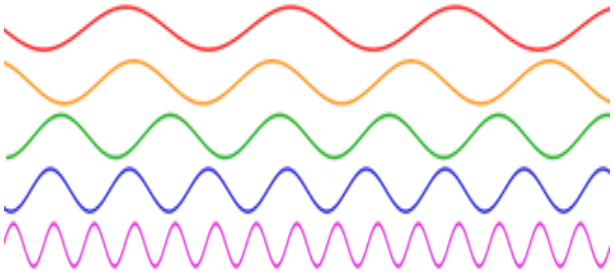
Sound in medicine



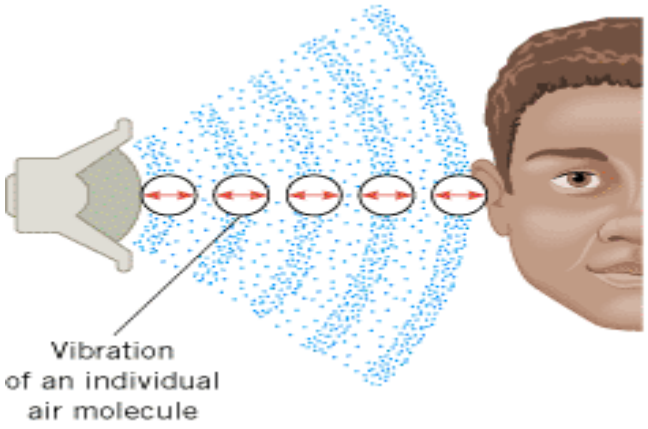
By: Dr. Enas S. AL-Mizban

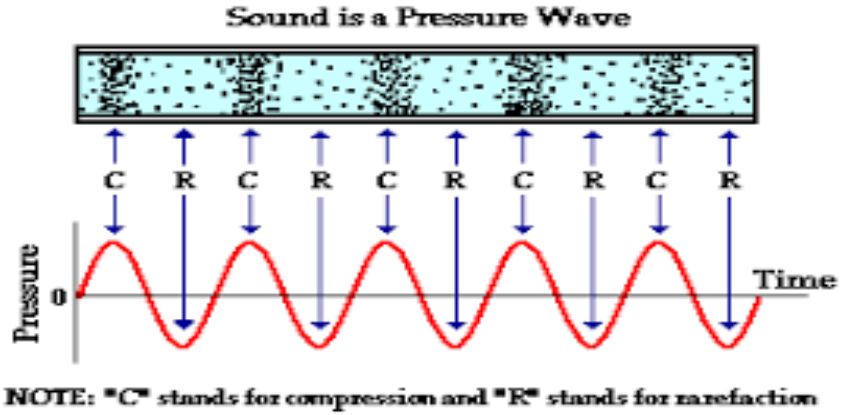
- **Sound is a major method of communication.**
- **General properties of sound:**

1- A sound wave is a mechanical disturbance in a gas, liquid, or solid, that travels outward from the source with some definite velocity.

2- A sound wave is longitudinal wave in which the pressure changes occur in the same direction the wave travels. The vibrations cause local increases and decreases in pressure relative to atmospheric pressure. These pressure increases called compressions and decreases called rarefactions as shown in next (fig.).

Sound in medicine





- **3- the relationship between the frequency of vibration (f) of the sound wave , the wave length (λ) and the velocity (v) of the sound wave is: $v = \lambda f$**
- **EX: Find the velocity for a sound wave with a frequency of 1000Hz in air at 20^0C ,if the wave length is (0.344m)?**
- **Solu.// $v = \lambda f = 0.344 \times 10^3 = 344$m/sec**

Sound in medicine

- **The decibel: The common unit of sound pressure or intensity (dB).**
- **The audible sound range : is usually defined as 20 Hz to 20,000Hz (20KHz) . Few people can hear over this entire range. Older people lose the ability to hear the frequencies above 10 KHz.**
- **Infrasound : Refers to sound frequencies below the normal hearing range or less than 20Hz . It is produced by natural phenomena like earthquake waves and atmospheric pressure changes.**
- **Ultrasound ; Is the frequency range above 20KHz.**
- **Ultrasound is used clinically in a number of specialties**

Sound in medicine

- In Ultrasonic imaging of the body.
- It used by obstetricians to examine the unborn child.
- It often gives more information than an X-ray and it is less hazardous for the fetus.

Sound in medicine

The Intensity of a Sound Wave

- Energy is carried by the wave as potential and kinetic energy ,the intensity **I** of a sound wave is the energy passing through $1m^2$/sec or watts per square meter, where **I** is measured in bel or decibel **(dB)**
- 1bel = 10 dB
- For hearing test, It is convenient to use a reference sound intensity (or **sound pressure)** to which other sound intensities can be compared.
- The reference sound intensity I_o is 10^{-16} w\cm^2 .

Sound in medicine

The Intensity of a Sound Wave

- The most intense sound that ear can tolerate without pain is about 120 dB .

Sound in medicine

The Intensity of a Sound Wave

- **Sound intensities above 160 dB can cause eardrum rapture.**

Source	Intensity	Intensity Level	# of Times Greater Than TOH
Threshold of Hearing (TOH)	$1*10^{-12}$ W/m^2	0 dB	10^0
Rustling Leaves	$1*10^{-11}$ W/m^2	10 dB	10^1
Whisper	$1*10^{-10}$ W/m^2	20 dB	10^2
Normal Conversation	$1*10^{-6}$ W/m^2	60 dB	10^6
Busy Street Traffic	$1*10^{-5}$ W/m^2	70 dB	10^7
Vacuum Cleaner	$1*10^{-4}$ W/m^2	80 dB	10^8
Large Orchestra	$6.3*10^{-3}$ W/m^2	98 dB	$10^{9.8}$
Walkman at Maximum Level	$1*10^{-2}$ W/m^2	100 dB	10^{10}
Front Rows of Rock Concert	$1*10^{-1}$ W/m^2	110 dB	10^{11}
Threshold of Pain	$1*10^{1}$ W/m^2	130 dB	10^{13}
Military Jet Takeoff	$1*10^{2}$ W/m^2	140 dB	10^{14}
Instant Perforation of Eardrum	$1*10^{4}$ W/m^2	160 dB	10^{16}

Sound in medicine

The Acoustic Impedance (Z)

The acoustic impedance (Z) for the sound wave can be calculated from the equation: $Z = \rho v$, (see next table).

Where ρ : is the density of medium where the sound wave transfer through it (Kg/m^3).

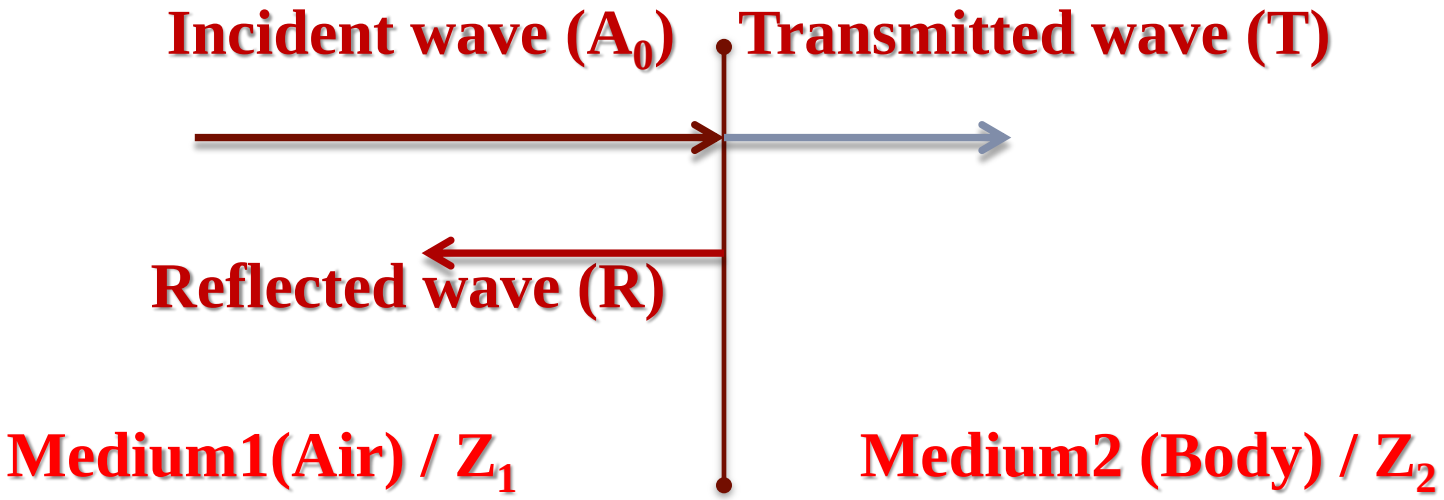
v: is the velocity of sound wave in the medium (m/sec).

Substance	ρ (kg/m^3)	v (m/sec)	Z($kg/m^2.sec$)
Air	1.29	3.31×10^2	**430**
Water	1×10^3	14.8×10^2	**1.48×10^6**
Brain	1.02×10^3	15.3×10^2	**1.56×10^6**
Muscle	1.04×10^3	15.8×10^2	**1.64×10^6**
Bone	**1.9×10^3**	**40.4×10^2**	**7.68×10^6**

Sound in medicine

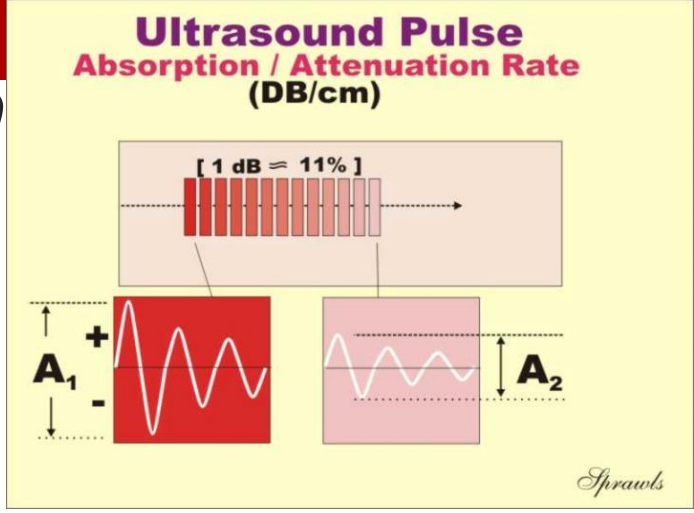
Sound/Ultrasound Wave Reflection, Transmission and Absorption.

- When sound wave hits the body, part of the wave is reflected and part is transmitted in to the body. The ratio of the reflected amplitude (R) to the incident amplitude (A_0) depend on the impedances of the two media Z_1 and Z_2



Sound in medicine

Attenuation of Ultrasound Wave



- When a sound wave passes through tissue, there is some loss in the energy due to the frictional effects.
- The absorption of energy in the tissue causes a reduction in the amplitude of the sound wave (attenuation).
- The Ultrasound wave amplitude (A) at a depth X cm in a medium is related to the initial amplitude $A_0(X=0)$ by the exponential equation : $A=A_0e^{-\alpha x}$

Where α in cm^{-1} ,is the absorption coefficient for the medium at a particular frequency.

Sound in medicine

Attenuation of Ultrasound Wave

- Since the intensity is proportional to the square of the amplitude ,its dependence with depth is:

$$I \propto A^2 \longrightarrow I = I_0 e^{-2\alpha x}$$

Where I_0 is the incident intensity at $X=0$ & I is the intensity at a depth X in the absorber ,

- Since the absorption coefficient is 2α ,the intensity decreases more rapidly than the amplitude with depth.

Material	Frequency (MHz)	α (cm^{-1})
Muscle	1	0.13
Fat	0.8	0.05
Brain	1	0.11
Bone(human skull)	0.6	0.4

Sound in medicine

Attenuation of Ultrasound Wave

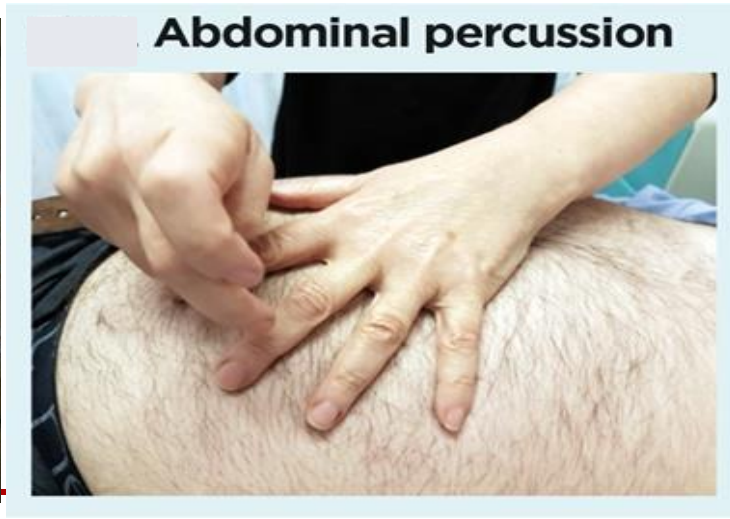
- **EX: What is the attenuation of sound intensity in 15cm of brain tissue?**
- **Solu./**

$$\frac{I}{I_0} = e^{-2\alpha x} = e^{-2(0.11)(15)} = 0.037$$

Sound in medicine

Percussion in Medicine

- **Percussion (tapping) is a method of tapping on a surface to determine the underlying structure, and is used in clinical examinations to assess the condition of the thorax or abdomen.**



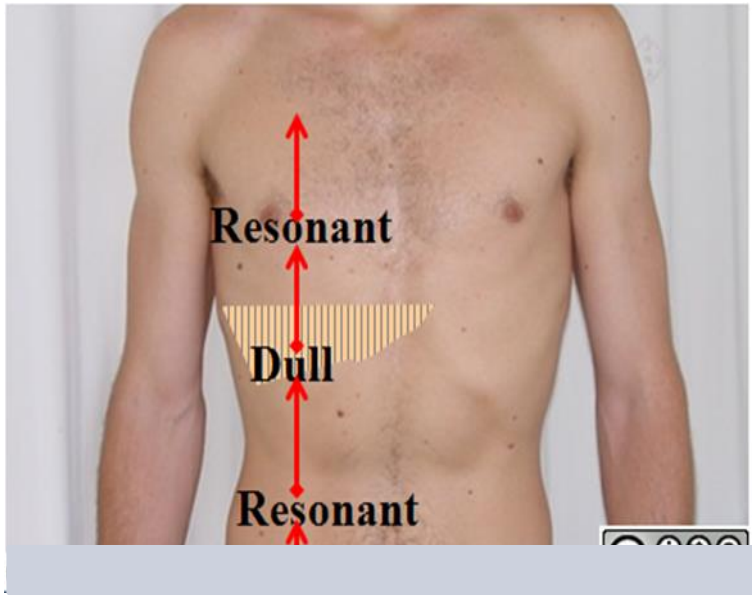
Sound in medicine

Percussion in Medicine

- **The quality of the sound:**

  Resonant = air filled space.

  Dull = underlying solid tissue.



https://www.youtube.com/watch?v=mSJKI9Pkxxw

Sound in medicine

Percussion in Medicine

- The first recorded use of percussion on the human body as a mean of diagnosis occurred in the eighteenth century.
- In 1761, L. Auenbrugger published a short book, On Percussion of the Chest, which was based on his clinical observations over seven years of patients in various places.
- In his book, Auenbrugger described how to strike the chest with the fingers and stated,{The sound thus elicited from the healthy chest resembles the stifled sound of drum covered with a thick woolen cloth or other envelope.

Sound in medicine

Percussion in Medicine

- He discussed both the sounds heard from healthy subjects and the sounds heard from patients with various pathological conditions.
- Auenbragger stated that with percussion he could diagnose cancer, the presence of abnormal cavities in an organ.
- He confirmed many of these diagnoses by examining bodies after death.
- Auenbragger's discovery was largely ignored until 1808 when his work, originally published in Latin.
- Percussion has since become an important technique in the detection of disease.

Sound in medicine

The Stethoscope

- Stethoscope is a simple hearing aid permits a physician or nurse to listen to sounds mad inside the body (in the heart and lungs).
- The act of listening to these sounds with a stethoscope is called **mediate auscultation.**

Sound in medicine

The Stethoscope

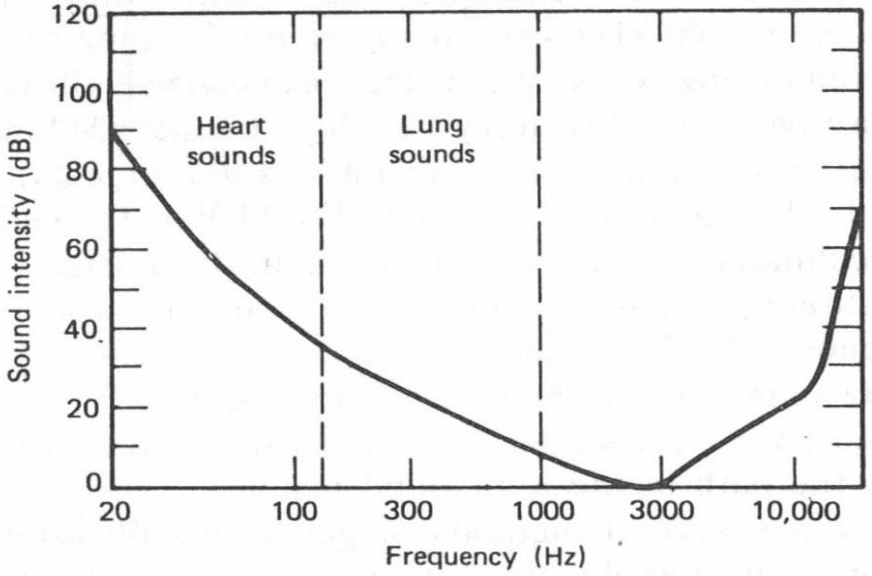
- **Stethoscope is the bell,**
  which is either open or closed by a thin diaphragm, to tubing, and the earpieces (see fig.)
- **The open bell is an impedance matcher between the skin and the air and accumulates sounds from the contacted area. The skin under the open bell behaves like a diaphragm.**
- **A closed bell is a bell with a diaphragm of known resonant frequency usually high that tunes out low frequency sounds.**

Sound in medicine

The Stethoscope

- The closed bell stethoscope is used for listening to lung sounds, which are of higher frequency than heart sounds.
- To see the typical frequency ranges of heart and lung sounds see (Fig).

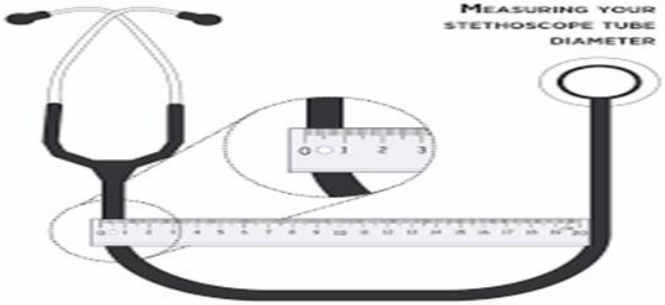
Most of the heart sounds are of low frequency in the region where the sensitivity of the ear is poor. Lung sounds generally have higher frequencies. The curve represents the threshold of hearing for a good ear. Some of the heart and lung sounds are below this threshold.



Sound in medicine

The Stethoscope

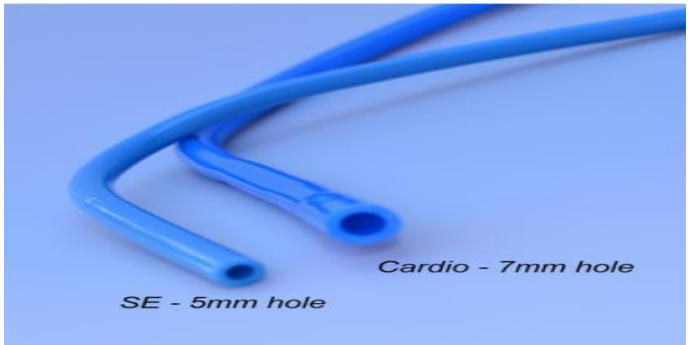
- The larger the bell diameter, the lower the skins resonant frequency.
- Thus It is possible to enhance the sound range of interest by changing the bell size and varying the pressure of the bell against the skin and thus the skin tension.
- The volume of the tubs should also be small, and there should be little frictional loss of sound to the walls of the tube.



Sound in medicine

The Stethoscope

- **The small volume restriction suggests short, small diameter tubes, while the low friction restriction suggests large diameter tubes.**
- **If the diameter of the tube is too small, frictional losses occur, and if it is too large, the moving air volume is too great. In both cases the efficiency is reduced.**
- **A compromise is a tube with a length of about 25 cm and diameter of 0.3 cm.**



Sound in medicine

The Ultrasound

What is Ultrasound

- Ultrasound is simply sound that has a very high frequency.
- Humans are not able to hear Ultrasound, though some animals can hear them.
- Sounds with frequencies above 20 000 hertz are called Ultrasounds.

Uses of Ultrasound in Medicine

- Ultrasound is used for examining soft tissue inside the body.
- Imaging parts of the body that may be examined include muscles and unborn babies.
- Blood flow can also be monitored using Ultrasound

Sound in medicine

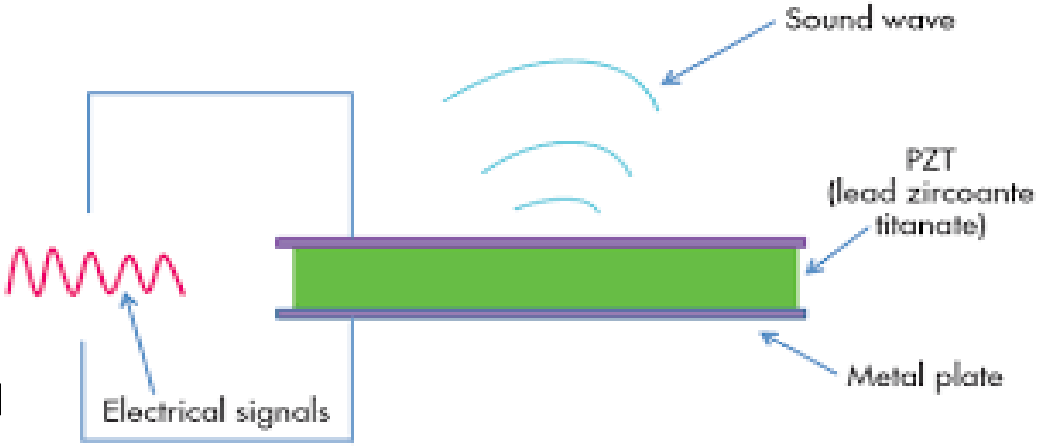
The Ultrasound

Why Use Ultrasound?

- Ultrasound is very safe. There is no firm evidence that it does any harm to the body (or the baby in the case of pregnancy scans).
- Ultrasound is often gives more information than X-rays.
- X-rays are dangerous, particularly to young children and pregnant women (they damage the unborn baby), because of that, Ultrasound is less hazard for the fetus.

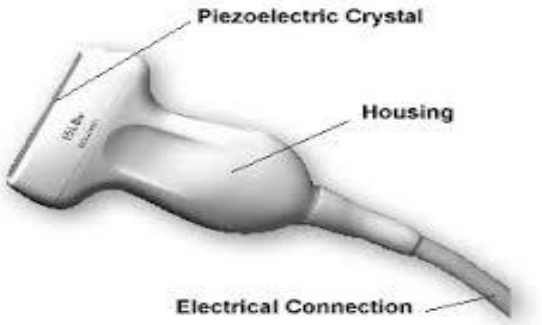
Sound in medicine

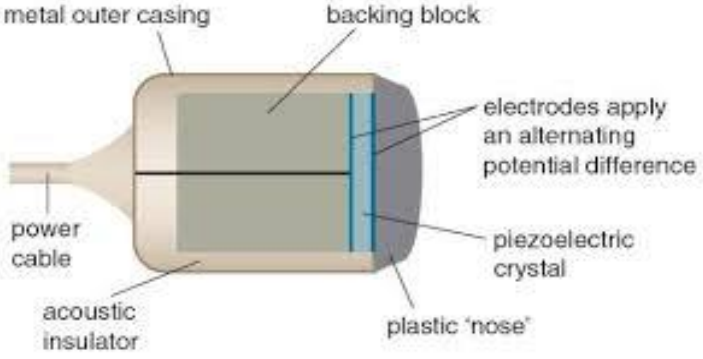
The Ultrasound



Generating Ultrasound

- There are several metho
  The most important for medical applications involves the (piezoelectric effect).
- Many crystals can be cut so that an oscillating voltage across the crystal will produce a similar vibration of the crystal, thus generating a sound wave.





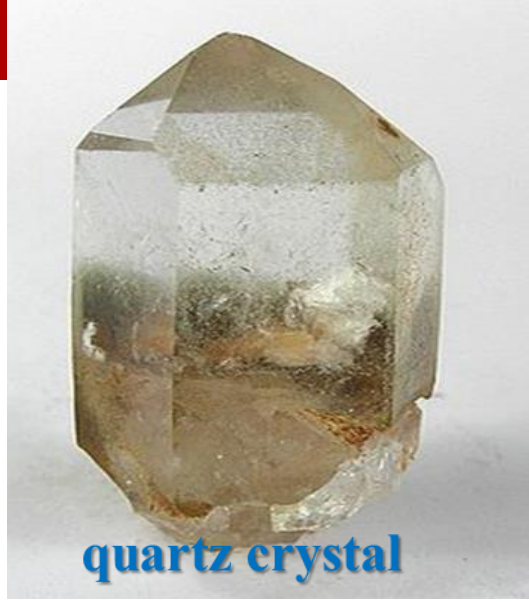
Sound in medicine

The Ultrasound

Generating Ultrasound

- A device that converts electrical energy to mechanical energy or vice versa is called (transducer), Ultrasound generators are often simply referred to as transducers.
- Each transducer has a natural resonant frequency of vibration.
- The thinner the crystal, the higher the frequency at which it will oscillate.

Sound in medicine


quartz crystal

The Ultrasound

Generating Ultrasound

- For a **quartz crystal** , a thickness of 2.85 mm give a resonant frequency of about 1MHz.
- Typical frequencies for medical work are in the 1-5 MHz range.
- An average power level for diagnostic applications a few mille watts per square centimeter.

Sound in medicine

Ultrasound Transducer Types

- You can find Ultrasound transducers in different shapes, sizes, and with diverse features. That is because you need different specifications for maintaining image quality across different parts of the body.
- Transducers can be either passed over the surface of the body – external transducers or can be inserted into an orifice, such as the rectum or vagina – these are internal transducers.
- The Ultrasound transducers differ in construction based on:

•Piezoelectric crystal arrangement

•Aperture (footprint)

•Frequency

transducers

Sound in medicine

Ultrasound Transducer Types

1-Linear Transducers:

- In this transducer type, the piezoelectric crystal arrangement is linear, the shape of the beam is rectangular, and the near-field resolution is good and its central frequency is 7-12MHz
- You can use this transducer for various applications, such as:

•Vascular examination

•Blood vessel visualization

•Breast

•Thyroid

Sound in medicine

Ultrasound Transducer Types

2-Convex Transducers:

- **The convex Ultrasound transducer type is also called the curved transducer because the piezoelectric crystal arrangement is curvilinear.**
- **The transducer is good for in-depth examinations, even though the image resolution decreases when the depth increases.**
- **The footprint frequency is 2-5MHz**
- **You can use it for:**

•Abdominal examinations

•Diagnosis of organs

Sound in medicine

Ultrasound Transducer Types

3-Phased Array Transducers:

- **This transducer is named after the piezoelectric crystal arrangement which is called phased-array and it is the most commonly used crystal.**
- **It has a small footprint and low frequency 1-3MHz**
- **It can use for :**

•Cardiac examinations.

•Abdominal examinations.

•Brain examinations.

Sound in medicine

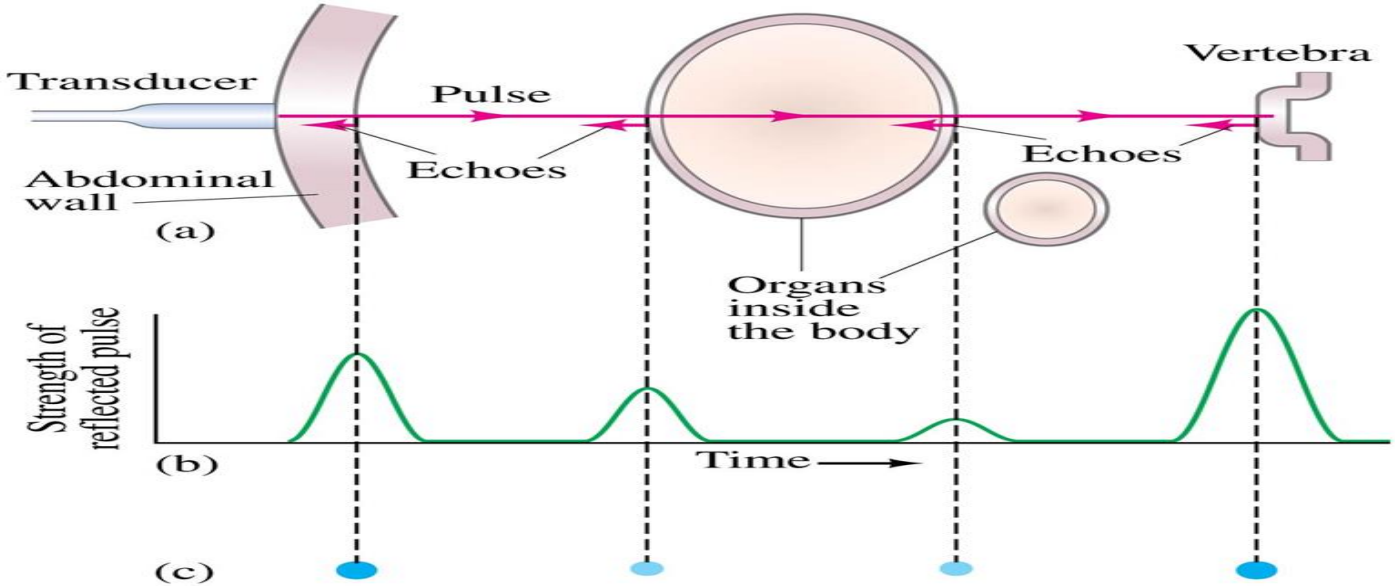
Ultrasound Transducer Types

Other Ultrasound Transducer Types

- The other Ultrasound transducer type is endocavitary.
- These probes provide you with the opportunity to perform internal examinations of the patient.
- Therefore, they are designed to fit in specific body orifices and they have small footprints .
- The endocavitary transducers include endovaginal, endorectal, and endocavity transducers.

Sound in medicine

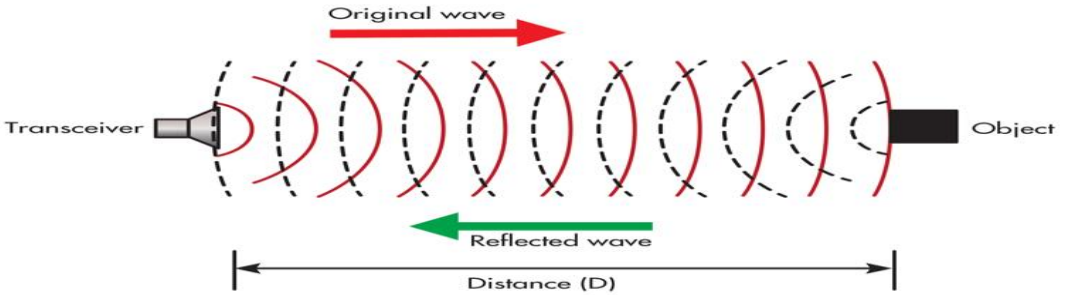
Generating Ultrasound



- **Pulses of Ultrasound are transmitted into the body by placing the vibrating crystal in close contact with the skin, using water or a jelly paste to eliminate the air. This gives good coupling at the skin and greatly increases the transmission of the Ultrasound in to the body and of the echoes back to the detector.**

Sound in medicine

Generating Ultrasound

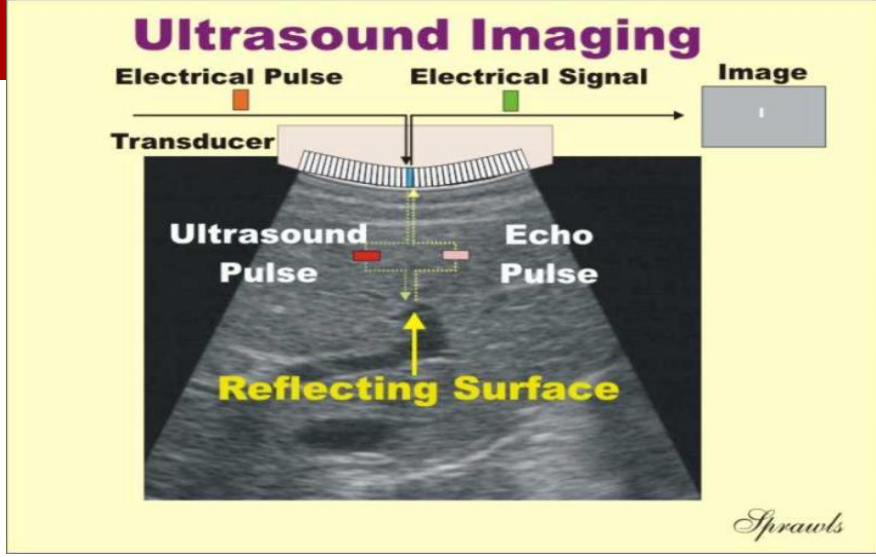


- The basis for the use of Us in medicine is the partial reflection of sound at the surface between two media that have different acoustical properties.
- The amount of the reflection depends primarily upon the:

1. Difference in the acoustical impedances of the two materials.
2. The orientation of the surface with respect to the beam.

Since the transmitter and detector are the same unit, the most intense detected signals are due to reflections from surface perpendicular to the beam.

Sound in medicine



The Ultrasound

Ultrasound Picture of the Body

- In this subject, we discuss the use of Ultrasound to produce pictures for medical diagnosis. Basically an Ultrasound source sends a beam of pluses of **1to 5 MHz** sound into the body. The time required for the sound pulses to be reflected (Echo pulse) gives information on the distances to the various structures or organs in the path of Ultrasound beam.

Sound in medicine

The Ultrasound

How the image is created…

- Millions of sound waves are transmitted every second.
- As the waves reflected at different times, the computer in the Ultrasound machine calculates how far the wave travelled before being reflected (using d=vt).
- Using this information the computer builds up an image of the inside of the patient.

Sound in medicine

The Ultrasound

❑Basic Question Example

Q1// How deep is a baby's head if it takes 0.05 ms for a sound wave to reach it in the mother's uterus? The speed of sound in body tissue is 1500 m/s.

Solu.// v = 1500 m/s , d= ?

t = 0.05 ms = 0.05×10^{-3} s

equation : d=vt

d = $1500 \times 0.05 \times 10^{-3}$

d= 0.075 m = 7.5 cm

Sound in medicine

The Ultrasound

Q2// The speed of sound in the human body is 1500 m/s. If a fetus is 6 cm below the mother's skin, how long will it take for the echo to be received.

Solu.//

v = 1500 m/s

d = 6cm ⟶ d= 0.12 m

t = ?

Equation : t = d/v

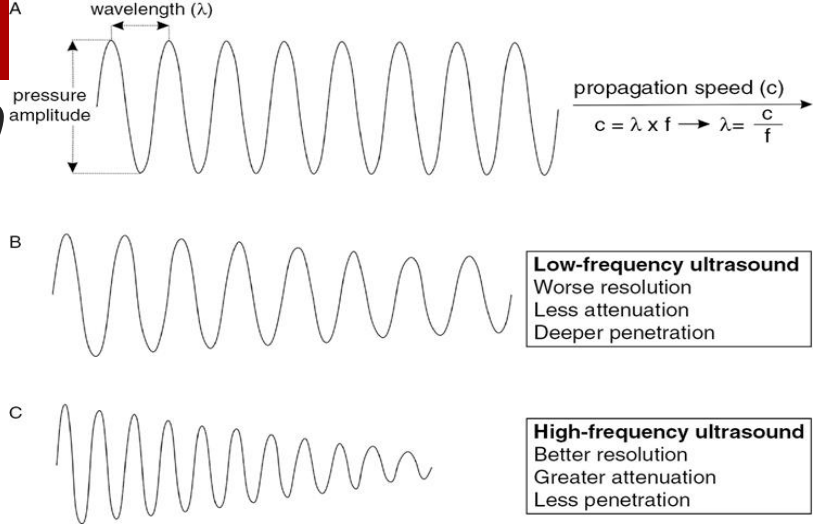
t = 0.12/1500

t = 0.00008 s

t = 8 x 10^{-5} s = 80 μs.

Cross-section image

Sound in medicine



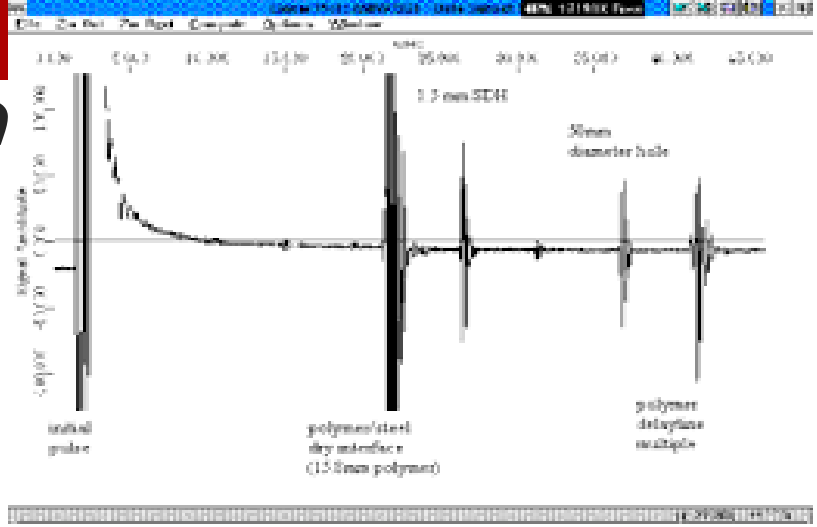
The Problems of Using US in Diagnosis

- **In many diagnostic uses of Us**

1. The echoes are very small signals due to weak reflection and the absorption of the sound by tissue . The solution for this problem by amplifying the echo electronically.

2. The lack of resolution, or the ability of the equipment to detect separate echoes from two objects close together. In general, structures smaller than the wavelength (λ) cannot be resolved since (λ= v/f), where (v) is the velocity of sound and (f) is the frequency, high frequency sound has shorter wavelength and allows better resolution than low-frequency sound.

Sound in medicine



Type of Ultrasound Mode

1-A-scan(Amplitude scan)

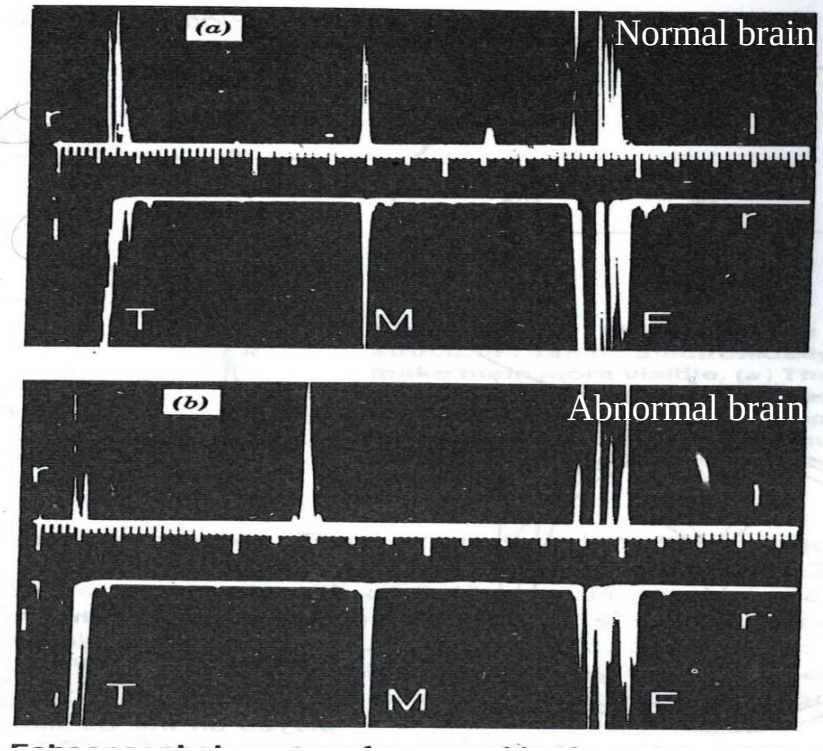
- To obtain diagnostic information about the depth of structures in the body, we send pulses of Us into the body and measure the time required to receive the reflected sound (echoes) from the various surfaces in it. This procedure is called the A-scan method of Us diagnosis.
- Pulses for A scan work are typically a few microseconds long. They are usually emitted at 400 – 1000 pulses\ sec.

Sound in medicine

The Ultrasound Mode

The applications of A-scan

A-scan in Echoencephalography;



- A-scan has been used in the detection of **brain tumors.**
- Pulses of Us are sent into thin region of the skull slightly above the ear and echoes from the different structures within the head are displayed on an oscilloscope. The usual producer is to compare the echoes from the left side of the head to those from the right side and to look for a shift in the **midline echo**. A tumor on one side of the brain tends to shift the **midline** toward the other side. Generally a shift of more than 3mm for an adult or 2mm for a child is considered abnormal (see fig.b).

Sound in medicine

The Ultrasound

A – scan in Ophthalmology:

- Application of A- scans in ophthalmology can be divided into two areas that concerned with obtaining information for use in the :

1. Diagnoses of eye diseases,
2. Measurements of distances in the eye **(Biometry)**.

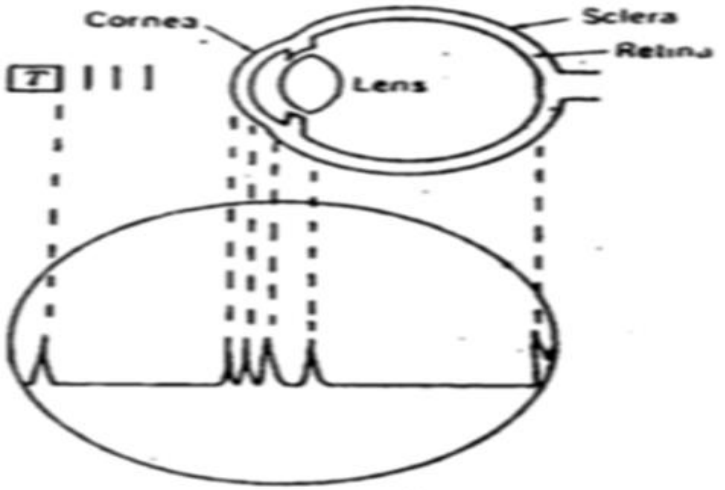
At the low power levels used, there is no danger patient's eye.

Sound in medicine

The Ultrasound

A – scan in Ophthalmology

- With Us it is possible to measure distances in the eye such as lens thickness, depth from cornea to lens, the distance to the retina, the thickness of the vitreous humor, and the curvature of cornea.



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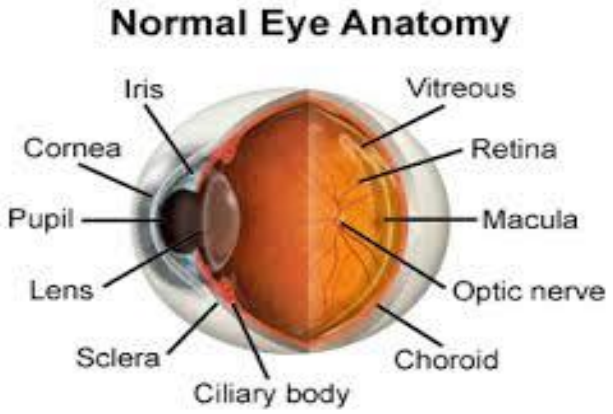
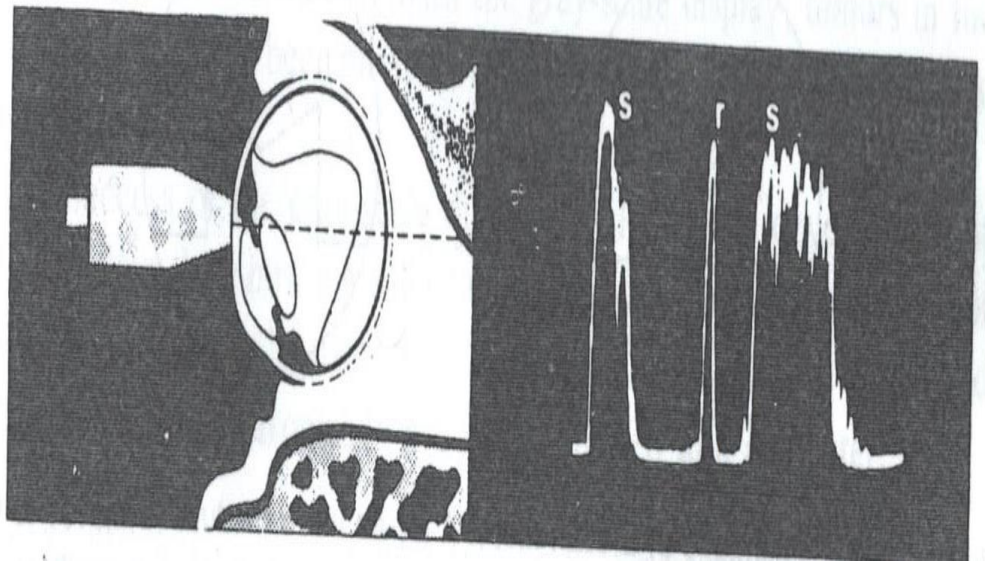


The Ultrasound

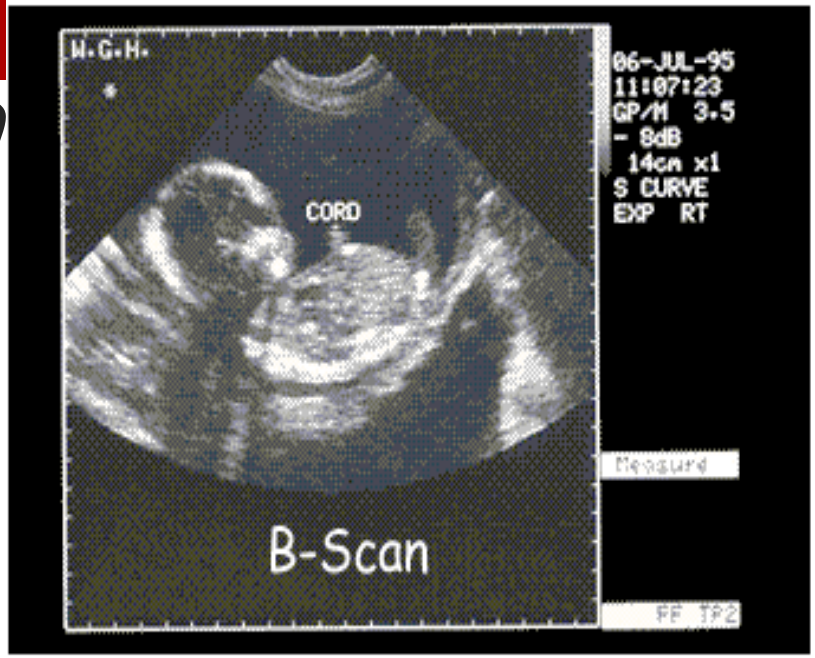
A – scan in Ophthalmology

- **Us frequency of up to 20MHZ are used. These high frequencies can be used in the eye to produce better resolution since there is no bone to absorb most of energy and absorption is not significant because the eye is small.**

Ultrasound studies of a detached retina. CRT shows an echo S from the anterior sclera, an echo r from the retina, and an echo S from the sclera at the back of the eye.
In a normal eye the echo from the retina would blend with the echo from the posterior sclera.



Sound in medicine



The Ultrasound Mode

2- B–scan (Brightness scan)

- **B - scan :- for many clinical purposes, A-scan have been largely replaced by B-scan. The principles are the same as for the A-scan except that the transducer is moved.**

1. B-scan can provide more information than X-rays.

2. They present less risk.

Sound in medicine

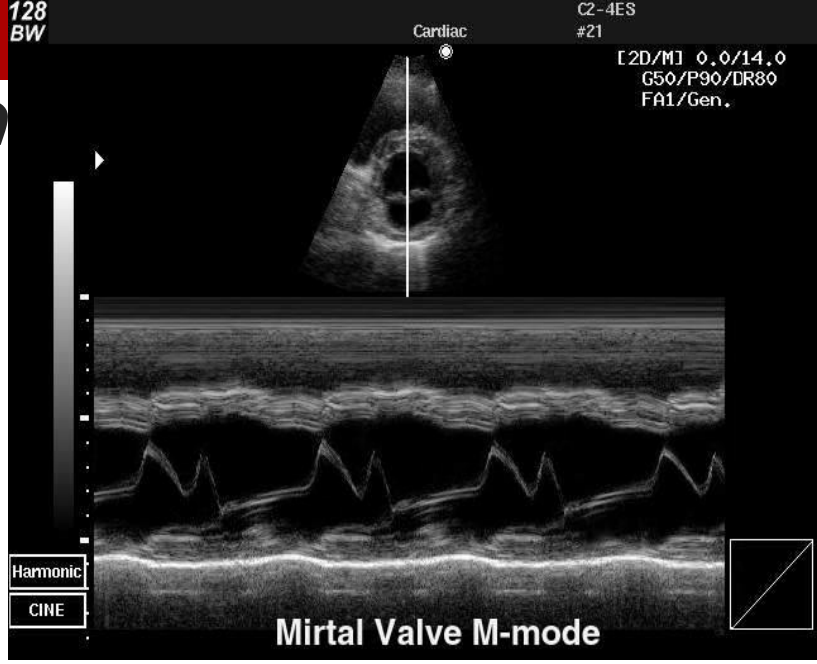
The Ultrasound Modes Comparison

A-scan	*B-scan*
The transducer is fixed.	**The transducer is moved.**
One dimensional views.	**Two dimensional views.**
Echo produces signal on the oscilloscope.	**Echo produces a dot on the oscilloscope.**
Less informative about the internal structure of the body.	**provide informative about the internal structure of the body, eye, liver, breast, hart and fetus.**

Sound in medicine

The Ultrasound Mode

Ultrasound in Measuring Motion



Two methods are used to obtain information about motion in the body with Ultrasound:

3- M–scan (Motion scan)

- **Which is used to study motion of the hart and to obtain diagnostic information about heart and heart valves.**

The M-scan combines certain features of A-scan and B-scan

The transducer is stationary as in A-scan and the echoes appear as dots as in the B-scan.

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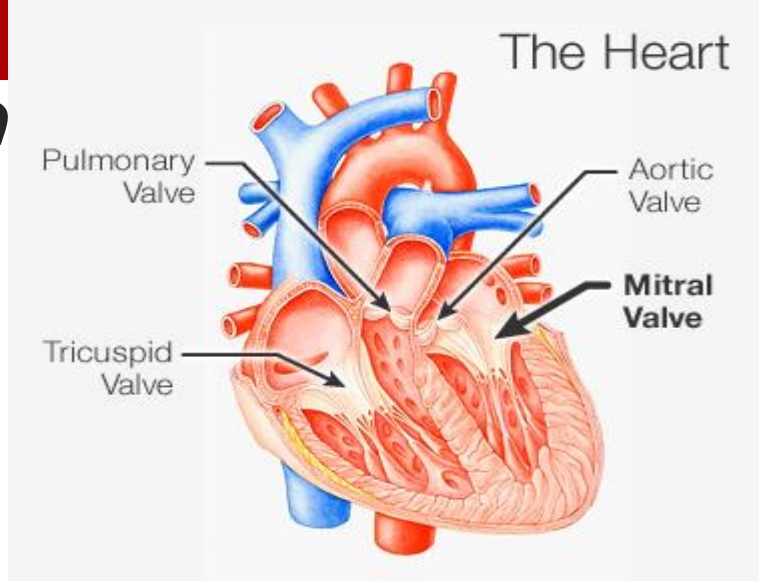
The Ultrasound Mode

Applications of M-scan:

a- M-scan of the mitral valve:



- **M- scan are used to obtain**

diagnostic information about the heart. The places where the heart can be probed are quite limited because of poor Ultrasound transmission through lung tissue and bone.

- **The usual method is to put the transducer on the patient's left side, aim it between the ribs over the heart, and tip it at different angles to explore various region of the heart.**
- **The examiner must be familiar with the patterns of specific cardiac echoes to interpret the information.**

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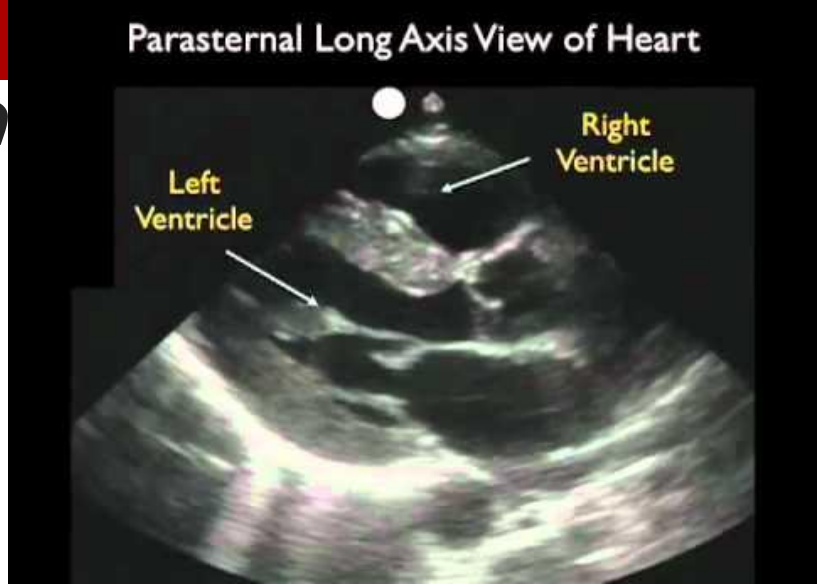

The Ultrasound Mode

Applications of M-scan:

- The information of interest is the rate of closing of the mitral valve.
- The rate of closing for a normal valve is indicated by the slope in (next slid Fig. a) in this case the rate of closing is 72 mm/sec.
- (next slid Fig. b) is an M-scan showing an abnormality called mitral stenosis (a narrowing of the valve opening).
- The reduced slope for mitral stenosis is quite different from the normal slope-the slower the rate of closure, the larger the amount of stenosis.

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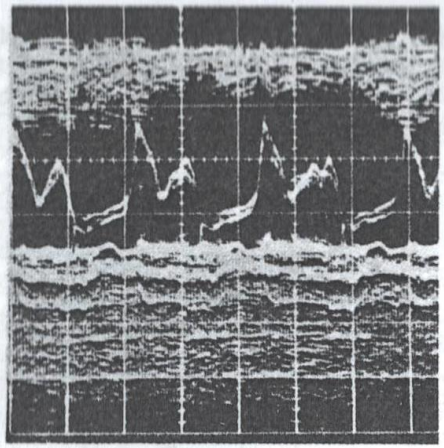
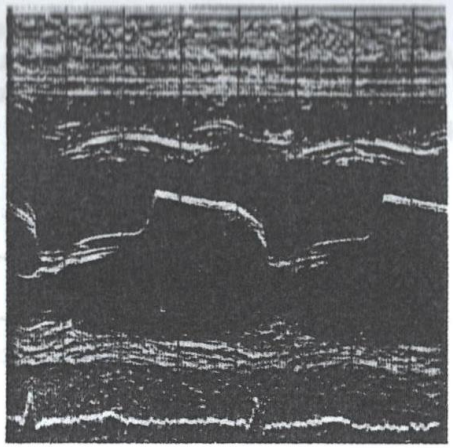
Applications of M-scan:



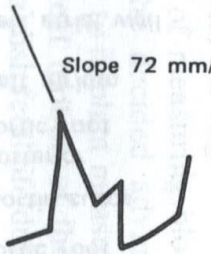
Normal motion of mitral valve

Time →

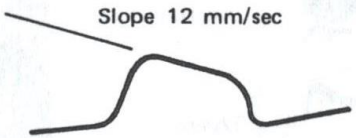


Abnormal motion of mitral valve in mitral stenosis

Time →



(a)



(b)

Figure 12.24. M scans showing the motion of the mitral valve of the heart; the rate at which the valve closes is indicated by the slope, which is sketched below each scan. (*a*) A slope of 72 mm/sec is normal. (*b*) A slope below 35 mm/sec indicates an abnormality called mitral stenosis (narrowing of the opening). (Scans courtesy of Richard D. Spangler, M.D., and Michael Johnson,

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The Ultrasound Mode

Applications of M-scan:

b- Accumulation of fluids in the heart sac (pericardial effusion).

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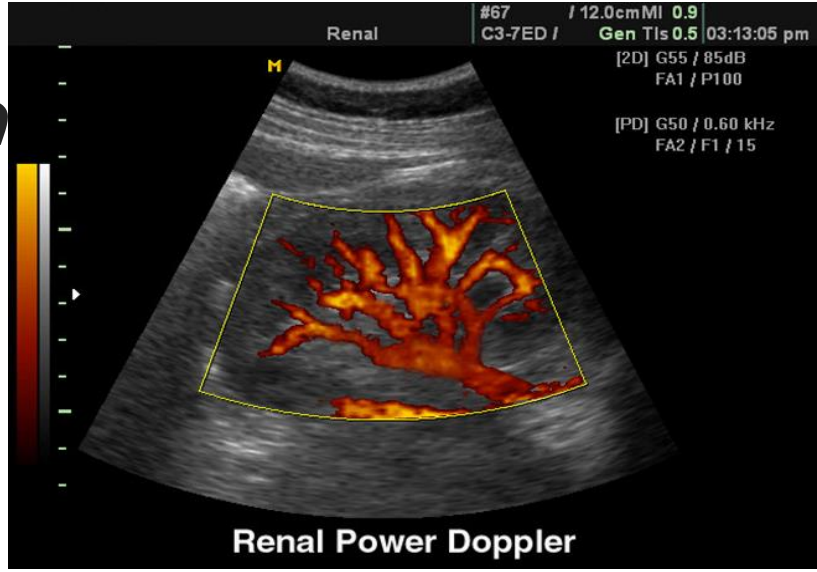


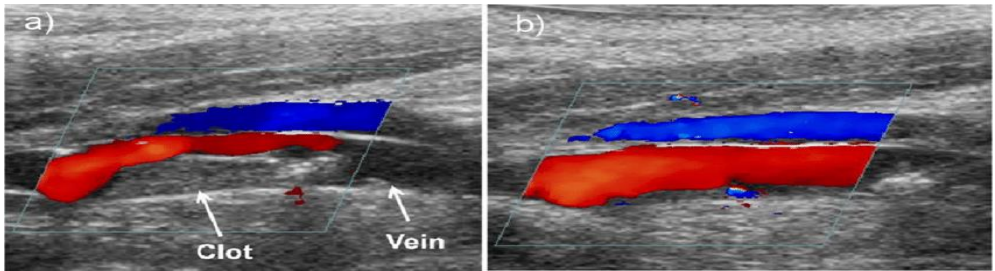
The Ultrasound

4- Doppler Technique:

- **Doppler effect is the perceived frequency of sound emitted by moving source.**
- **The Doppler technique is used for:**

a-Study the blood motion in the circulatory system:

- **Two transducers are used in the audio mode, one as transmitter and the other as a receiver.**
- **Continuous Ultrasound wave is sending to the artery with a frequency *(f_0).***



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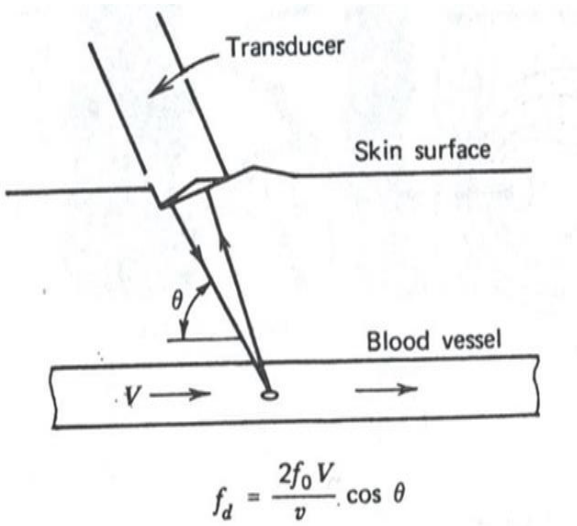
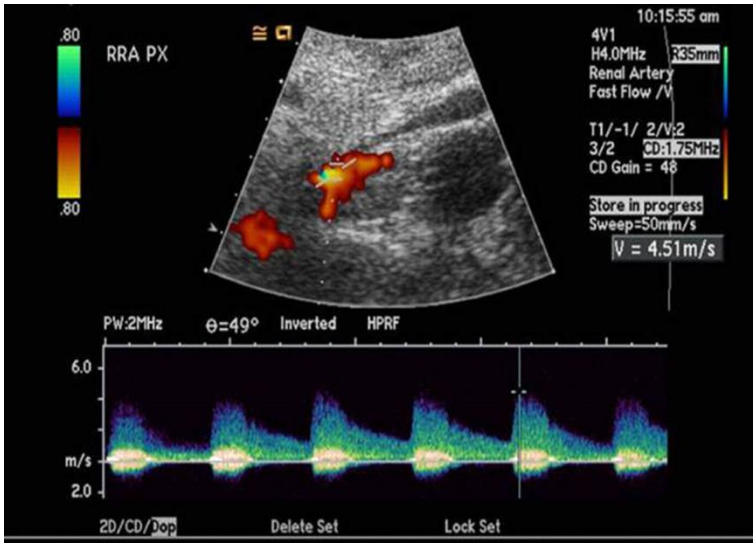
Doppler Technique:

- When the blood move with a speed **V** at an angle **θ** from the direction of the sound waves of speed **v**, the frequency change f_d is: $f_d = \frac{2 f_0 V}{v} \cos\theta$

Where f_0 is the frequency of the initial Ultrasonic wave ,V is the velocity of the blood ,v is the velocity of sound and θ is the angle between V and v, (see Fig.)



Schematic arrangement for using the Doppler effect to measure the velocity of blood in a blood vessel. The transducer contains two crystals—one for transmitting the sound wave and one for receiving the echo. A continuous rather than a pulsed sound wave is used.



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Doppler Technique:

- When the fetal heart is moving, a variation in the frequency give the fetal heart rate.
- The output can be audible or displayed on an oscilloscope.

b- The Doppler technique is also used to locate the point of the entry of the umbilical cord into the placenta to detect if there is bleeding due to misplaced placenta (placenta praevia)or there is an intrauterine transfusion for *Rh* incompatibility.