

Review; Ultrasound Diagnostic Methods

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Abstract - An Ultrasonography (USG) is a method by which internal body organs can be detected by ultrasonic energy. Rushes of Ultrasound energy are transmitted from a transducer through the skin and into the internal body organs.

Transducer receives the returned reflection, when the Ultrasound energy strikes a crossing point between two tissues of different acoustical impedance. These reflections are converted to an electrical signal by the transducer.

This electrical signal is then amplified and displayed on an oscilloscope; each tissue interface would appear as a vertical deflection along the base line of the oscilloscope at a distance associated to the depth of the interface.

This type of ultrasonic technique is similar to the time domain reflectometry technique used to measure the length of electrical cable and the sonar system used to detect objects under water. In this paper the basis of the various Ultrasonic techniques (US) in use will be briefly discussed and described.

Key Words: Methods, Ultrasound, Images, Diagnostic, Medical.

1. INTRODUCTION

This simple physics behind the spread of Ultrasound waves in an isotropic flexible medium will be described here where each material has its characteristic. The fundamental equations that describe the propagation of sound waves are presented in the Table . Audio impedance Z describing the audio "conductivity" of the medium.

Characteristic impedance is a complex quantity in analogy with electricity which determined by its resistive and sensitive component (real and imaginary parts). In Table a simplified relationship of acoustic impedance with material density and sound is presented.

Sound velocity is assumed as a planar sound wave propagating in a non-absorbent medium. At a planar discontinuity of audio impedance the sound wave will be partially reflected with amplitude as described by the reflection coefficient R. The amplitude of this reflection however depends on the difference between the audio impedances of the materials at this discontinuity.

The continues transmitting helps the sound waves to travel in the medium at certain refraction angle depending on the difference between the audio impedances at the interface and the angle of incidence of the wave.

The use of pulse-echo ultrasonic wave or energy, as described above, is to some extent similar to the use of X-ray outcome obtained however differ since from an X-ray picture, a cross sectional plan or simply a linear plan is generated while from the proposed ultrasonic techniques described a complete 3D profile of the area examined will be generated [1, 2, 3].

Table 1. Basic equations describing the propagation of planar sound waves in isotropic elastic medium

Parameter	Equation
Particle displacement	$u = u_0 \sin(\omega t - f)$
Acoustic impedance	$Z = \rho C$
Sound wave pressure	$p = \rho C Y$
Sound wave amplitude	$A = A_0 e^{-2\alpha(f)d}$
Reflection coefficient	$R = \frac{Z_2 \cos q_1 - Z_1 \cos q_2}{Z_2 \cos q_1 + Z_1 \cos q_2}$
Transmission coefficient	$T = \frac{4Z_1 Z_2 \cos q_1 \cos q_2}{Z_2 \cos q_1 + Z_1 \cos q_2}$

Z = acoustic impedance, A = amplitude, v = Poisson's ratio, r = density, d = distance, t = time and, a = attenuation coefficient, q1 and q2 are the angles of the incidence and refraction, respectively, Subscripts 1 and 2 refer to the first and second medium [4].

2. Medical Diagnostic

Medical diagnostics have been a very important target area, among the applications of Ultrasound techniques. It has provided an extensive range of development during the past fifteen years. B-scan Ultrasound machines are now available with good imaging and Doppler flow measurement capabilities.

The work on the transducer part of these machines is often based on advanced developed techniques of generating thin circles of transducer elements. Extensive work carried out recently to improve transducer arrays, linear and sector-scan multi component structure, possibility of varying the aperture, focusing and beam forming more than two or three ranges of depths and signal recognition on multiple elements with electronic delay elements. In addition, high level signal

processing and scan conversion have been combined into these machines using fast digital processing methods with the recent day high speed DSP hardware [1, 2, 3].

With all these improvements, B-scan machines are now capable of showing much clearer and sharper images of internal organs than before. Ultrasound technique can also help, using Doppler technique, to unite information in cases such as blood flow measurements, particularly in echocardiograph situations. The essential function of ultrasonic diagnostic equipment is to measure distances between crossing points that split body structures by timing the echoes produced by these interfaces. This timed echo information can be used to produce different forms of display.

3. Commonly Used Display Modes

The ultrasonography (USG) modes, which are widely used in medicine and by Sonographers (medical professionals who perform the scans), resulting from ultrasonic techniques development, are listed below.

These ultrasonic diagnostic modes are increasingly used by clinicians, in their office and hospital practices, as they represent an efficient low-cost, and dynamic diagnostic imaging techniques for treatment planning, while avoiding any ionizing radiation exposures.

The study to be carried out here will be made for the following nine Ultrasound diagnostic techniques, shown below [1, 2, and 3]:

1. A-scan mode
2. B-scan mode
3. T-M mode
4. Doppler mode
5. Duplex mode
6. Three dimensions scanning mode
7. Four dimensions scanning mode
8. Color Doppler mode
9. Bio microscopy mode

3.1 A-Scan Mode

The bases of A-scan procedure are to use timing data on sound echoes to determine the distance of objects from the Ultrasound transducer. The distance to an object can be calculated (assuming a constant speed of sound), using the time between the initial pulse (the snap in this case) and the echo.

With "A" scan, pulses can be transmitted on a periodic basis into an object and the reflecting echo profiles can be then synchronizes to appear on an oscilloscope screen. The horizontal axis represents the range while the vertical axis represents the echo amplitude. These profiles or traces provide only one-dimensional spatial information, it is not usually thought of as an image of the object being examined.

Combining the "A" scan concept with a careful raster movement, two dimensional spatial information can be generated and the resulted trace can be named as "image".

When performing an "A" scan with the transducer held against the side of the patient head, echoes are received from each side of the patient's skull. The echo produced by the midline is termed the "M" echo and should be symmetrically placed between the echoes received from each side of the topic's skull.

Decades ago, A-scan of the skull was done in diagnosing brain injuries in accidents in Neurology Clinics by noting the mid line shift. Today, it is done by CT and MRI scans which are extensive and very detailed. **Error! Reference source not found.** shows "A" scan wave form [5].



Fig. 1; output of A-scanning mode

3.2 B-Scan Mode

This technique is one that has become a multipurpose diagnostic tool and has seen huge developments over the past two decades. B-scanning (brightness mode scanning) offers two dimensional cross section image of the object being scanned. Proportional signals are supplied to the position and direction of the probe by this scanning system. The resulting images are a two - dimensional cross sectional presentation of that part of the subject under scanning.

Through a transducer placed in different positions on the scanned object, a series of strengthened areas appear on the monitor, shown by bright dots, however, when the transducer is slowly, turned over the object it creates a repetitive echo patterns at a 500Hz rate; this makes the display continuous instead of several bright dots. When the transducer is pulsed repeatedly at 500 Hz while collecting the echo signals concurrently with the movement, the image appears as a stable pattern giving details of reflective objects inside the area under study.

B-Scan therefore offers an advanced method to biometry investigations by allowing simultaneous observations of the images and their corresponding waveforms. This could eliminate errors due to misalignment or false waveforms caused by retinal objectivities, or short or long slightness. The B-scan equipment, an advanced receiver-in-probe cable, therefore provides consistent performance, reduced noise, and high quality images as shown in Fig.2.



Fig.2; The output image of “B” scan

3.3 T-M Mode

Time Motion mode (TM-Mode), is an Ultrasound scanning which displays of a one-dimensional image that is used for analyzing moving body parts spatially in cardiac and fetal cardiac imaging. This can be achieved by recording the amplitude and rate of motion in real time the distance of the object from the single transducer at a given instant by repeated measurement.

The single sound beam is transmitted and the reflected echoes are displayed. These echoes are showed as dots of varying intensities thus creating lines across the screen.

As explained previously, B-mode generates cross-sectional images of anatomical region using information gathered from the entire length of the transducer while M-mode images displays information taken from the midpoint of the transducer as a continuous images over time. By means of time on the x-axis, and the depth of the underlying anatomical structure on the y-axis, the M-mode image represent changes in thickness, or depth of a structure, over time and that’s why it’s called “time-motion” mode. M-mode has been used as a reliable technique to measure muscle thickness changes.

Recently, M-mode is used to assess the structure and motion of the myocardium and the heart valves also, M-mode can represents tissue velocity imaging of different sites, it can be found if there is a difference in velocity between the points Fig. shows the output image of M-mode [8, 9, 10].



Fig. 3 M-mode output image and the used device

3.4 Doppler Mode

In Doppler mod, continuous ultrasonic energy is used in ultrasonography rather than bursts of ultrasonic energy, to detect motion within a subject. When ultrasonic energy is reflected from a moving object a small frequency shift occurs. This shift is proportional to the speed of the object being scanned. In a living body there are movements which can reflect ultrasonic energy, as an example, blood flowing through arteries, actions of the heart, intestinal movement and passage of urine and gastric juices.

Doppler ultrasonic is commonly used in obstetrics to detect movement caused by fetal heart and fetal blood flow incidents with fetal activities being detected as early as the tenth week of gestation. Another major application of Doppler ultrasonic is in the detection of blood flow in the peripheral circulation of the body.

Doppler processing of echo signals is built-up by today machines. The reflected echoes, as outlined above, have a change of frequency (or Phase) when an Ultrasound signal strikes a moving target, the Doppler frequency (FD) shift (Fig.) is related to the motion of the target:

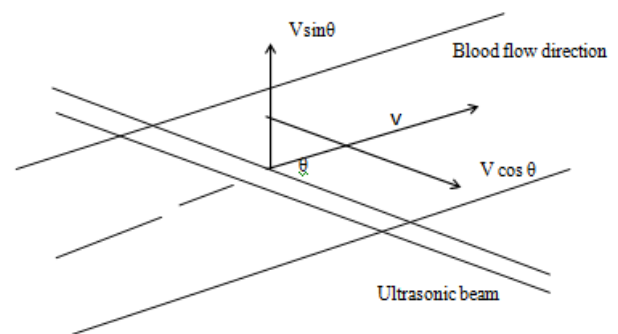


Fig. 4 Doppler relation for Ultrasound signal in a blood vessel

Typical paths of the beam could be chosen while scanning a region by the linear or sector transducer, to process the Doppler sampled volume inside the region of concern. The velocity information in that region can be then processed using the measured frequency shift and plotting the spectrogram.

The received signals, normally comprises of reflections from blood vessels, walls with low frequency shifts, and signal from the blood flow in arteries, are attributed to Raleigh scattering of the beam by blood moving particles and are of a higher frequency varying from 2 to 16 KHz depending on the nature of the blood flow.

The pathology of the heart valves and their narrowness can also be analyzed by echo cardiography, in diseased or abnormal conditions, by noting the velocity patterns during the systole and diastole in the heart beat cycle [11, 12, 13,

and 14]. Fig. shows Doppler scanning image and the used device.



Fig. 5 Doppler scanning image and the used device

3.5 Duplex Mode

Duplex Doppler systems, commonly used in clinical practice, provide a combination of both B-mode images and a Doppler signals from an identified region within the images. This system uses a pulsed Doppler. It offer analyses anywhere within the object of interest, through the use of beam direction and location of the sample imposed on the B-mode display.

As in cardiac examination, the problem of aliasing can be avoided; continuous waves Doppler mode may also be used. The main gain of such a system, despite of their increased complexity and cost, is the ability to determine the exact location of the sample under examination within the area under investigation. Abnormalities in areas under study can also be diagnosed from the image display. Fig. shows Duplex Doppler mode output image [15].

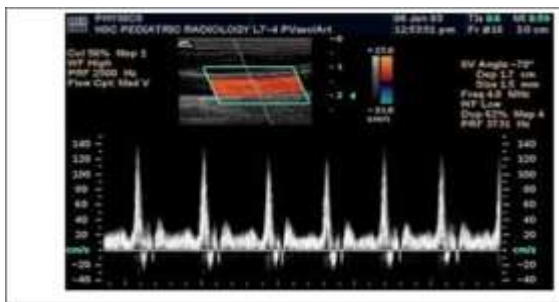


Fig. 6 Duplex Doppler mode output image

3.6 Three Dimensions Mode

The aim of 3D Ultrasound (US) imaging is to overcome the limitations of 2D US by providing an imaging technique that decreases the subjectivity of the 2D technique and allows the clinician to view the structure in 3D.

In recent years the three-dimensional (3D) Ultrasound (US) have had a significant attention from both clinical and researchers, due to its advantages over traditional two-dimensional (2D) imaging, e.g., direct opinion of entire 3D anatomy, volume measurement and more correct localization of anatomical parts. A number of techniques

have been developed to obtain 3D US images. They were mostly grouped into following two categories:

(a) Using a dedicated 3D probe to obtain a small region of interest in real-time; and

(b) Using a freehand scanning protocol with a spatial locator to sweep over a region of interest with random size and shape.

It should be emphasized, however, that:

1. Designated 3D probes are comparatively large and expensive, when compared with usual 2D probes;
2. Their field of view is limited by the dimensions of piezoelectric elements in the probe cover;
3. Their resolution, of the images, is not as good as their equivalent 2D probes.

The tracked freehand scanning protocol, however, is capable of overcoming the disadvantages of 3D probes, as listed above. Used with attached spatial locator it can be moved by freehand in a random manner to obtain random sized volumes in the area of the scan. After the freehand scanning, a set of resulting 2D B-scans with high image resolution is recreated into a regular voxel array (volume) or a 3D surface using the consistent positional information recorded by the spatial locator.

To date, fetal, cardiac and gynecological areas have received most attention using this method of scanning. Other clinical areas such as imaging of vascular anatomy, prostate volume measurement and assessment of seed placement, leadership of interventional needles and catheters, neonatal head evaluation, and evaluation of breast mass vascularity etc, are increasingly adopting this approach. Fig. shows 3D-image [17, 18].



Fig. 7. 3-Diamentions Ultrasound image

3.7 Four Dimensional Mode

4D- Ultrasound scanning (US), is a dynamic 3D US, it offers real-time feature of volume datasets instead of "static" 3D US images. It enables more intuitive recognition of the 3D spatial relationship between the probe and the objective lesion, and allows easy change in the orientation of the needle under real-time monitoring.

Two new techniques recently developed based on volume-rendering will be discussed here. They are volume contrast imaging (VCI) and inversion mode techniques. VCI is a new 4D US technology based on a real-time volume gaining and has the potential advantage of contrast enhancement and speckle suppression in the 2D US image. The main feature of VCI is the use of a thin volume containing of about 10 to 25 B-planes depending on the thickness setting, for example, 3, 5, 10, 15 mm instead of a single B-plane. 4D USG makes it possible to determine the exact direction of the fetal hand, but the exact number of all type of hand movements can still not be determined. 4D Ultrasound imaging in the check of cleft lip and Pure mouth movements such as mouth opening, yawning, tongue expulsion and pouting are present, but at a lower incidence.

Facemask expressions such as smiling and scowling can be exactly observed using 4D USG. All the movements observed in fetal life that were present in neonatal life as show in Fig. [16, 17, 18].



Fig. 8 4-Dimensions scanning image

3.8 Color Doppler Mode

The Doppler method, in medicine, was used also to count Low Blood Flow (LBF) in cows. Conservative Doppler Ultrasound, like continuous wave Doppler and pulsed wave Doppler are usually used to measure high blood flow velocities.

Since blood vessels of the corpus luteum (CL) have a very low blood flow velocity, Power scanning mode ultrasonography is an advanced method of color Doppler ultrasonography that detects the number of red blood cells moving in the vessel per time and displays them as colored pixels and this way is helpful for LBF measurement.

Through the last 15 years, color Doppler ultrasonography has increasing in fluency in bovine reproduction and showed suitable to exchange the highly invasive methods of blood flow measurement. A number of studies were lead to test the benefits of this new diagnostic tool with respect to the evaluation of luteal blood flow (LBF). Therefore, cycle-related changes of LBF, changes during early pregnancy, and alterations of LBF in response to hormonal treatments in addition to total inflammatory conditions were determined.

Fig shows color Doppler output images [19, 20].

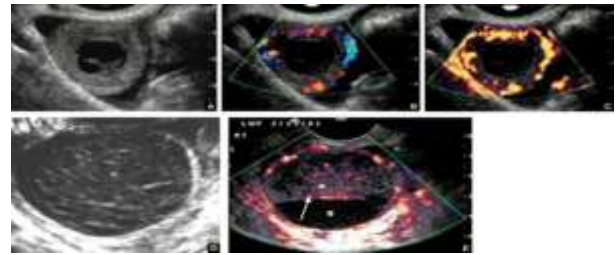


Fig.9; Color Doppler output images

3.9 Bio Microscopy Mode

These diagnostic ultrasonography scanners normally operate in the frequency range of 2 – 18 megahertz. Frequencies up to 50–100 megahertz have been used in a technique known as bio-microscopy in special areas, such as the anterior chamber of the eye.

The optimal of frequency to be used is a compromise between spatial resolution of the image and imaging depth. Lower frequencies yield less resolution but images deeper into the body. Higher frequency on the other hand has a smaller wavelength and therefore is capable of reflecting from smaller structures within the body. Higher frequency sound waves also have a larger weakening coefficient and thus are more readily engrossed in tissue, limiting the depth of penetration of the sound wave into the body.

For imaging soft tissues of the body sonography is effective. Constructions such as muscles, tendons, testes, breast, thyroid and parathyroid glands, and the neonatal brain are imaged at a higher frequency (7–18 MHz), which offers better axial and side resolution. Deeper structures such as liver and kidney are imaged at a lower frequency (1–6 MHz) with lower axial and lateral resolution but greater penetration. Fig. shows Bio microscopy mode output image and the used device [21].



Fig. 10; Bio microscopy mode output image and the used device

4. CONCLUSIONS

The nine Ultrasound scanning methods, techniques and capabilities were briefly discussed together with their resulting output images. A- Scanning and TM- Scanning modes usually produce one-dimensional spatial information only, which are not regarded as images. The resulting

information from these methods is presented in graphic form with two axes by transmit the single sound beam and display the reflected echoes.

The B-scanning mode, from the brief study, indicated that this type of Ultrasound scanning has become a multipurpose diagnostic tool and has been developed over the past two decades significantly, especially for the pregnant women and other diagnostic purposes. B-scanning offers two dimensional cross section images of the object being scanned. The B-scan provides consistent performance, reduced noise, and high quality images but the output image still needs an enhancement because of other types of interfering noises.

Doppler -mode is also produces two dimensional output images but in using a different scanning techniques. A continuous ultrasonic energy is used in ultrasonography rather than bursts of ultrasonic energy to detect motion within a subject. The produced images could be colored or non colored images with big size, narrow field of view and they however produce poor images and that is the case for all the Ultrasound produced images.

In three and four dimensions scanning techniques the tracked freehand scanning protocol is capable of producing a set of 2D B-scans type images with high image resolutions. The latter are recreated into a regular volume or a 3D surface by in co-operating the consistent positional information recorded by the spatial locator.

4-D scanning offers real-time feature for than the static features as the case in the 3-D images type. The used devices for both types are expensive and in principle depend on the 2-D images as outlined.

Bio microscopy mode uses high frequency for scanning; however, these higher frequency sound waves limit the depth of penetration of the sound wave into the body. This result in limiting their use for special cases only.

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