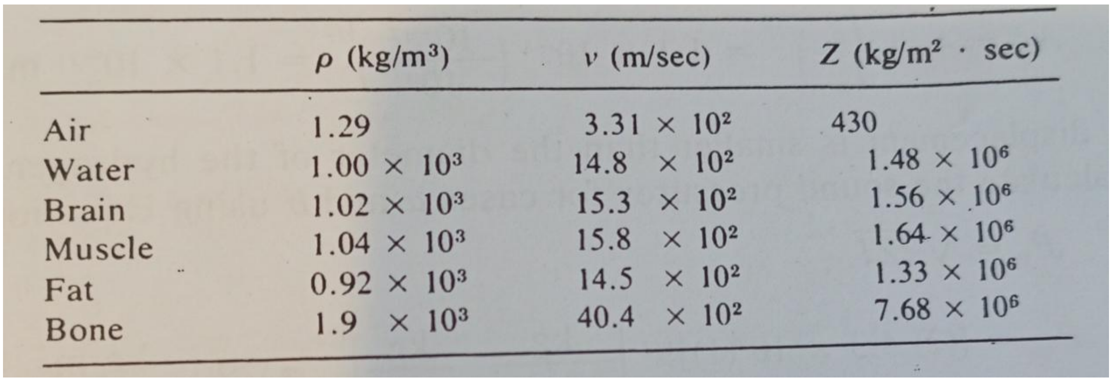
Ultrasound

A-scan

To obtain diagnostic information about the depth of structures in the body, we send pulses of ultrasound 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 ultrasound diagnosis. Pulses for A scan work are typically a few microseconds long. They are usually emitted at 400 - 1000 pulses/sec.

The A scan method is illustrated schematically in fig. 1 . In Fig. 1a, a transducer T sends a pulse of ultrasound through a beaker of water of diameter d. The sound is reflected from the other side of the beaker and returns to the transducer, which also acts as a receiver. The detected echo is converted to an electrical signal and is displayed as the vertical deflection R on the cathode ray tube (CRT) of an oscilloscope (Fig. 1a'). Since the echo has been attenuated by the water, R is smaller in amplitude than the initial pulse shown on the oscilloscope at 0. The time required for the pulse to travel from the transducer to the far side and return to the transducer is indicated on the horizontal scale of the oscilloscope. This time can easily be converted to distance by using the known velocity of sound in water (Table 1) to calibrate the scale.

Table1 Values of ρ, ν, and Z for various substances at clinical ultrasound frequencies



	ρ (kg/m^3)	v (m/sec)	Z (kg/m^2 · sec)
Air	1.29	3.31×10^2	430
Water	1.00×10^3	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
Fat	0.92×10^3	14.5×10^2	1.33×10^6
Bone	1.9×10^3	40.4×10^2	7.68×10^6

An object in the beaker can be located with ultrasound. In Fig. 1b a surface S at a distance d_1 produces an additional echo, which is displayed on the oscilloscope as S at the position d_1 (Fig. 1b'). Note that the echo R is now smaller. When the surface vibrates (Fig. 1c), the position of the echo on the oscilloscope also moves (Fig. 1c').

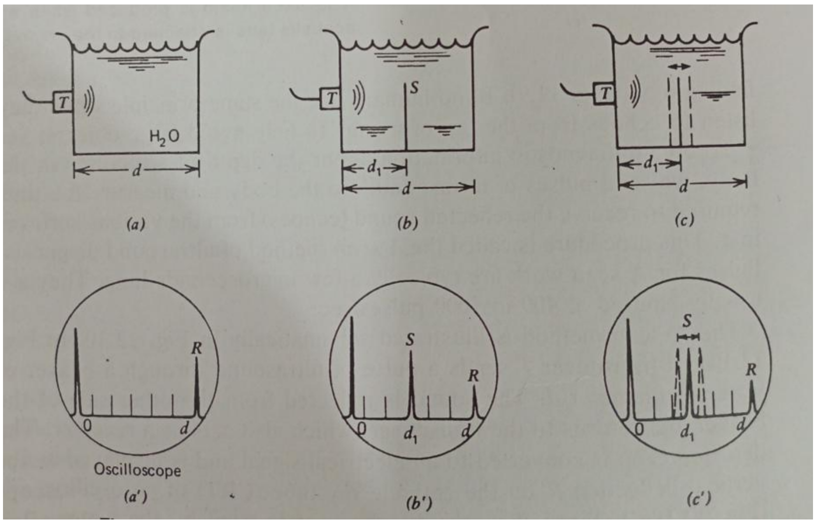


Figure 1

B scan

For many clinical purposes A scans have been largely replaced by B scans. The B scan method is used to obtain two-dimensional views of parts of the body. The principles are the same as for the A scan expect that the transducer is moved. As a result each echo produces a dot on the oscilloscope at a position corresponding to the location of the reflecting surface (Fig. 2).

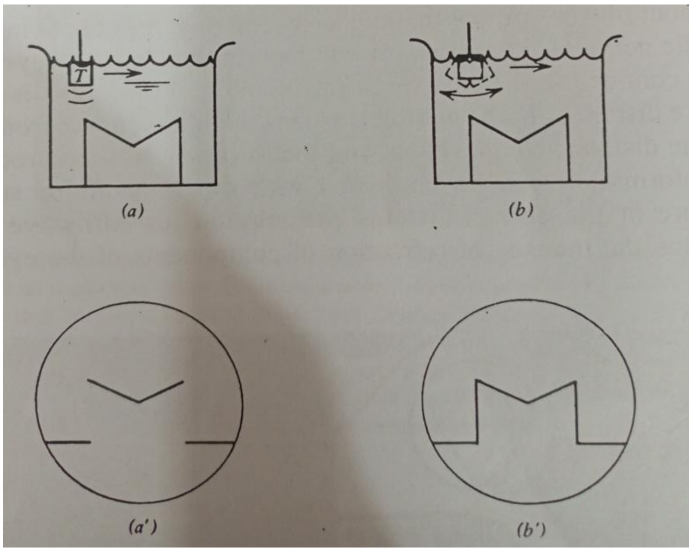


Figure 2

M-scan

Method is used to obtain information about motion in the body with ultrasound; the M (motion) scan, which is used to study motion such as that of the heart and the heart valves.

The M scan combines certain features of the A scan and the B scan. The transducer is held stationary as in the A scan and the echoes appear as dots as in the B scan.

Figure 3a shows a transducer fixed at one position emitting a pulse of ultrasound into a beaker of water that a vibrating interface in it. Figure 3 b is a standard B scan showing the motion of the interface on the oscilloscope screen. When the oscilloscope trace is made to move vertically as a function of time, the motion of the interface is displayed as an M scan as seem in Fig. 3c.

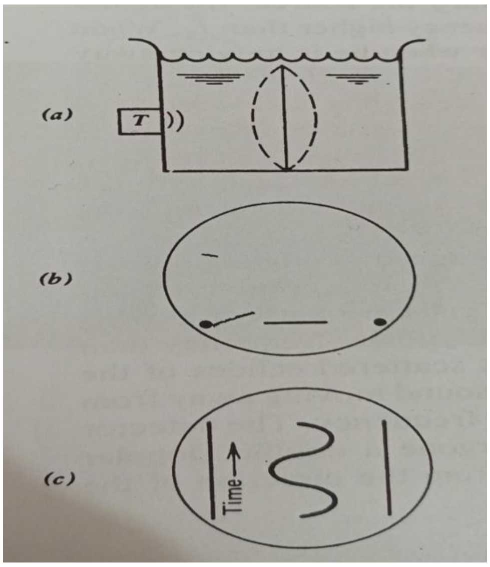


Figure 3

M scans 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 regions of the heart (fig. 4). By moving the probe it is possible to obtain information about the behavior of a particular valve or section of the heart. The examiner must be familiar with the patterns of specific cardiac echoes to interpret the information. Several heart conditions can be diagnosed with M scans; we consider here M scans of mitral valves and M scans showing accumulation of fluid in the heart sac (pericardial effusion).

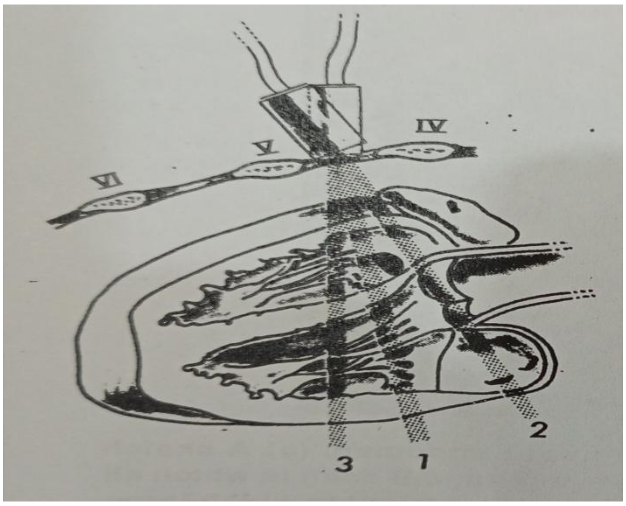


Figure 4

Doppler effect

The Doppler effect can be used to measure the speed of moving objects or fluids within the body, such as the blood. When a continuous ultrasound beam is " received" by some red blood cells in an artery moving away from the source, the blood "hears" a slightly lower frequency than the original frequency f_0. The blood sends back scattered echoes of the sound it "hears," but since it is now a source of sound moving away from the detector, there is another shift to a still lower frequency. The detector receives a back-scattered signal that has undergone a double Doppler shift. When the blood is moving at an angle θ from the direction of the sound waves, the frequency change f_d is

$$f_d = \frac{2f_\circ V}{\nu} cos\theta$$

Where $f_\circ$ is the frequency of the initial ultrasonic wave, V is the velocity of the blood, ν is the velocity of sound, and θ is the angle between V and ν (Fig. 5).

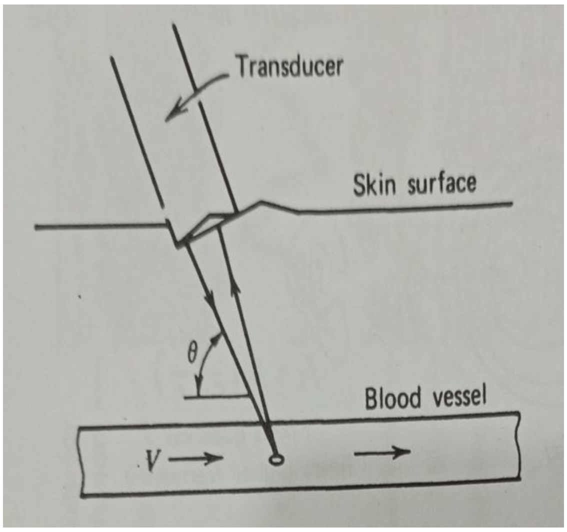


Figure 5

The Doppler effect is also used to detect motion of the fetal heart, umbilical cord, and placenta in order to establish fetal life during the 12-20 week period of gestation when radiological and clinical signs are unreliable. When a continuous sound wave of frequency $f_\circ$ is incident upon the fetal heart, the reflected sound is shifted to frequencies slightly higher than $f_\circ$ when the fetal heart is moving toward the source of sound and slightly lower than $f_\circ$ when the fetal heart is moving away from it. Variation in the frequency give the fetal heart rate. Figure 6 shows the instrument arrangement for monitoring the fetal heart. The output can be audible or displayed on an oscilloscope.

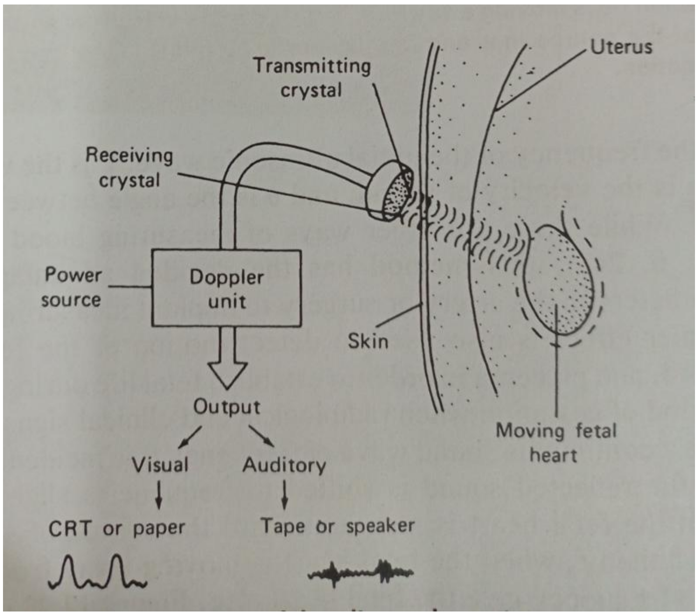


Figure 6

Physiological effect of ultrasound in therapy

Various physical and chemical effects occur when ultrasonic waves pass through the body, and they can cause physiological effects. The magnitude of the physiological effects depends on the frequency and amplitude of the sound. At the very low intensity levels used for diagnostic work (0.01 W/cm^2 average power and 20 W/cm^2 peak power) on harmful effects have been observed. As the power is increased, ultrasound becomes useful in therapy. Ultrasound is used as a deep heating agent at continuous intensity levels of about 1 W/cm^2 and as a tissue-destroying agent at intensity levels of 10^3 W/cm^2.

The primary physical effects produced by ultrasound are temperature increase and pressure variations. The primary effect used for therapy is the temperature rise due to the absorption of acoustic energy in the tissue.

In physical therapy the typical intensity is about 1-10 W/cm^2 and the frequency is about 1 MHz. Using Equation 1, we find that the amplitude of displacement A at 10 W/cm^2 in tissue is about 10^{-6} cm

$$\mathrm{I} = \frac{1}{2}\,\rho v A^2\,(2\pi f)^2 = \frac{1}{2} Z (A\omega)^2 \ldots\ldots\ldots\ldots (1)$$

Using Equation 2, we find that the maximum pressure amplitude P_0 is approximately 5 atm.

$$\mathrm{I} = \frac{P_o^2}{2Z} \ldots\ldots\ldots\ldots\ldots (2)$$

Recall that the change from maximum to minimum pressure occurs in a distance of one-half the wavelength; for a 1 MHz wave in tissue, $\lambda/2=0.7$ mm. Thus there is a substantial pressure change over a short distance. A beam of ultrasound with an intensity of 35 W/cm^2 can produce pressure changes of approximately 10 atmospheres! At very high frequencies, the energy can be passed to the molecules so quickly that it is impossible for the molecules to disperse the energy to the surrounding tissue through vibrations. The molecules can gain sufficient energy to break their chemical bonds. Intense ultrasound waves can change water into H_2 and H_2O_2 and rupture DNA molecules.

At power levels of 10^3 W/cm^2 it is possible to selectively destroy tissue at a desired depth by using a focused ultrasound beam. Work on the brains of cats indicates that the mechanism for the destruction of tissue appears to be biochemical and not merely due to local heating.