and promoting healing processes.
4. may be used to generate highly localized heating to treat cysts and tumors (benign or malignant).
5. may be used to break up kidney stones.
6. used for cataract treatment.

b) Non- thermal effects: cavitation

- Cavitation, is the creation of tiny gas bubbles in the tissues as a result of ultrasound energy.
- Cavitation can be two types, stable cavitation or non- stable cavitation

1. Stable cavitation, occurs when the bubbles oscillate within ultrasound pressure waves but remain intact.
2. Non-stable (collapse) cavitation, occurs when the volume of the bubble changes rapidly and these collapse causing high pressure and heat, resulting damage of individual cells to tissues.



Note: Skill is needed by therapist to avoid (bone burns) and other tissue damage caused by overheating and cavitation, sometimes made worse by reflection and focusing of the ultrasound by joint and bone tissue.

Disadvantage of Ultrasound

a. The major disadvantage is that the resolution of images is often limited.

c. Bone absorbs ultrasound so that brain images are hard to get.

d. US display performs very poorly when there is a gas between the transducer and the organ of interest.

e. Attenuation can reduce the resolution of the image.

End the p2 of lecture