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STUDY OF THE OPERATION OF SOME MEDICAL DEVICES AND THEIR PHYSICAL APPLICATIONS. A FIELD STUDY ON THE ULTRASOUND DEVICE

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Abstract: One of the most important branches of applied physics is the application of physics in the medical field, especially in the diagnosis and treatment of human diseases. It is divided into four main branches: (radiation therapy, nuclear medicine, diagnostic imaging, and radiation protection). The Radiation Therapy Physics Division is often the largest, as physicists provide support services to the Department of Radiation Oncology, ensuring that it accurately reaches a patient in the hospital, such as planning radiation doses and X-rays. Classification and MRI oncology. Diagnostic imaging devices such as Important Humans and their treatment. We will also discuss some other medical devices (the EKG device, the EEG device, and the centrifuge). Physics in medicine is of great importance because it is manifested in employing various physical phenomena and making the most of them with devices that allow us to diagnose and treat many diseases, and we see now with the development of these, The devices have become an important possibility in wave therapy without the need to resort to surgical operations.

Keywords:

Introduction

Medical device technology is the specialty that applies principles and methods derived from engineering, science, and culture, especially physics, because it explains and solves issues and problems of a biological or medical nature. Therefore, medical devices enjoy a distinguished are directly position among the devices and equipment in our lives, because these devices related to human health and safety. Medical devices are divided in terms of use into three main sections: diagnostic, therapeutic, and supportive. In this chapter, we will discuss one device for each type2, Electrocardiography device (abbreviated as ECG or EKG) Electrocardiography is considered a diagnostic test. Electrocardiography records electrical signals in the heart. It is a common, painless test used to quickly detect heart problems and monitor your heart health. An EKG is usually done in a doctor's office or in a hospital room. Electrocardiogram machines are standard equipment found in operating rooms and this ambulance. Some personal devices, such as smart watches, allow ECG monitoring. Ask your doctor whether this is an option for you. An electrocardiogram is a painless, non-invasive procedure used to help diagnose many common heart problems. Your doctor may use an EKG to identify or detect the following: Arrhythmia • Whether the arteries in the heart are blocked or narrowed (arterial disease). Coronary artery disease (causing chest pain or a heart attack). Whether you've ever had a heart attack • How well certain heart disease treatments work, such as a pacemaker You may need an EKG if you have any of the following signs and symptoms: Chest pain. Lightheadedness, dizziness, or confusion. Heart palpitations. • Increased pulse rate. Shortness of breath. Weakness, fatigue, or decreased ability to exercise. The American Heart Association recommends that ECG should not be used to evaluate adults who do not have any symptoms and have a low risk. But if you have a family history of heart disease, your doctor may suggest an EKG as a screening test, even if you don't have any symptoms. If symptoms come and go repeatedly, they may not be detected during a regular ECG recording. The doctor may advise remote or continuous ECG monitoring. Types 2,3. Holter monitor: A Holter monitor is a small, wearable device that records an ECG continuously, usually for 24 to 48 hours. Cardiac event monitor: This portable device is similar to a Holter monitor, but it only records at certain times for a few minutes at a time. You can also wear it for a while monitor, usually 30 days. In general, you can press the buLtotonnger duration than the Holter automatically record when an when you feel symptoms. There are some devices that irregular heartbeat is detected.[5] 4-2 Risks Performing an ECG is a safe procedure. It does not involve the risk of electric shock while undergoing it, because the electrodes used do not produce electricity. Electrodes only record electrical activity in the heart. You may feel slight discomfort when removing the electrodes, such as the discomfort you feel while removing a bandage. Some people develop a slight rash where the skin patch was placed. 5-2 Planning procedure No special preparations are required before undergoing a standard ECG. An EKG may be performed in a health care provider's office or hospital. Before the procedure, you may be asked to wear a hospital gown. If you have hair on the parts of your body where the electrodes are placed, your provider may shave that hair so it sticks. Well the skin patch .During the procedure During the EKG procedure, up to 12 sensors will be connected. Electrodes are skin patches attached to a monitor. It records signals. The computer recordisnftohrismation and displays it to the electrical signals that make the heart beat. l Form waves on screen or on paper. You can breathe normally during the test, but you will need to lie down. Make sure you feel warm and ready to lie still. Moving, talking, or shaking may cause errors in test results. A standard ECG takes a few minutes 2-3-5 after the procedure and you can usually return to your usual activities EEG device (abbreviated as EEG) The nervous system is the most complex device in the systems that make up the human body. While the glands represent the chemical control device for the human body, the nervous system is the electrical control device for that body. The brain is the most important part of the nervous system, and here lies the importance of diagnosing the functioning of the brain. The work of the brain is diagnosed using an electroencephalography device, which is a technique that helps record the electricity resulting from the work of the cells of the nervous system, specifically the brain cells. Brain signals are recorded by placing surface electrodes (electrodes) on the surface of the scalp or inserting needle electrodes (electrode An EEG can detect changes in brain activity, which may be useful in diagnosing brain disorders, especially epilepsy or other seizure disorders. An EEG may also be useful in diagnosing or treating: Brain tumors Brain damage due to a head injury Brain dysfunction that can have a variety of causes (neuropathy) Sleep disorders Encephalitis (encephalitis caused by herpes virus) Stroke , Sleep disorders • Creutzfeldt-Jakob disease An EEG can also be used to confirm brain death in a person in a persistent coma. A continuous EEG is used to help find the appropriate level of sedation for a person in a medically induced coma.[7]. Risks EEG tests are safe and painless. Sometimes, seizures are intentionally induced in people with epilepsy during testing, with appropriate medical care available if it is needed.[8] EEG test -During the test, you will feel little or no discomfort during the EEG procedure. The electrodes do not transmit any sensations. It only records your brain waves. Here are some things you can expect to happen during an EEG:[8]. A qualified technician will measure your head and make marks on your scalp using a special pen to indicate where to attach the electrodes. A cream may be applied to these points on your scalp to improve the recording quality. • The technician places discs (electrodes) on your scalp using a special adhesive. Sometimes, a flexible headgear equipped with electrodes is used instead. The electrodes are connected via a set of wires to an instrument that amplifies your brain waves and records them on a computer. Once the electrodes are in place, the EEG usually takes between 20 and 40 minutes. There are tests for specific medical conditions that require you to sleep during the test. In this case, the test may take longer.[9]. You will relax in a comfortable position with your eyes closed during the test. At various times, the technician may ask you to open and close your eyes, do simple math, read a paragraph, look at a picture, breathe deeply for a few minutes, or look at a flashing light. A video will usually be recorded during the EEG procedure. A video camera captures your body movements while an EEG records your brain waves. This combined recording may help your doctor diagnose and treat your condition. Mobile EEG allows for longer-term monitoring outside of a clinic or hospital. But these types of EEG devices are not always an option. This test can record brain activity over several days, which increases the likelihood of recording during epileptic seizure activity. However, compared to video EEG monitoring performed in a hospital, EEG does not have the same, The mobile device is equally efficient in determining the difference between epileptic seizures and other pathological seizures.[10] 2-After the test and sedation, The technician removes the electrodes or headgear. If you have not received you will not feel any side effects after the procedure. You can return to your usual routine. And take time to wear off. [11] BuSt eindactaivse Tyohue rmeecedivceinea,will, Results Trained doctors analyze the EEGs, interpret the recording, and send the results to the doctor who ordered the EEGs. You may need to make an appointment to discuss your test results in the office. Ask a family member or friend to come with you to the appointment if possible. This is the information you will receive. To help yoduecide, write down questions to ask your doctor, such as: *Based on the results, what are my next steps? What kind of follow-up do I need, if any? *Are there any factors that may affect the results of this test in some way? *Do I need to repeat the test? [12]. Centrifuge, Principle of operation of the centrifuge The centrifuge works under the influence of the force of gravity, and using the principle of materials according to their density, as centrifugal acceleration causes sedimentation, in which the less dense materials are separated and move on, separating and moving the materials and molecules. Where T. displaced To the center, the denser materials settle in the form of a sediment at the bottom of the tube, and the low-density materials rise to the top. It is mentioned that there are different types of separation that leave the particles ifnortmheof granules at the bottom, the most prominent of which is pelleting, in which the centrifuge tube g, then the separation processes begin. from the solution and the excess materials remain as floating materials. During this process, the chemicals are transformed from a basic substance or aqueous medium into a solvent substance. It is noteworthy that there are protocols that determine centrifugal forces, acceleration, and rotation in centrifuges. What is a centrifuge? It is a device used to separate mixtures using centrifugal force. The centrifuge is operated by an electric motor that rotates in a rotational motion around a fixed axis. The centrifuge also works by placing the body in a state of rotation around a fixed axis, while applying a force perpendicular to the axis of rotation. To the outs. Physical applications of the centrifuge Low-speed centrifuges are often used in laboratory departments in hospitals. Doctors at the hospital will allow patients to draw blood for testing. It will be loaded into vacuum blood collection tubes and transported to the laboratory for examination. People will find it wary that most doctors will place vacuum blood collection tubes in the centrifuge. Centrifuge in the machine, the following is the process of using centrifuge in hospital laboratory. [14] First of all, after the doctor gets the blood collection tube, it will be placed on a vacuum tube rack, and when a certain amount is reached, it will be placed in the centrifuge. An equal number is necessary, because a test tube cannot be centrifuged. The centrifuge must be balanced during the centrifugation process. Although some centrifuges are balanced Automatically, it is impossible to say that the test tube can be centrifuged, but the relative weight difference is not large can maintain normal operation. The centrifuge has a very strong throwing force during the centrifugation process. If it is unbalanced, it will cause accidents. At present, medical centrifuges have protective devices, and they cannot work normally under unbalanced conditions.[15]. When the doctor places the test tube in the low-speed So centrifuge, it is isostatic. The general setup time is 5 minutes, and the spin speed is about 5000 rpm, excluding special tests. After the centrifuge starts, the rotation speed increases slowly, and then reaches the set speed. When the set time is reached, the centrifuge will stop automatically. Due to inertia, the centrifuge speed is slower than the group speed. When the centrifuge is slowly lowered, it will not stop to zero immediately, so after stopping the centrifuge, the door cannot be opened immediately. It can only be opened when the centrifugal speed is zero. When the speed is zero, the current speed display will open on the screen. . Cover the door automatically. At this time, the doctor will take out the centrifuge blood collection tube, place it on the test tube rack, and send it for examination.[16]. All diagnostic applications of the ultrasound device: Detect and display connected acoustic energy from interfaces within the body. These interactions provide the information needed to create high-resolution gray scale images of the body, as well as displaying information related to blood loss. Its unique imaging features have made ultrasound an important and versatile medical imaging tool. However, modern expensive equipment does not guarantee the production of high-quality stuThdaiteasnd yet Of diagnostic value. Gaining the most benefit from this complex technology requires a range of skills, including knowledge of the physical principles that enable ultrasound with its unique diagnostic capabilities. The user must understand the basics of the interactions of acoustic energy with tissues and the methods and tools used to produce and by improving this knowledge, the user can gather maximum ultrasound presentation. With information from each examination, avoid pitfalls and errors in diagnosis that may result from omission of information or misinterpretation of artifacts. Ultrasound and Doppler ultrasound rely on the dispersion of acoustic energy by interfaces of materials with different properties through interactions governed by acoustic physics. The associated energy amplitude is used to generate ultrasound images, and the frequency waves in scattered ultrasound provide information regarding moving targets such as blood. To produce, detect, and process ultrasound data, users must manage many variables, many of which are under their direct control. To do this, operators must understand the methods used to generate ultrasound data and the theory and operation of instruments that detect, display, and store acoustic information generated by clinical examinations.[17]. Sonar characteristics, wavelength and Compress if frequency Sound is the result of mechanical energy that is transmitted through matter as a wave that produces alternating and rarefied conditions. Pressure waves propagate by the limited physical displacement of the material through which the sound travels. The plot of these changes in pressure is a sine wave form (Figure 1-3), where the Y axis indicates the pressure at a given point and the The time pressure such as the wavelength (ÿ) and the time (T) to complete one cycle is called the period. The number of complete cycles in a unit of time is the sound frequency (f). Frequency and period are inversely related. If the period (T) is expressed in seconds, (T / 1 = f), or sec × T = f 1.ÿ The unit of audio frequency is hertz (Hz); 1 Hz = 1 cycle per second. High frequencies are expressed in kilometers Hz (kHz, 1 kHz = 1000 Hz) or MHz (MHz, 1 MHz = 1,000,000 Hz). In nature, sound frequencies range from less than 1 Hz to more than 100,000 Hz (100 kHz). Human hearing is limited to At the bottom of this range, which extends from 20 to 20,000 Hz, ultrasound differs from audible sound only by its frequency, which is 500 to 1,000 times higher than the sound frequencies used for applications. The sound we hear generally ranges from 2 to 15 MHz, on the range. Although diagnostic frequencies of 50 to 60 MHz are under investigation for some specialized imaging.tahips plications, in general the frequencies used in sonography are higher than those used in Doppler imaging. Regardless of frequency, the same basic principles of sound apply[18].

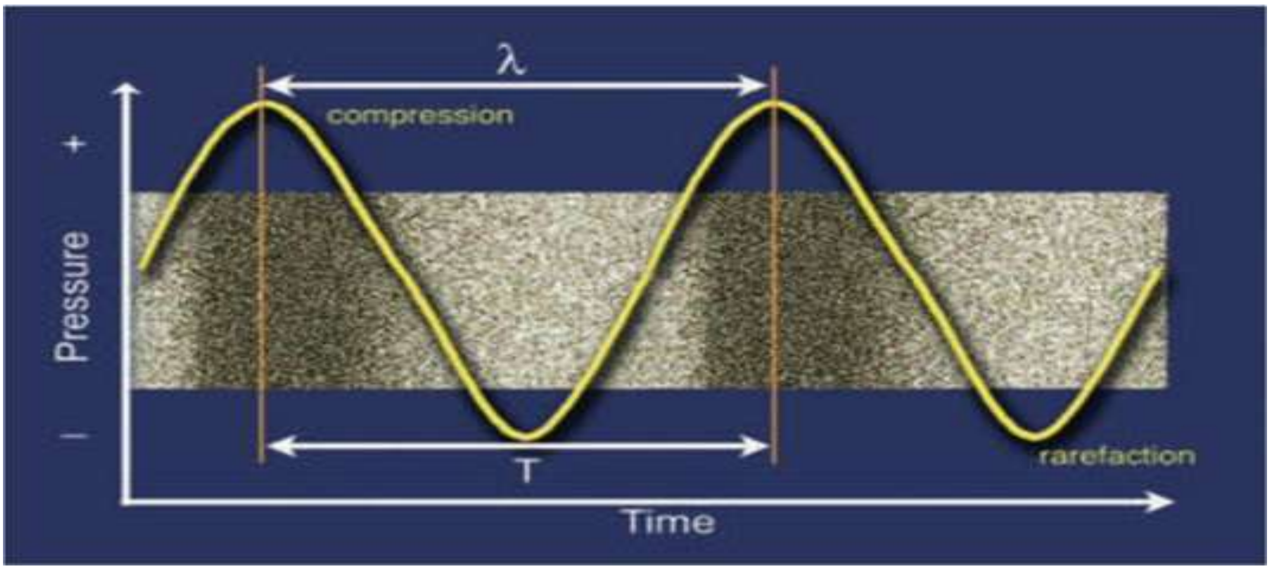

Figure 1-3 : Sound waves. Sound is transmitted mechanically at the molecular level. At rest, the pressure is around the middle. Collapse and loosening of the medium due to compression Sound propagates as a series of alternating pressure waves that are produced uniformly throughout the conductor. The time that a pressure wave passes a given point is the period, T. The frequency of the wave is 1/T. The wavelength, ÿ, is the distance between corresponding points on the pressure- time curve[18].

Sound Propagation In most clinical applications of ultrasound, short bursts or pulses of energy are transmitted into the body and spread through the tissues. Acoustic pressure waves can travel in a direction perpendicular to the direction of the particles being displaced (transverse waves) , but in tissues and fluids, sound propagation is primarily along the direction of particle motion (longitudinal waves). Longitudinal waves are important in conventional ultrasound imaging and Doppler, while transverse waves are measured in shear wave elastography. The speed at which pressure waves move through tissue varies greatly and is affected by the physical properties of the tissue. The speed of propagation is largely determined by the resistance of the medium , which in turn is affected by the density of the medium and its rigidity or elasticity. Speed is increased To press , Diffusion increases hardness and reduces density. In the body, the speed of spread can be considered Longitudinal waves are constant for a given tissue and are not affected by the sound frequency or wavelength. that it In contrast to transverse (shear) waves, whose speed is determined by.Young's modulus, which is a measure of tissue stiffness or elasticity. Figure 2-3 shows typical longitudinal diffusion velocities for a variety of materials. It is assumed that the speed of sound propagation in a body is 1540 meters per second (m/s). sec). Its value is the average of the measurements obtained from mucosal tissue Normal. Faster speeds. Because only a small number of normal tissues have diffusion values If the width of these tissues differs significantly from the average value assumed by different the ultrasound scanner, the width of these tissues may be subject to measurement or artifact errors. Manual (Figure 3-3). The speed of sound propagation (c) is related to the frequency and wavelength, With the following simple equation: fÿ=c It can be shown that a frequency of 5 MHz has a wavelength of 0.308 mm in tissue: c = ÿ /s x 5,000,000 s ÿ 1 = 0.000308 m = 0.308 1540 = f/m Important for spatial resolution in ultrasound imaging millimeter. Wavelength is an acoustic determinant, and choosing the transducer frequency for a particular application is a major user decision.[19].

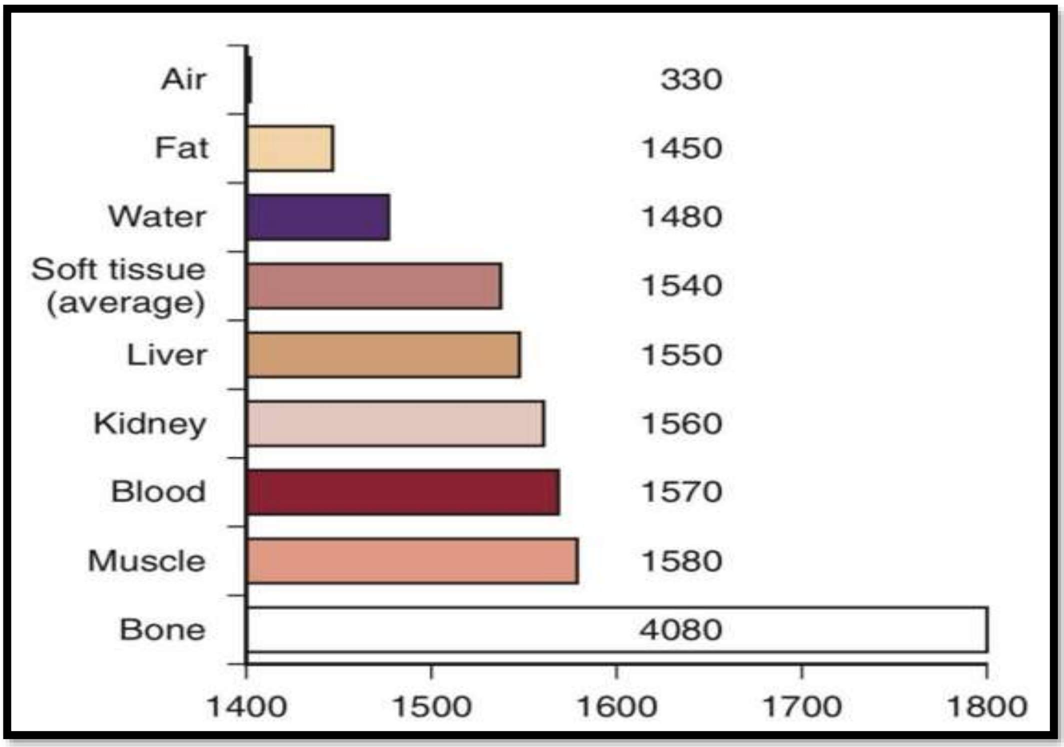

Figure 2-3: Speed of spread. In the body, the speed of sound propagation is determined by physical properties For tissues. As shown, this varies greatly. Medical ultrasound devices base their measurements on an average /s [19] Assumed soft tissue propagation velocity of 1540 m.

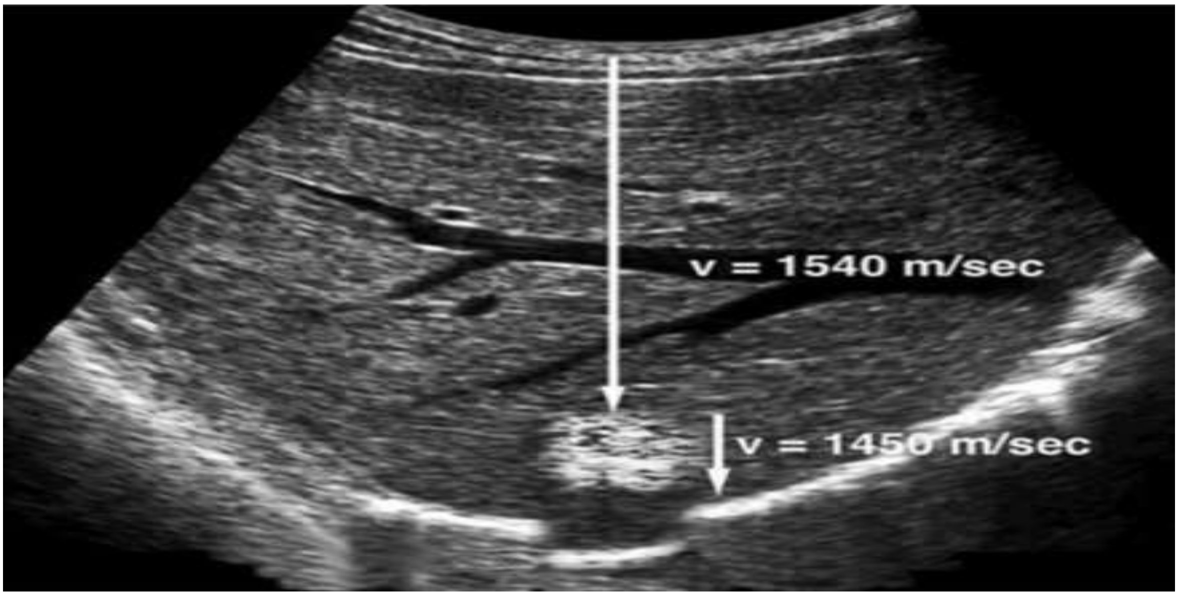

Figure 3-3: Diffusion speed tool. When sound passes through an area containing fat, the Allen echo feedback is delayed /s, which is less than the liver. Because the ultrasound scanner is supposed to.With a fat propagation speed of 1450 m/s, the delay in the echo returning is interpreted as indicating a deeper target. Sound propagates at an average speed of 1540 m. In the recording, the diaphragm and other deep structures up to the fatty lesion appear in ththee internal image, so it appears , Deeper position than expected (simulated image)[19]. Distance measurement Propagation velocity is a particularly important value in clinical ultrasound It is critical in determining the distance of the link interface from the transducer. It depends a lot Information used to generate the ultrasound scan on precise measurement If a pulse of waves is transmitted, it employs echoband principles (Figure 3-4). Ultrasound to the body and the time until the echo return is measured, it is easy to calculate, The

depth of the interface that generated the echo, provided that the speed of sound propagation through the tissues known. For example, if the time from sending the pulse until the echo returns /sec,the distance should be 0.000145 seconds and the speed of sound was 1540 m × M m/s x 100 cm / 0.000145, The distance traveled by the sound is 22.33 cm (1540 sec = 22.33 cm). Since the time measured includes the time, Sound transmission to the interface and then back along the same path to the transducer, The distance from the transducer to the reflective interface is = 22.33 cm / 2 11.165 cm. By rapidly repeating this process, a binary map is created Dimensions (2D) of the mirrored interfaces to form the ultrasound image. Therefore, the accuracy of this measurement is greatly affected by how close the assumed speed is of sound with the actual velocity in the tissue being observed (see Figures 1-3 and). 2-3), and also with the important assumption that the sound pulse travels in a straight path to and from ,Reflective facade. [20].

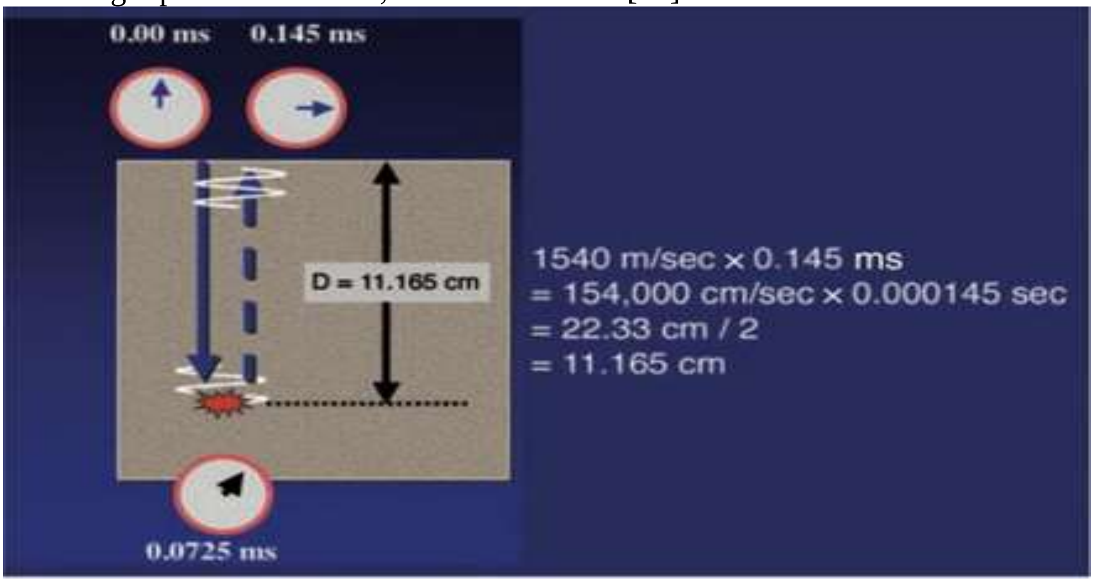

Figure : 4-3 Ultrasound range. The information used to place an echo for display depends on the exact measurement For time. Here the travel time of the echo from the transducer to the target and back to the transducer is 0.145 ms /s) by the time that the sound returning from the target has (0.000145 sec). It shows the speed of sound multiplied by tissue (1540 m) so, through repetition the target is half this distance, or 11.165 cm, from the transducer. Move 9 inches. This process quickly creates a two-dimensional map of the binding interfaces to form the ultrasound image [20]. Acoustic Impedance Current diagnostic ultrasound examination devices rely on the detection and display of sound or continuous echo. Imaging based on ultrasound transmission is also possible, but this is not currently used clinically. To produce an echo, the reflection interface must be present. Sound passing through a perfectly homogeneous medium encounters no interfaces to reflect sound, and the medium appears anechoic or saccular. The intersection of textures or materials with different physical properties produces an acoustic interface. These interfaces are responsible for reflecting the varying amounts of resulting sound energy. Thus when ultrasound waves pass from one tissue to another or encounter the wall of blood vessels or circulating blood cells, some of the incident sound energy is detected. The amount of bounce or backscatter is determined by the difference in acoustic impedances of the materials that make up the interface. Acoustic impedance (Z) is determined by the product of the density (ÿ) of the medium that propagates sound and the propagation speed (c) of sound in that medium (ÿc = Z). Interfaces with large differences in acoustic impedance, such as tissue interfaces with air or bone, reflect almost all of the incident energy. Interfaces composed of materials with smaller differences in acoustic impedance, such as the muscle-fat interface, reflect allowing the rest to continue forward. As it is only a part of the incident energy, as is the propagation velocity, acoustic impedance is determined by the properties of the tissues involved and is independent of free. Reflection, The way ultrasound waves relate when they strike an acoustic interface is determined by the size and surface features of the interface (Figure 5-3). If the interface is large and relatively smooth, it senses sound as much as a mirror reflects light. Such interfaces are of sound". The amount of energycalled Mirror meters because they act as “mirrors associated with an audio interface can be expressed as a fraction of the incident enter.

This is called the reflection coefficient (R). If the specular detector is perpendicular to the incident sound beam, the amount of associated energy is determined by the following relationship: Where 1Z and 2Z are the acoustic impedances of the media forming the interface. Because ultrasound scanners only detect links back to the transducer, the width of specular interfaces is highly dependent on the angle of interference (ultrasonic exposure). Specular repeaters will only return echoes back to the the beam If the interface is not at approximately a 90-degree transducer if angle to the sound beam, it will be isolated away from the transducer, and the echo will not be detected (see Figure 5-3 A). Most echoes in the body do not originate from specular reflectors but from much smaller interfaces within solid organs. In this case, acoustic interfaces comprise structures with odd dimensions much smaller than the wavelength of the incident sound. The echoes of these facades spread in all directions. These are called transmissive accelerators. They see through the organs and count the echoes that form the characteristic echo patterns that form the solid tissues (see Figure 5-3 B). Constructive and destructive interference of scattered sound is produced by repeaters deployed in the production of spot ultrasound, which is a feature of tissue texture for solid organ ultrasound (Figure 6-3). For some diagnostic applications, the nature of inverse structures creates important conflicts. For example, For example, most blood vessel walls behave as specular reflectors that require a 90-degree angle for best imaging, while Doppler imaging requires an angle of less than 90 degrees between the sound

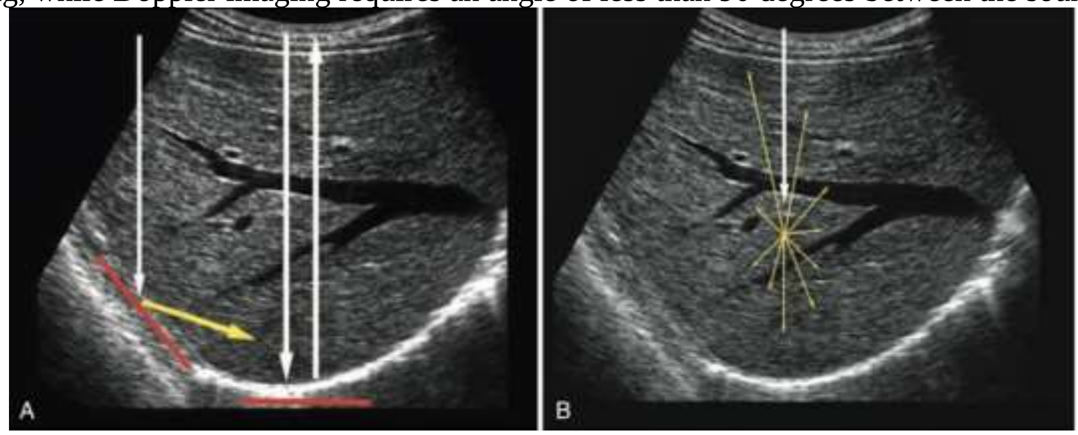

Figure 5-3 : Bright and diffuse reflectors . (A) Specular reflector. The diaphragm is a large, relatively smooth surface that transmits sound like a mirror that reflects light. Thus, sound hitting the diaphragm at an angle of approximately 90 degrees returns directly to the transducer, producing a strong resonance. Sound hitting the diaphragm is reflected indirectly away from the transducer, and the echo is not shown (yellow arrow). (B) Diffuse reflection. In contrast to the diaphragm, the liver parenchyma consists of sound interfaces that are small compared to the wavelength of sound used for imaging. These interfaces scatter the sound in all directions, and only part of the energy returns to the transducer to produce the image.

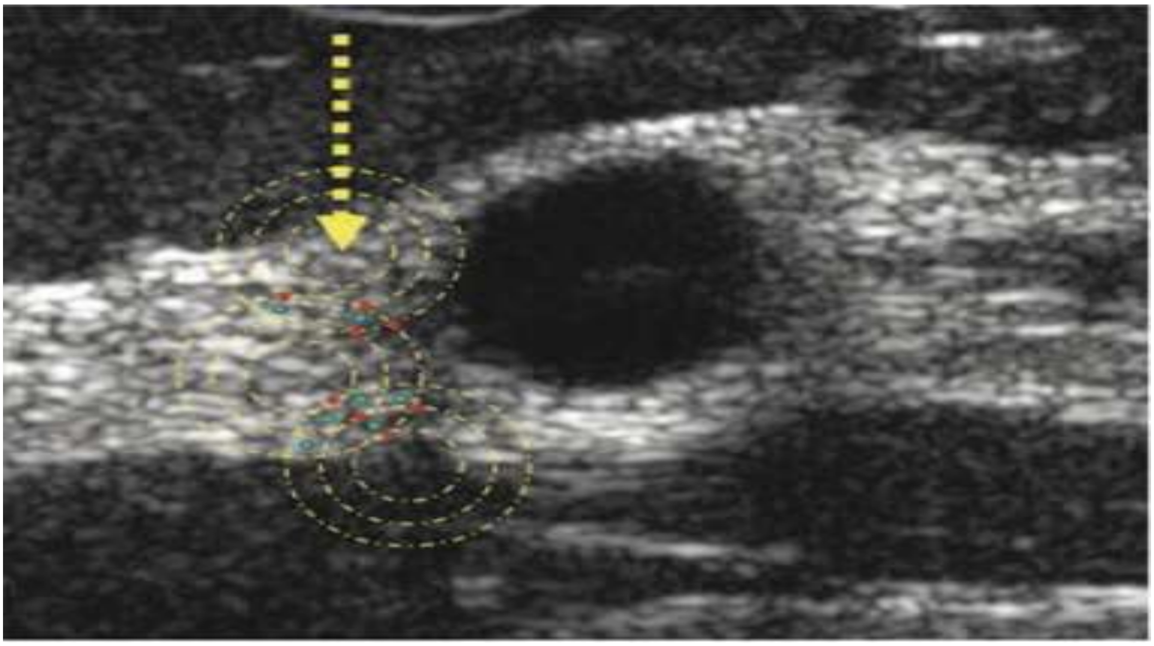

Figure 6-3 Ultrasound speckle. Close examination of an ultrasound image of a breast containing a small cyst reveals that it is composed of several areas of varying intensity (a spot). The spot results from the constructive (red) and destructive (green) interaction of sound fields (yellow rings) generated by the scattering of ultrasound waves from devices Detection of small tissues. This interference pattern gives ultrasound images their characteristic grainy appearance and may reduce the contrast of the ultrasound spot that is the basis of the tissue seen in ultrasound images of solid tissues.[22]

Refraction ;When sound passes from a tissue with a single sound propagation speed to a tissue with a higher or lower sound speed, a change in the direction of the sound wave occurs. Its change in the direction of

reproduction is called refraction and is governed by Snell's law:

$$\sin\theta_1 / \sin\theta_2 = c_1 / c_2$$

Where 1ÿ is the angle of incidence of sound approaching the interface, 2ÿ is the angle of refraction , and 1c and 2c are the speeds of sound propagation in the media that form the interface (Figure 3-7). Refraction is important in the ultrasound image. (Figure 3-8). When an ultrasound scanner detects an echo, it assumes that the source of the echo is located along a fixed line of sight from the transducer. If the sound is refracted, the detected echo may be coming from a different depth or location than the image shown On the screen, increasing the scanning angle so that it is perpendicular to the interface reduces the suspicion of this effect.[23].

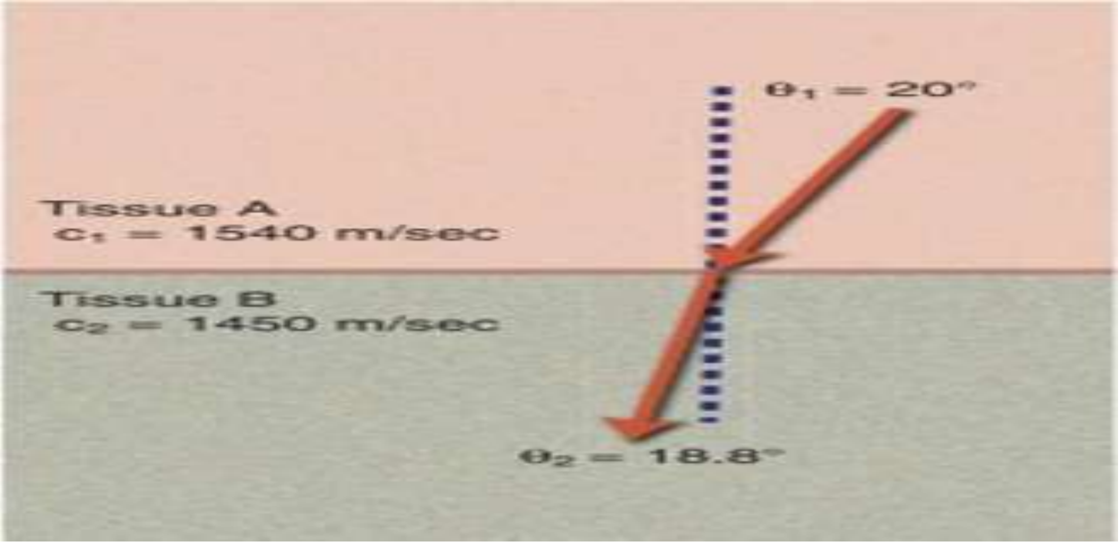

Figure 7-3: Refraction. When sound passes from tissue A with a speed of propagation (1c) to tissue B with a different speed of propagation (2c), a change in the direction of the sound wave occurs due to refraction. The degree of change is related to the ratio of the diffusion velocities of the media forming the interface (2c / 1c = 2sinÿ / 1sinÿ)[23].

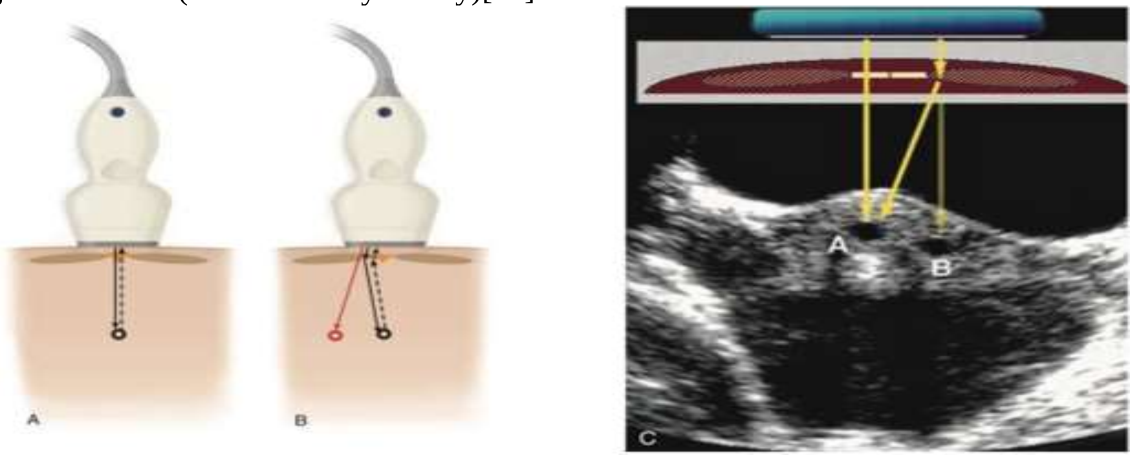

Figure 8-3: Effect of refraction. (A) and (B) Production of sound refraction artifact in a transverse scan of the mid-abdomen. The live audio path correctly depicts the location of the object. (B) "Ghost image" (red) resulting from refraction at the edge of the rectus abdominis muscle. The transmitted and attached sound travels along the path of the black arrows. The scanner assumes the signal is bouncing off a straight line (red arrow) and displays the structure in the incorrect location. (B) C) Transabdominal axial image of the uterus showing a small gestational sac (A) and what appears to be a second sac (B) due to the refractive effect. [23]. Attenuation; When sound energy moves through a uniform medium, work is done and the energy is eventually transferred to the conducting medium in the form of heat. The ability to perform work is determined by the amount of sound energy produced. Acoustic power , expressed in watts (W) or milliwatts (mW), describes the amount of sound energy produced in a unit of time. Although measuring power provides an indication of energy as it relates to time, using intensity (I) to describe the distribution does not take into account the spatial distribution of energy. Spatial energy is calculated by dividing the energy by the area over which the energy is distributed, as follows:

$$I\,(W/cm^2) = Power\,(W) / Area\,(cm^2)$$

The attenuation of sound energy as it passes through tissue is of great clinical importance because it affects the depth in the tissue at which useful information can be obtained. It in turn optimizes transducer selection and a number of operator- controlled instrument settings, including temporal (or depth) gain compensation, power output attenuation, and system gain levels. Attenuation is measured in relative units rather than absolute units. It uses decibels (dB) notation Generally to compare different levels of power or intensity of ultrasound. Its value is 10 times the 10th logarithm of the power ratio or intensity values being compared. For example, if the intensity measured at one point in the tissue is 10 mW/cm2 and at a deeper point it is 0.01 mW/cm2, the difference in intensity is as follow

$$(10)(\log_{10} 0.01/10) = (10)(\log_{10} 0.001) = (10)(-\log_{10} 1000)$$
$$= (10)(-3) = -30\ \text{dB}$$

Passing through tissues, sound loses energy, and the amplitude of pressure waves decreases as they travel farther from their source. Contributing to sound attenuation is the transfer of energy to tissues, leading to heating (absorption), and the removal of energy by reflection and scattering. Therefore, attenuation is the result of the combined effects of absorption, scattering, and reflection. Attenuation depends on the resonant frequency as well as the nature of the attenuated medium. High frequencies more rapidly than low frequencies, and the frequency of the transducer is a major determinant of the useful depth at which information can be obtained with ultrasound. Attenuation determines the efficiency with which ultrasound waves penetrate a given tissue and varies greatly in normal tissue (Figure 3-9). [24] Vocal

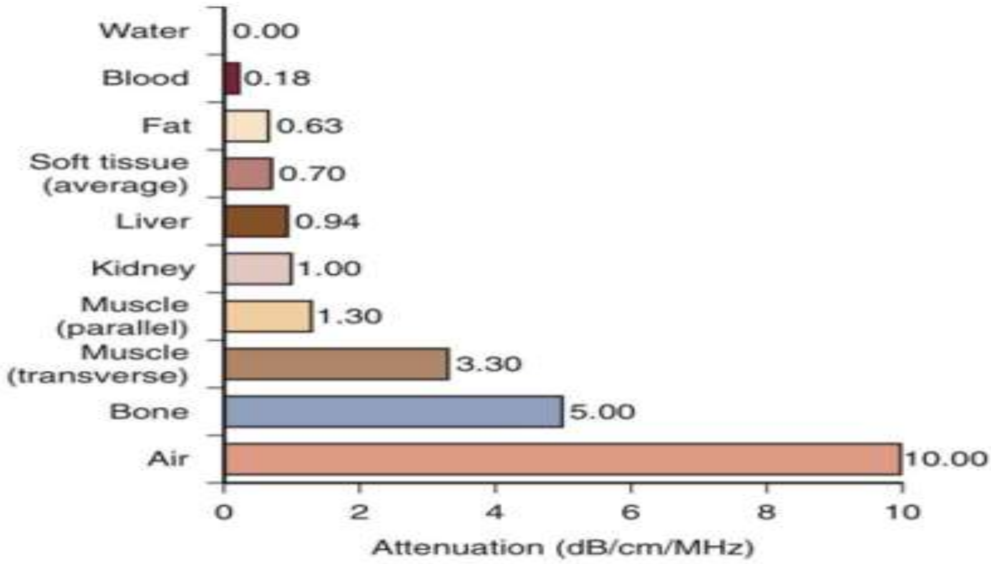

Figure : 9-3 Attenuation. When sound passes through tissue, it loses energy by transferring energy to the tissue via heating, re-reflection, and scattering. Attenuation is determined by the resonant frequency and the nature of the attenuating medium. The values show a large discrepancy. Attenuation also increases in proportion to the resonant frequency, resulting in reduced attenuated penetration into normal tissue at higher frequencies[24.]. Components of Sonar Sonar (ultrasound scanners) are complex and sophisticated imaging devices, but they all consist of the following basic components to perform the main functions: • A transmitter or user to activate the transducer. • An ultrasound transducer. • A receiver and processor To detect and amplify backscatter, power and handle signals related to display.A display that displays the ultrasound image or data in a format suitable for analysis and interpretation. • How to record or store an ultrasound image. Transmitter Most clinical applications use pulsed ultrasound, in which short bursts of sound energy are transmitted to the body. The source of these pulses, the ultrasound transducer, is activated by applying a high-amplitude voltage at precisely the right time The maximum voltage that can be applied to the transducer is limited by federal regulations that restrict the audio output of diagnostic scanners. Because the use of a maximum output voltage limit increases the patient's exposure to ultrasound energy, The transmitter also controls the rate of pulses emitted by the transducer, or pulse repetition frequency between ultrasound pulses (PRF). PRF determines the time interval and is important in determining the depth at which unambiguous data can be obtained in both imaging and Doppler modes. Ultrasound pulses should be spaced with sufficient time between pulses to allow the sound to travel to the depth of interest and return before the next pulse is sent. For imaging, PRFs of 1 to 10 kHz are used, resulting in an interval of 0.1 to 1 ms between pulses. Thus a PRF of 5 kHz allows the echo to travel and return from a depth of 15.4 cm before sending the next pulse [25]. Transformer A power transformer is any device that converts one form of energy into another form. In ultrasound, a transducer converts electrical energy into mechanical energy, and vice versa. In diagnostic ultrasound systems, the transducer performs two functions: (1) converting electrical energy provided by the transmitter into acoustic pulses directed to the patient and (2) acting as a receiver for the connected echoes, converting weak pressure changes into electrical signals for treatment. Ultrasound transducers are used Piezoelectric ultrasonication , a principle discovered by Pierre and Jacques Curie in 1880. [21] Piezoelectric materials have the unique ability to respond to the action of an electric field by changing shape. They also have the property of generating electrical potentials when compressed, changing the polarity of the voltage applied to the transducer The piezoelectric effect also results in the generation of small potentials across the transducer when the transducer is struck by the resonance. Positive pressures result in the appearance of polarity Small transducer; negative pressure during the rarefaction portion of the sound wave produces opposite polarity across the transducer. These small polarity changes and associated voltages are the source of all the information that is processed to create an ultrasound image or Doppler view. When stimulated by applying a potential difference across its thickness, the transducer vibrates. The vibration frequency is determined by the material of the transducer. When a transducer is electrically excited, it produces a range or range of frequencies. The preferential frequency generated by the transducer is determined by the propagation speed and thickness of the transducer material. In the pulsed wave operating modes used in most clinical ultrasound applications, ultrasound pulses contain additional frequencies above and below the preferential frequency. the higher the ultrasound pulse, the higher its frequency. In general, the shorter the power adapter produces, the greater the bandwidth Most modern digital ultrasound systems use broadband technology. Ultrasound bandwidth refers to the range of frequencies produced and detected by the ultrasound system. It is important because each tissue in the body has a distinct response to ultrasound at a certain frequency, and different tissues respond differently to different frequencies. The range of frequencies arising from tissue exposed to ultrasound is referred to as the bandwidth of the tissue's frequency spectrum , or tissue signature. Broadband technology provides a means of capturing the frequency spectrum of immersed tissue, preserving the acoustic information and tissue signature. Wide-bandwidth beamformers reduce the effect of speckle through frequency doubling. This is possible because speckle patterns at different frequencies are independent of each other, and combining data from multiple frequency bands (i.e. composite) results in speckle reduction in the inset image, resulting in improved contrast resolution. The length of the ultrasound pulse is determined by the number of voltage changes AC applied to the transducer. For continuous wave (CW) ultrasound machines, a constant alternating current is applied to the transducer, and the alternating polarity produces a continuous ultrasound wave. For imaging, a single, brief voltage change is applied to the transducer, causing it to vibrate at its preferential frequency. Because the transducer continues to vibrate or "ring" for a short time after being stimulated by a voltage change, the ultrasonic pulse will be several cycles long. The number of sound cycles in each pulse determines the pulse length. For imaging, short pulse lengths are desirable because longer pulses result in lower axial resolution. To reduce the pulse length, damping materials are used in the construction of the transducer. In clinical imaging applications, very short pulses are applied to the transducer, and the transducers feature It is a very small type of ultrasound, generally consisting of only two or three sound cycles.

The ultrasound pulse generated by a transducer must propagate into the tissue to provide clinical information. Special transducer coatings and ultrasound coupling gels are necessary to allow efficient transfer of energy from the transducer to the body. Once inside the body, ultrasound pulses are propagated according to basic acoustic principles by being transmitted, bound, refracted, and absorbed. Previously summarized, the ultrasound pulses produced by the transducer produce a series of wavefronts that form a three-dimensional (3D) beam of ultrasound. The features of this beam are affected by the constructive and destructive interference of pressure waves, the curvature of the transducer, and the acoustic lenses used to form the beam. The interference of pressure waves produces a region near the transducer where the pressure amplitude varies greatly. Its region is called the near field, or Fresnel zone. Farther from the transducer, at a distance determined by the transducer's radius and frequency, the sound begins to diverge, and the pressure amplitude decreases at a constant rate as distance from the transducer increases. Its area is called the far field, or Fraunhofer zone. In modern multi-element transducer arrays, precise timing of excitation of the elements allows this asymmetry in the ultrasound beam to be corrected and focused at specific depths. Only the pulse correlations returning to the transducer are able to stimulate the transducer with small pressure changes, which are converted into voltage changes that are detected, amplified and processed to create an image bas ; Rather (receiver) 3-3-3 Receiver When returning echoes strike the face of the transducer, minute voltages are produced across the piezoelectric elements. The receiver detects and amplifies these weak signals. The receiver also provides a means of compensating for differences in echo strength, which result from attenuation with different tissue thicknesses by controlling time gain compensation (TGC) or (DGC). The sound is attenuated as it passes through the depth gain compensation body, and additional energy is removed as the echo returns through the tissue to the transducer. Sound attenuation is proportional to frequency and is constant for specific tissues. Because echoes returning from deeper tissue are weaker than those returning from more superficial structures, they must be further amplified by the receiver to produce a uniform echo profile of the tissue (Figure 3-10). Adjusted by TGC controls that allow the user to selectively amplify signals from structures deeper or suppress signals from superficial tissue, to compensate for tissue attenuation Although many newer machines offer some means of automatic TGC, manual adjustment of this control is one of the most important user controls and may have a profound effect on the quality of the ultrasound image provided. For interpretation. Another important function of the receiver is to compress the wide range of amplitudes returned to the transducer into a range that can be displayed to the user. The ratio of the highest amplitudes to the lowest amplitudes that can be displayed can be expressed in decibels and is referred to as the dynamic range. In a typical clinical application, the range of signals may vary associated with a factor of up to 1:10^12, resulting in a dynamic range of up to 120 dB. Although the amplifiers used in audio equipment over this range of voltages, audio displays are capable of handling a limited gray scale display. The signal intensity range is only 35 to 40 dB. Data compression and remapping are required to adapt the dynamic range of intensity of the backscattered signal to the dynamic range of the display (Figure 3-11). Receiver compression, Additional manual post-processing controls for the user by selectively selecting a return- to-screen signal. This controls the brightness of different echo levels in the image and thus determines the contrast of the image.[27].

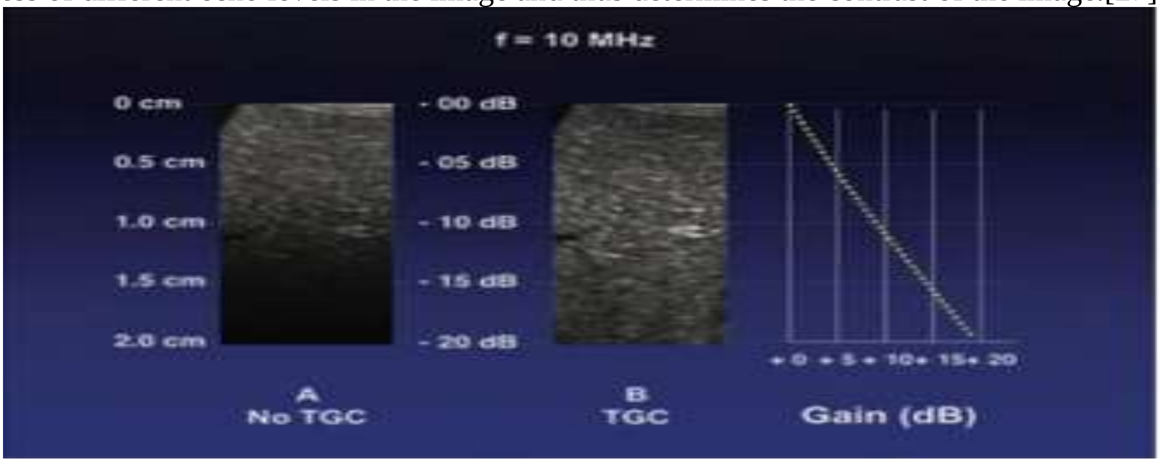

Figure: 10-3 Time Gain Compensation (TGC). Without TGC, tissue attenuation causes a gradual loss of deep tissue width (A). In this example, a tissue attenuation of 1 dB/cm/MHz is simulated. For a 10 transducer, the intensity is 20 dB (1% of the initial value). By applying increased amplification or MHz gain at a depth of 2 cm to the scattered signal to compensate for this attenuation , uniform tissue density is restored at all depths (B). A [27].

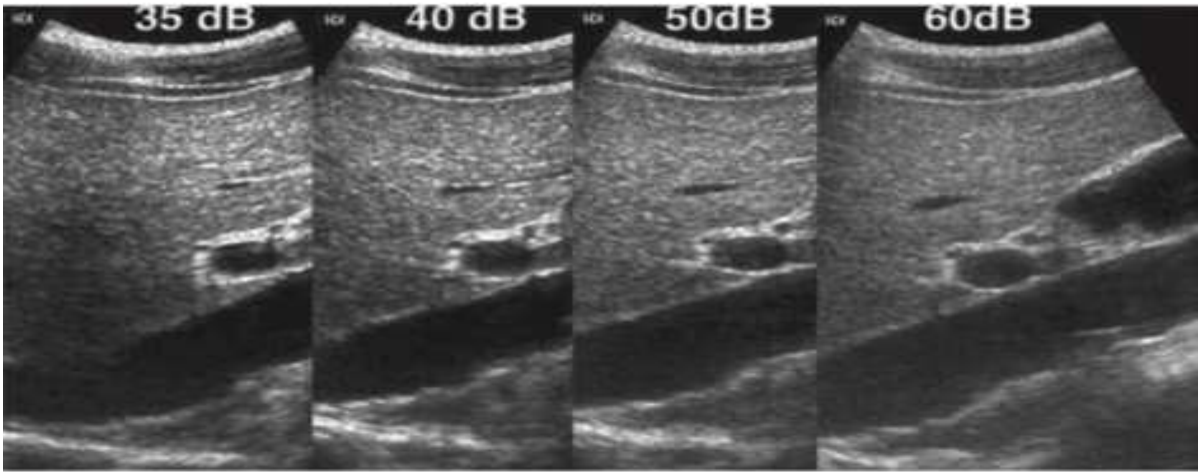

Figure:11-3 Dynamic range. The ultrasound receiver must compress a wide range of amplitudes returned to the transducer into a range that can be displayed to the user. Here, data compression and remapping are demonstrated to display dynamic ranges of 35, 40, 50, and 60 dB. The wider dynamic range offered (60 dB) allows for the best discrimination of subtle differences in echo intensity and is preferred for most imaging applications. Narrower ranges increase the clarity of larger echo difference Displaying Images Ultrasound signals can be displayed in several ways. Over the years, imaging has evolved from simple Mode A (amplitude mode) and stabilized display to high-resolution, real-time, grayscale. imaging. Older Mode A devices displayed the voltage generated across the transducer by a backscattered echo as a vertical line on the face of the oscilloscope. Horizontal time scanning of the oscilloscope to indicate the distance from the transducer to the bound surface. In this form of display, the strength or amplitude of the sound is indicated by the vertical pumping height displayed on the oscilloscope. Using ultrasound in mode A , the position and strength of the structure are recorded Echo-only Another simple form of imaging, M-mode ultrasound , displays the amplitude of the echo and shows the position of the moving equalizers (Figure 3-12). M-mode imaging uses the brightness of the screen to indicate the intensity of the associated signal[28].

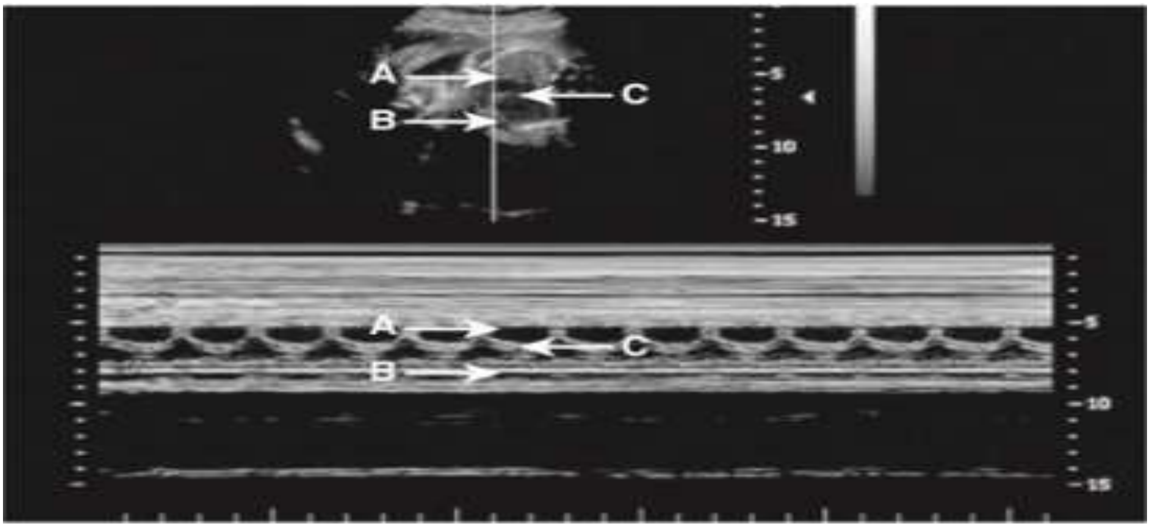

Figure: 12-3 M-Mode screen. M-mode ultrasound displays changes in echo amplitude and position over time. Viewing changes in echo position is useful in evaluating fast-moving structures such as heart valves and chamber walls. Here, the three major moving structures in the upper gray scale image of the fetus are recorded in the corresponding M-mode image and include the proximal ventricular wall (A), the interventricular septum (B) and the distal ventricular wall (C). The baseline is a time scale that

allows heart rate to be calculated from M mode data [28]. The monitor's time base can be adjusted to allow varying degrees of temporal accuracy, as dictated by the clinical application. Mode-M ultrasound is interpreted by evaluating the movement patterns of specific indicators and determining the anatomical relationships of the characteristic movement patterns. Currently, the main application of the M-mode monitor is in the evaluation of fetal and fetal heart rates, as well as in echocardiography, the rapid movement of heart valves, heart chambers and blood vessel walls. M-mode imaging may play a future role in measuring subtle changes in elasticity of the vessel wall associated with atherosclerosis. The mainstay of ultrasound imaging is provided by real -time , grey -scale , B-mode display, where differences in display intensity or brightness are used to indicate relevant signals of variable amplitude. To create a 2D image, multiple sound pulses are sent across a series of successive scanning lines (Figure 3-13), creating a 2D representation of the echoes created by the object being scanned. When an ultrasound image is viewed against a black background, it appears The most intense signals are shown in white; the absence of signal appears in black; intermediate intensity signals appear as shades of gray if the ultrasound beam is moved with respect to the object being scanned and the position of the connected signal is stored, indicating the brighter parts of the resulting 2D image. To structures that reflect more of the sound.

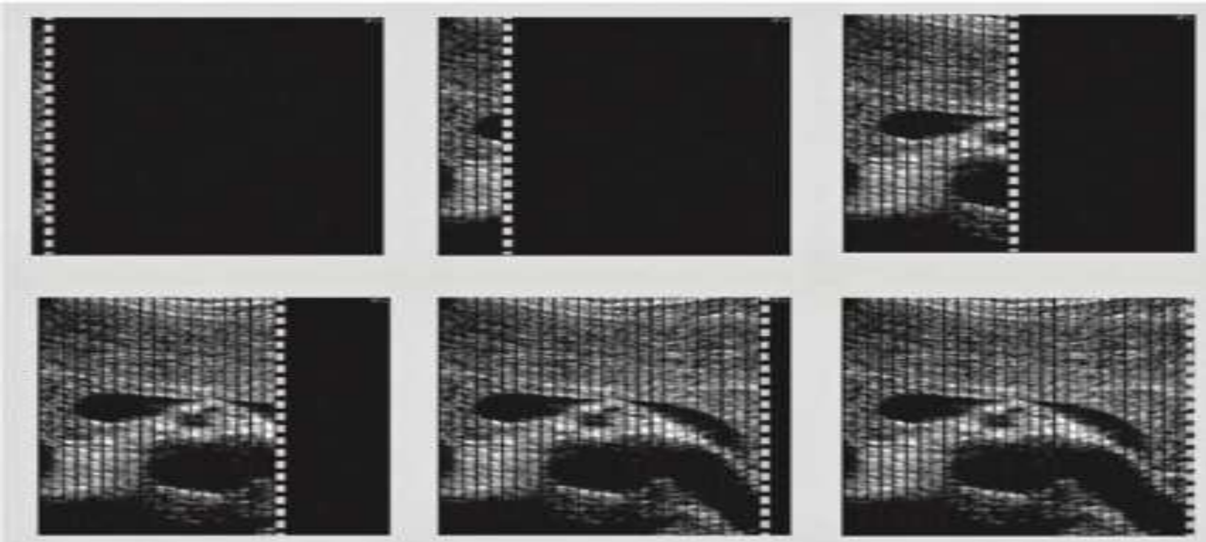

Figure 3-13: B-mode imaging A two-dimensional (2D) image is created in real time by ultrasound pulses sent along a series of successive scan lines. Each scan line adds to the image, creating a 2D representation of echoes from the object being scanned. In real-time imaging, a complete image is

created 15 to 60 times per second.[28] Mmemory will be used to store values that, In most modern instruments, digital correspond to echo intensities arising from corresponding positions in the patient. At least 28, or 256, shades of gray are possible per pixel, corresponding to the amplitude of the echo being represented. The image stored in memory in this way can then be sent to the screen for display. Because a B-mode display relates the strength of the returned signal to the brightness level on the display device, it is important that the operator understand how the amplitude information in the ultrasound signal is translated into a brightness scale in the image display. Each ultrasound manufacturer offers several options for the way the dynamic range of the target is compressed for display, as well as a transfer function that maps the amplitude of a given signal to a shade of gray. Although these technical, Equipment, the way the operator uses it may significantly affect the value Clinical internal imaging. In general, a wider width is desirable, Dynamic is possible, to identify subtle differences in tissue echogenicity (see Fig11-3(.Real-time ultrasound produces an impression of movement by creating.A series of individual 2D images at rates ranging from 15 to 60 frames per the second. Real-time, 2D, ultrasound is the method,Parts of the body are the shape The main ultrasound imaging unit in all the most common B-mode displays. Allow ultrasound in real-time assessment of both anatomy and movement. When the images are acquired And displayed at rates several times per second, the effect is dynamic, and the image is...related to the condition and movement of the organ at the time of its examination, the information is viewed as

Displayed in real time. In cardiac applications, the two terms planning are used 2D echocardiography and 2D echo to describe real-time imaging , and B mode; In most other applications, the term ultrasound is used real-time audio. The transducers used for real-time imaging can be classified in this way taking in with Used to direct the beam in creating each individual image quickly, that up to 30 to 60 complete images per second must be generated for applicatiocnosnsidering In real time. The beam may be directed by mechanical rotation or...Oscillation of the transformer or by electronic means (Figure 3-14). Uses beam steering Electronic use in linear array and phased array power converters is allowed , In a variety of image display formats. Most power adapters provide adjustable tuning for thEe lceucrtrentclyaa lusted electronically controlled depth. Mechanical beam steering may use single-element transducers with focus Fixed or toroidal arrays of elements with electronically controlled concentration may be used. For real-time imaging, transducers are generated using mechanical beam steering, Or electronic screens in a rectangular or circular shape. For obstetric, small parts and peripheral vascular examinations, linear transducers with a rectangular image format are used. A rectangular image display has the advantage of a larger field of view near the surface but requires a large surface area to contact the transducer. Sectional scanners with mechanical or electronic guidance require only a small contact area and are best suited for tests wher Access is limited.

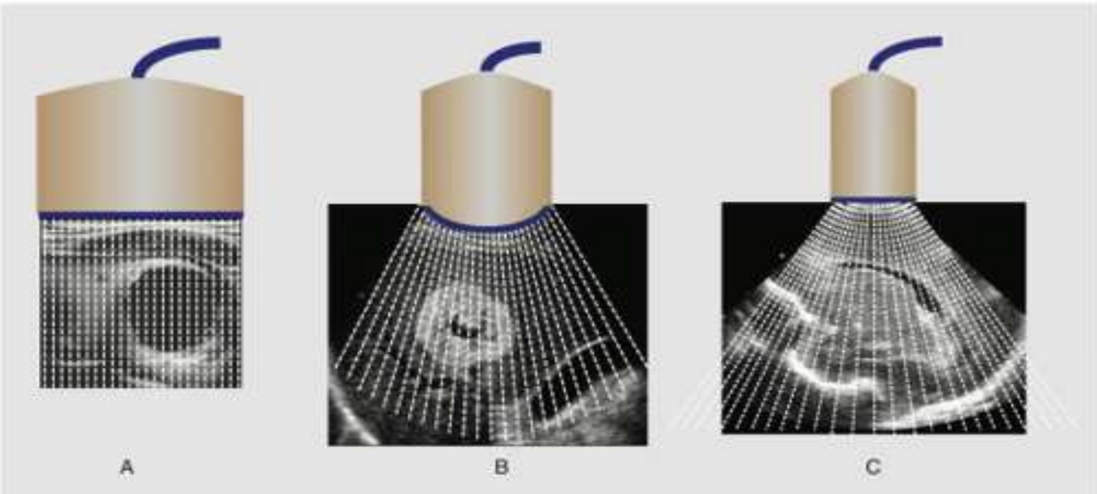

Figure: 14-3 Steering beam. (A) Linear array. In a line array transducer, the individual elements or groups of elements

Nested sequentially. This produces a series of parallel ultrasound beams, each perpendicular to the face of the transducer. When these beams move across the face of the transducer, they generate lines of sight that combine to form the internal image. Depending on the number of transducer elements and the sequence in which they are installed, focusing can be achieved at specific depths of the surface. Small high-frequency linear arrays are well suited for scanning small parts. (B) Curved array. A variation of the linear array, the curved array uses transducer elements arranged in an arc, producing a circular-shaped image.These transducers are well suited for abdominal, pelvic and fetal examinations. (C) Phased array. A phased array transducer produces a sectoral field of view by inserting multiple transducer elements in precise sequence to generate interference from acoustic wave fronts that direct the beam. It generates an ultrasound beam that produces a series of lines of sight at different angles from one side of the transducer to the other, resulting in a sectional image format. These transducers require a small contact area compared to most linear and curved arrays and are useful for area scanning where access is limited.[28] Mechanical Sector Scanners; Early ultrasound scanners used single-element piezoelectric transducers. To create real-time images using these transducers, mechanical devices were required to move the transducer in a linear motion or one or more transducers in a circular motion. Mechanical sector scanners that use a single element do not allow variable focus. His problem was overcome by using toroidal array transducers. Although important in the early days of real- time imaging, mechanical section scanners with single-element transducers are not currently in common use.[29] Arrays Current technology uses a transducer consisting of several elements, usually produced by precisely cutting a piece of piezoelectric material into many small units, each with its own electrodes. Transducer arrays These power arrays can usually be configured in a variety of configurations. Linear, curvtheisd, phased or toroidal. High-density two-dimensional matrices have also been developed. By carefully timing the formation of groups of elements in these arrays, the interference of wave fronts generated by the individual elements can be exploited to change the direction of the ultrasound beam, and this can be used to provide a steerable beam for generating real-time images in a linear or sector format.[30] Linear arrays (or linear array) Linear array transducers are used for small parts, blood vessels, and obstetric applications T because the rectangular image format produced by these transducers is well suited for these applications. In these transducers, the individual elements are arranged in a linear manner By moving the transducer elements in sequence, either individually or in groups, a series of parallel pulses is created, each It forms a line of sight perpendicular to the face of the transducer. These individual lines of sight combine To form the field of view of the image (see Figure 14-3 A). Depending on the number of elements The transducer and sequence in which it is located, focusing can be achieved at selected depths From the surface.[31] Curved arrays (or curved array); Linear arrays formed into convex curves produce a combined image A relatively large surface field of view with a sector view format (see Figure 3-14 B). These are curved array transducers for a variety of applications, and larger versions T It is used obstetric, and trans-pelvic scanning. work for general abdominal, Belly. Small high-frequency and matrix scanners are used Curved probing in vaginal, transrectal, and pediatric imaging.[31]. Phased arrays (or phased array) Unlike mechanical sector scanners, array scanners do not ICs on moving parts. The sectoral field of view is produced by elements Multiplexings of the transducer are made in precise sequence under electronic control. Through Controlling the time and sequence in which individual power transformer elements are connected,The resulting ultrasound waves can be directed in different directions as well as focused At different depths (see Figure 14-3 C). By routing the packet quickly To generate a series of lines of sight at different angles from one side of the transducer to manufacture power transformersThe other side, a sector image format is produced. It is allowed to Relatively small size but with large fields of view in depth. Power transformers These are particularly useful for head ultrasounds of newborns, as well Self For intercostal scanning, to evaluate the heart, liver, or spleen, and for regional examinations others where access is limited.[31] Two-dimensional arrays (or two-dimensional array) Transducer arrays can be formed either by cutting a rectangular piece of transducer material perpendicular to its long axis to produce a number of small rectangular elements or by creating a series of overlapping concentric elements with each other in a circular piece of piezoelectric material to produce a circular array array. The use of multiple elements allows for precise focusing. A particular advantage of the 2D array construction is that the beam can be focused in both the elevation plane and the lateral plane, and a uniform, highly focused beam can be produced (Figure 15). -3). These arrays improve spatial resolution and contrast, reduce clutter, and are well suited to collecting data from tissue volumes for use in 3D processing and display. Unlike 2D linear arrays, where delay in firing individual elements can be used to guide the beam, Ring arrays do not allow beam steering, must be used for real-time imaging, and must be machan

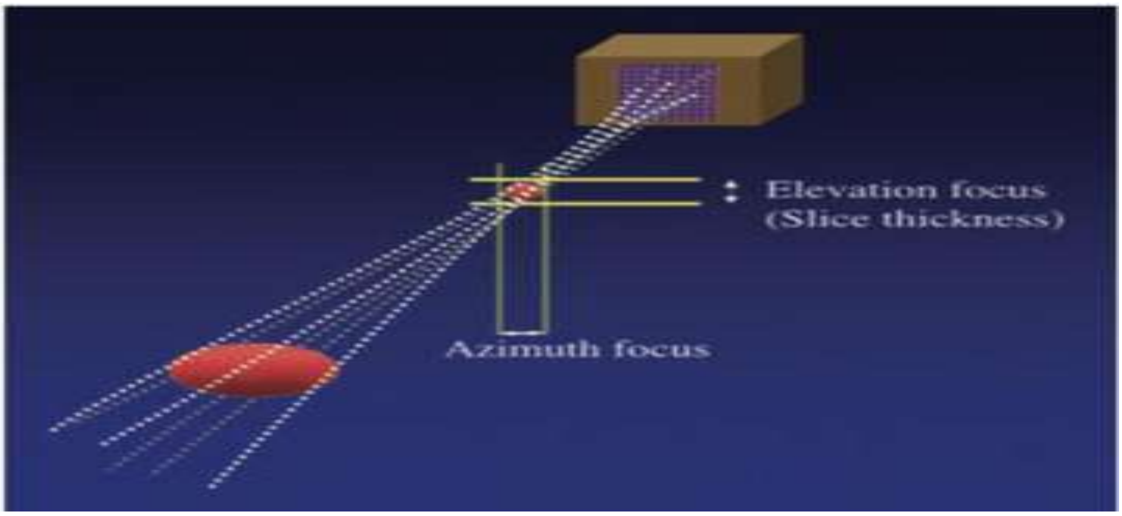

Figure 3-15 Two-dimensional array. Two-dimensional (2D) high-density arrays consist of a two-dimensional matrix, Instead of one level of tissue. Electronic control allows the acquisition of volume data for the transducer elements, allowing precise identification of individual elements at both azimuth and elevation levels.[32]. Transducer Selection Practical considerations in selecting the optimal transducer for a particular application include not only spatial resolution requirements, but also the distance of the target object from the transducer because the penetration of ultrasound waves diminishes as frequency increases. In general, the highest ultrasound frequency that allows penetration to the depth of interest should be chosen. For superficial vessels and organs, such as the thyroid, breast, or testicle, which are located 15 MHz, imaging frequencies from 7.5 to 1 to 3 cm from the surface are typically used. These high frequencies are also ideal for in-process applications. If the area to be scanned is too superficial to allow the probe to focus on the area of interest, a free-standing pad may be used. To evaluate deeper structures in the abdomen or pelvis more than 12 to 15 cm from the surface, frequencies as low as 2.25 to 3.5 MHz may be accuracy needed. When extreme accuracy is needed, a high-frequency transducer with excellent sideways and height resolution at the depth of interest is rerun therapeutic applications: High-intensity focused ultrasound Although the primary medical application of ultrasound was for diagnosis, as we mentioned briefly, it also has many medical diagnoses of the organism's body and its parts such as (the liver, spleen, biliary tree, gallbladder, (Pancreas, digestive system, kidneys, urinary tract, etc.) Therapeutic applications are developing rapidly, especially the use of high-intensity focused ultrasound (HIFU). HIFU relies on three important capabilities of ultrasound: (1) focusing the ultrasound beam to produce a highly localized energy deposition, (2) focusing the focal area, and (3) using sufficient intensity to destroy tissue to control the location and size of the focal area. His interest is in HIFU as a means of non-invasive tumor destruction and control of bleeding and cardiac malformed HIFU exploits thermal (tissue heating) and mechanical (cavitation) mechanisms. When ultrasound waves pass through tissue, attenuation occurs through scattering and absorption. Ultrasound scattering results in some of the transmitted energy returning to the transducer, where it is detected and used to produce an image , or Doppler view. The remaining energy is transmitted to the particles in the acoustic field and produces heating at the spatial peak temporal average (SPTA), intensity of 50 to 500 mW/cm2 used for imaging and Doppler, heating is minimal, and no noticeable biological defects have been documented. Related to tissue heating in humans With higher intenwsitihty,dtehvaict es, sufficient clinical tissue heating can be achieved. And to destroy tissue. Using 1 to 3 MHz HIFU, focal peak intensities of 5,000 to 20,000 W/cm2 can be achieved. Its energy can be delivered down to several millimeters, producing a rapid temperature rise of a small point size with minimal damage to adjacent tissue (Figure 1) and leading to coagulation Tissues, 16-3). Tissue destruction is a function of the temperature reached and the duration of the temperature rise. In general, elevation of tissue to a temperature of 60°C for one second is sufficient to produce coagulation necrosis. Due to its ability to cause very localized destruction For tissues, HIFU has been investigated as a tool for non-surgical or

minimally invasive treatment of bleeding sites, uterine tumors, and tumors in the prostate, liver, and breast [32] [33]. Ultrasound, HIFU may be limited by the presence of intervening gas or bone between the transducer and the target tissue Reflection of high-energy ultrasound from powerful interfaces produced by intestinal gas, lung air, or bone results in heating of tissues along the

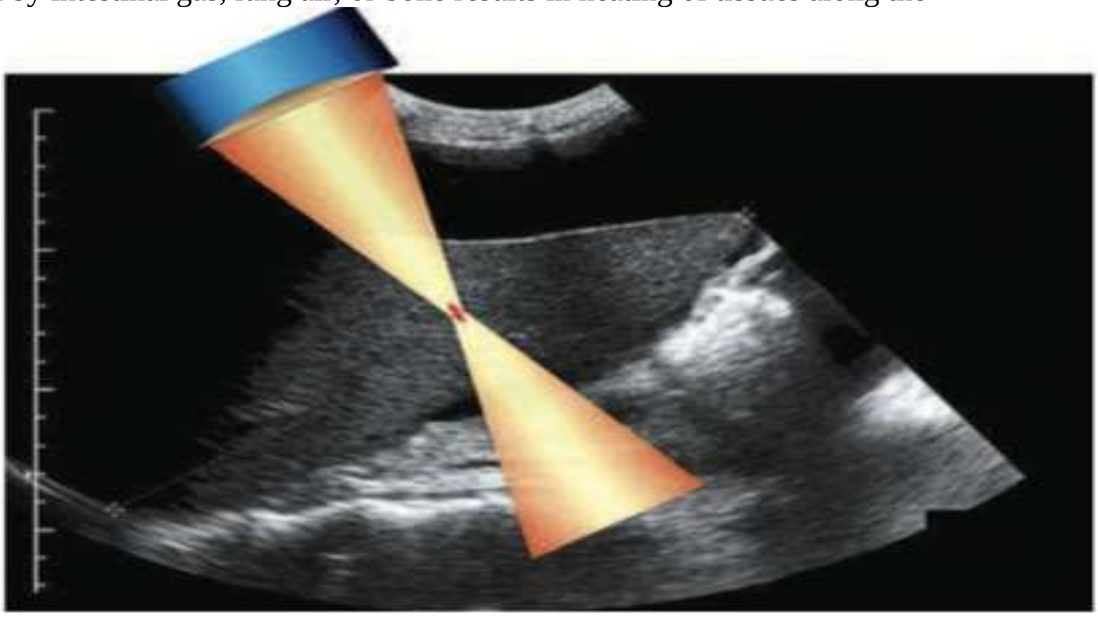

Figure: 16-3 High-focus ultrasound (HIFU). Local tissue destruction can be achieved by heating with HIFU delivered at a focal peak intensity of up to several thousandths of a 2cm/W. Tissue destruction can be confined to an area as small as a few millimeters in size without injury to adjacent tissue. HIFU is a promising tool for the minimally invasive treatment of bleeding sites, uterine tumors, and tumors in the prostate, liver, and breast[32] [33]. The main challenges with HIFU include image guidance and careful monitoring of the treatment as it is being delivered. Magnetic resonance imaging (MRI) provides a way to monitor temperature rise during treatment, which is not possible with ultrasound. Treatment may be guided using ultrasound or MRI with ultrasound guidance having the advantage of verifying the acoustic window and vocal pathway for HIFU delivery. [33].

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