BASIC PHYSICAL PRINCIPLES OF MEDICAL ULTRASOUND

1

INTRODUCTION

The introduction of ultrasound to obstetrics and gynecology has made tremendous impact to patient care as it allowed imaging of the fetus and placenta in obstetrics and maternal internal organs in gynecology with such clarity to allow advanced diagnosis and also to guide various life saving interventions. Understanding the physical principles of ultrasound is essential for a basic knowledge of instrument control and also for understanding safety and bioeffects of this technology. In this chapter, we present the basic concepts of the physical principles of ultrasound, define important terminology, review the safety and bioeffects and report on ultrasound statements of national and international organizations.

PHYSICAL CHARACTERISTICS OF SOUND

Sound is a mechanical wave that travels in a medium in a longitudinal and straight-line fashion. When a sound travels through a medium, the molecules of that medium are alternately compressed (squeezed) and rarefied (stretched). Sound cannot travel in a vacuum; it requires a medium for transmission, as the sound wave is a mechanical energy that is transmitted from one molecule to another. It is important to note that the molecules do not move as the sound wave passes through them, they oscillate back and forth, forming zones of compression and rarefaction in the medium. Seven acoustic parameters describe the characteristics of a sound wave. **Table 1.1** lists these characteristics.

TABLE 1.1	Characteristics of Sound Waves
- Frequency - Period - Amplitude - Power - Intensity - Wavelength - Propagation speed	

Frequency of a sound wave is the number of cycles that occurs in one second (**Figure 1.1**). The unit Hertz is 1 cycle / second. *Frequency* is an important characteristic of sound in ultrasound imaging as it affects penetration of sound and image quality. *Period* of a sound wave is related to the time that a wave takes to vibrate up and down and thus is reciprocally related to frequency. For instance, a sound wave with a frequency of 10 Hertz will have a period of 1/10 second. *Amplitude*, *power* and *intensity* are three wave characteristics that relate to the strength of a sound wave. *Amplitude* is defined by the difference between the peak (maximum) or trough (minimum) of the wave and the average value (**Figure 1.2**). The peak or crest, represents the zone of compression and the trough represents the zone of rarefaction (**Figure 1.2**). Units of amplitudes are expressed in pressure parameters (Pascals) and in clinical imaging in million Pascals (MPa). The *amplitude* of a sound wave diminishes as sound propagates through the body. *Power* is the rate of energy transferred through the sound wave and is expressed in Watts. *Power* is proportional to the amplitude squared of a sound wave. *Power* can be altered up or down by a control on the ultrasound machine. Intensity is the concentration of energy in a sound wave and thus is dependent on the power and the cross sectional area of the sound beam. The *intensity* of a sound beam is thus calculated by dividing the power of a sound beam (Watts) by its cross sectional area (cm^2), expressed in units of W/cm^2. The *wavelength* of a sound wave is the length of a wave and is defined as the distance of a complete cycle. It is designated by the symbol lambda (λ), is expressed in mm in clinical settings (**Figure 1.3**), and can be calculated by dividing the velocity of the wave by the frequency of the wave ($\lambda = v/f$). The *propagation speed* is the distance that a sound wave travels through a specified medium in 1 second.

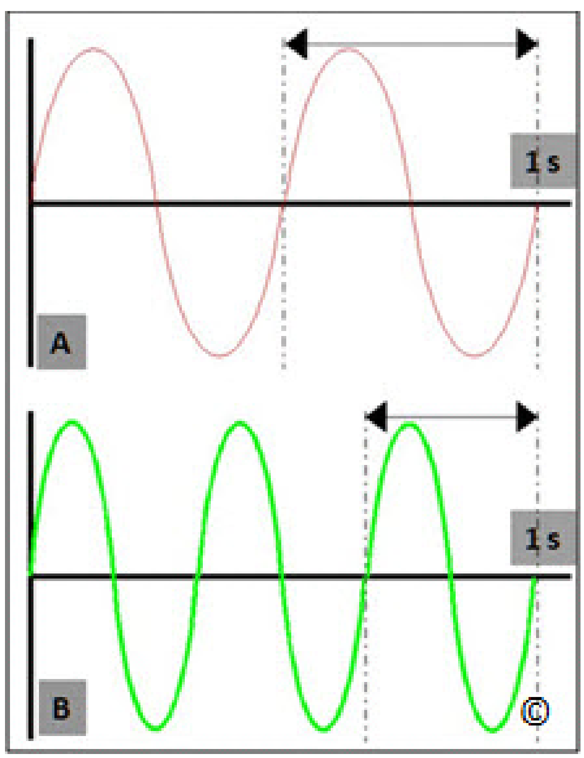

Figure 1.1: Frequency of sound is the number of cycles per second (s) and is expressed in Hertz (1 cycle / sec). In Wave A, the frequency is 2 cycles per sec or 2 Hertz and in wave B the frequency is 3 cycles per sec or 3 Hertz. The double arrows denote sound wavelengths, described in figure 1.3.

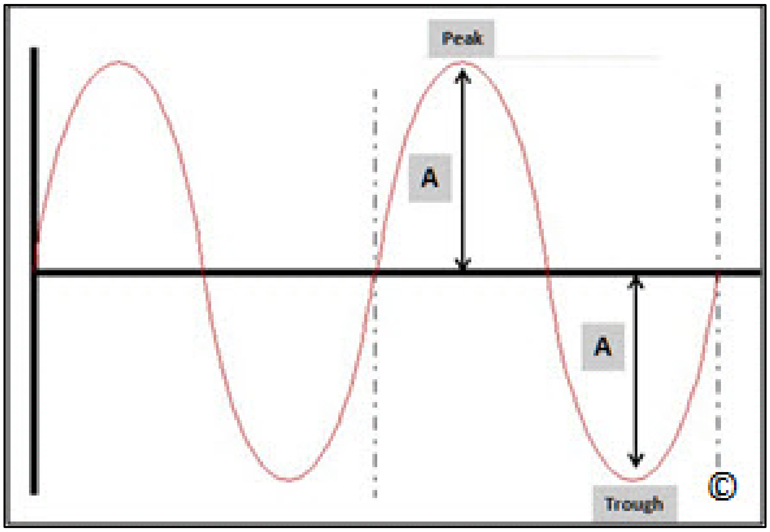

Figure 1.2: Amplitude (A) is defined by the difference between the peak (maximum) or trough (minimum) of the wave and the average value. Units of amplitude are expressed in million Pascals (MPa).

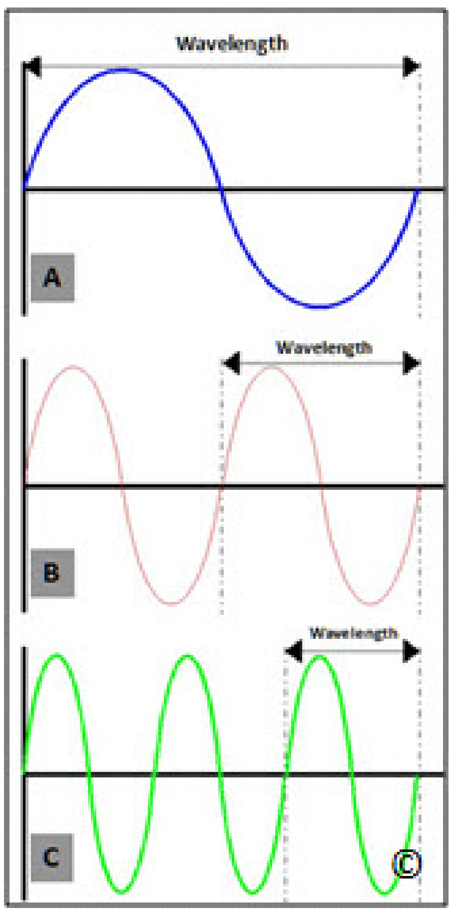

Figure 1.3: The wavelength of a sound wave is the length of a wave and is defined as the distance of a complete cycle. It is designated by the symbol lambda (λ), and is expressed in mm. In this schematic, 3 sound waveforms are shown with respectively shorter wavelengths from A to C.

TABLE 1.2	Speed of Sound in Various Media
Medium Type	**Speed (m/s)**
Air	330
Fat	1,450
Water	1,450
Soft Tissue	1,540
Bone	3,500
Metals	up to 7,000

The sound source, which is the ultrasound machine and/or the transducer, determines the frequency, period, amplitude, power and intensity of the sound. Wavelength is determined by both the sound source and the medium and the propagation speed is a function of the medium only. The propagation speed of sound in soft tissue is constant at 1,540 m/s. **Table 1.2** shows the propagation of sound in other biologic media and materials.

WHAT IS ULTRASOUND?

Sound is classified based upon the ability of the human ear to hear it. Sounds sensed by young healthy adult human ears are in the range of 20 cycles per second or Hertz, abbreviated as Hz, to 20,000 Hz, or 20 KHz (Kilo Hertz) termed audible sound (Range of 20 – 20,000 Hz). If the frequency of a sound is less than 20 Hz, it cannot be heard by humans and is defined as infrasonic or infrasound. If the frequency of sound is higher than 20 KHz, it cannot be heard by humans and is called ultrasonic or ultrasound, **Table 1.3**. Typical frequencies used in medical ultrasound are 2-10 MHz (mega, (million), Hertz). Ultrasound frequencies that are commonly used in obstetrics and gynecology are between 3 and 10 MHz.

TABLE 1.3	Frequency Spectrum of Sound
Sound Wave	**Frequency**
Ultrasound	Greater than 20 KHz
Audible Sound	20 Hz to 20 KHz
Infrasound	Less than 20 Hz

HOW IS ULTRASOUND GENERATED?

Ultrasound waves are generated from tiny piezoelectric crystals packed within the ultrasound transducers (**Figure 1.4**). When an alternate current is applied to these crystals, they contract and expand at the same frequency at which the current changes polarity and generate an ultrasound beam. The ultrasound beam traverses into the body at the same frequency generated. Conversely, when the ultrasound beam returns to the transducer, these crystals change in shape and this minor change in shape generate a tiny electric current that is amplified by the ultrasound machine to generate an ultrasound image on the monitor. The piezoelectric crystals within the transducer therefore transform electric energy into mechanical energy (ultrasound) and vice-versa. One crystal is not sufficient to produce an ultrasound beam for clinical imaging and modern transducers have large number of crystals arranged into parallel rows (**Figure 1.4**). Each crystal can nevertheless be stimulated individually. The crystals are protected by a rubber covering that helps decrease the resistance to sound transmission (impedance) from the crystals to the body. The high frequency sound generated by a transducer do not travel well through air, so in order to facilitate their transfer from the transducer to the skin of the patient, a watery gel is applied that couples the transducer to the skin and permits the sound to go back and forth. Ultrasound is therefore generated inside transducers by tiny crystals that convert electric current to ultrasound and convert returning ultrasound beams from the body into electric currents. Modern transducers have crystals made of synthetic plumbium zirconium titanate (PZT).

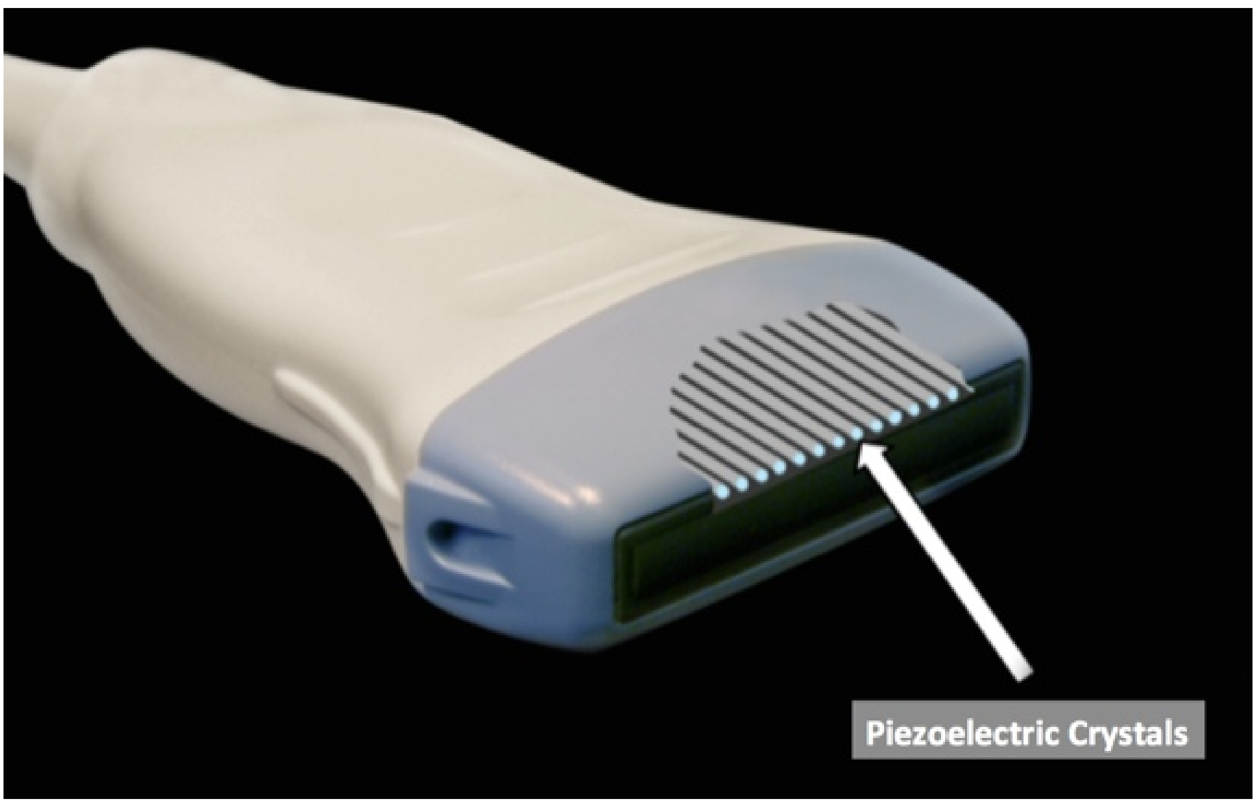

Figure 1.4: Piezoelectric crystals shown within a transducer. Note the symmetrical arrangement of the crystals. This figure is a diagrammatic representation, as the crystals are typically much smaller than shown. Figure 1.4 is modified with permission from the Society of Ultrasound in Medical Education (SUSME.org).

HOW IS AN ULTRASOUND IMAGE FORMED?

Modern ultrasound equipment create an ultrasound image by sending multiple sound pulses from the transducer at slightly different directions and analyzing returning echoes received by the crystals. Details of this process is beyond the scope of this book, but it is important to note that tissues that are strong reflectors of the ultrasound beam, such as bone or air will result in a strong electric current generated by the piezoelectric crystals which will appear as a hyperechoic image on the monitor (**Figure 1.5**). On the other hand, weak reflectors of ultrasound beam, such as fluid or soft tissue, will result in a weak current, which will appear as a hypoechoic or anechoic image on the monitor (**Figure 1.5**). The ultrasound image is thus created from a sophisticated analysis of returning echoes in a grey scale format. Given that the ultrasound beam travels in a longitudinal format, in order to get the best possible image, keep the angle of incidence of the ultrasound beam perpendicular to the object of interest, as the angle of incidence is equal to the angle of reflection (**Figure 1.6**).

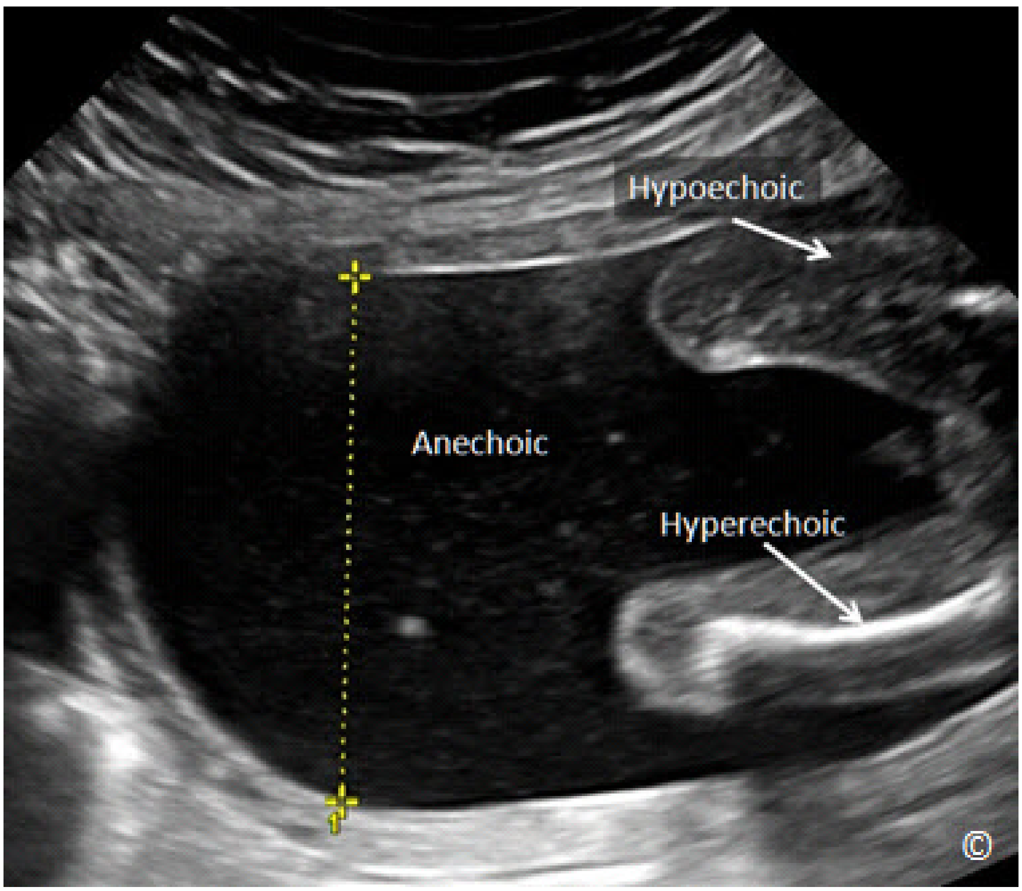

Figure 1.5: Ultrasound image of fetal extremities in the second trimester. Note the hyperechoic femur, the hypoechoic soft tissue in the thigh and anechoic amniotic fluid. Calipers measure the maximal vertical pocket of amniotic fluid (chapter 9).

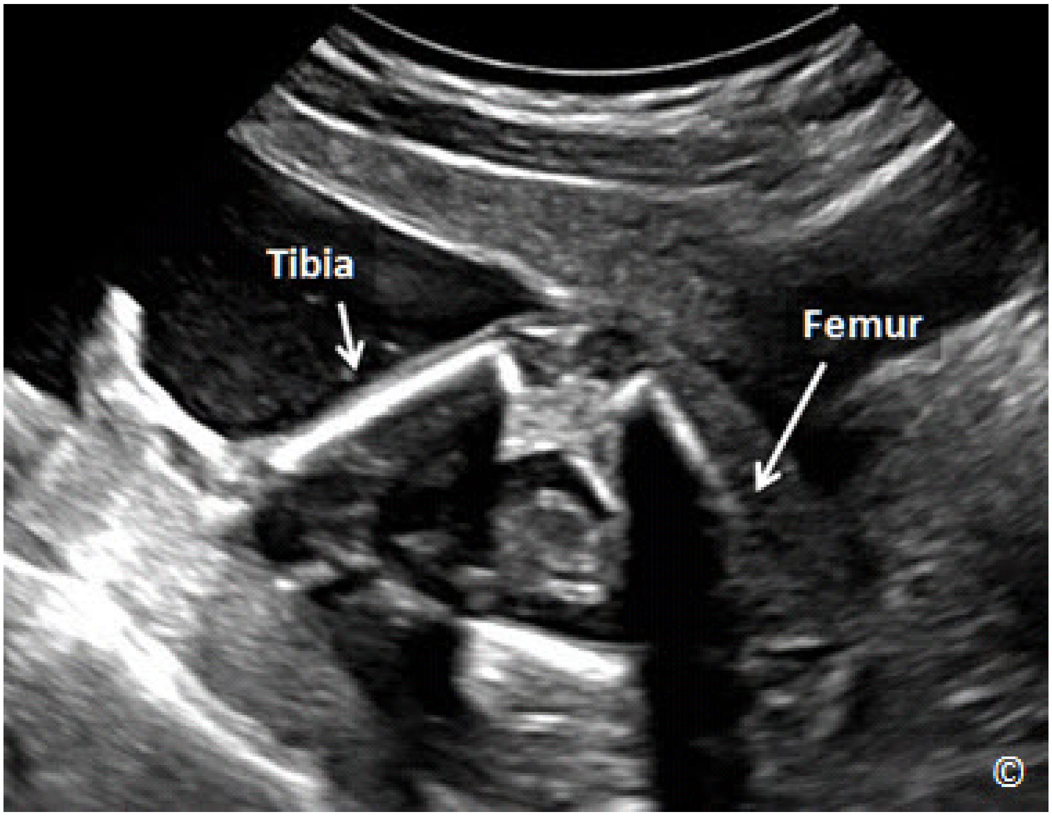

Figure 1.6: Ultrasound image of fetal lower extremity in the second trimester demonstrating the effect of the angle of insonation. Note how clearly the tibia is seen, as the angle of insonation is almost 90 degrees to it. The femur is barely seen, as the angle of insonation is almost parallel to it.

WHAT ARE DIFFERENT TYPES OF ULTRASOUND MODES?

A-mode, which stands for "Amplitude mode", is no longer used in clinical obstetric and gynecologic ultrasound imaging but was the basis of modern ultrasound imaging. In A-mode display, a graph shows returning ultrasound echoes with the x-axis representing depth in tissues and the y-axis representing amplitude of the returning beam. Historically, A-mode ultrasound was used in obstetrics in measuring biparietal diameters (**Figure 1.7**). B-mode display, which stands for "Brightness mode", known also as two-dimensional imaging, is commonly used to describe any form of grey scale display of an ultrasound image. The image is created based upon the intensity of the returning ultrasound beam, which is reflected in a variation of shades of grey that form the ultrasound image (**Figure 1.8**). It is important to note that B-mode is obtained in real-time, an important and fundamental characteristic of ultrasound imaging. **Table 1.4** shows various echogenicity of normal fetal tissue.

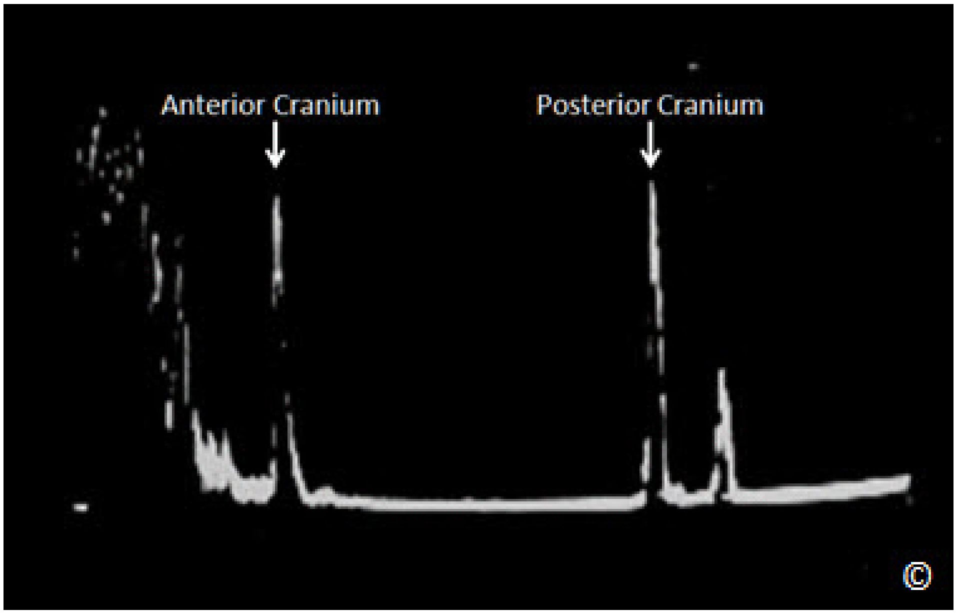

Figure 1.7: A-Mode ultrasound of fetal head. The first spike corresponds to the anterior cranium and the second spike corresponds to the posterior cranium. The biparietal diameter is the distance between these 2 spikes.

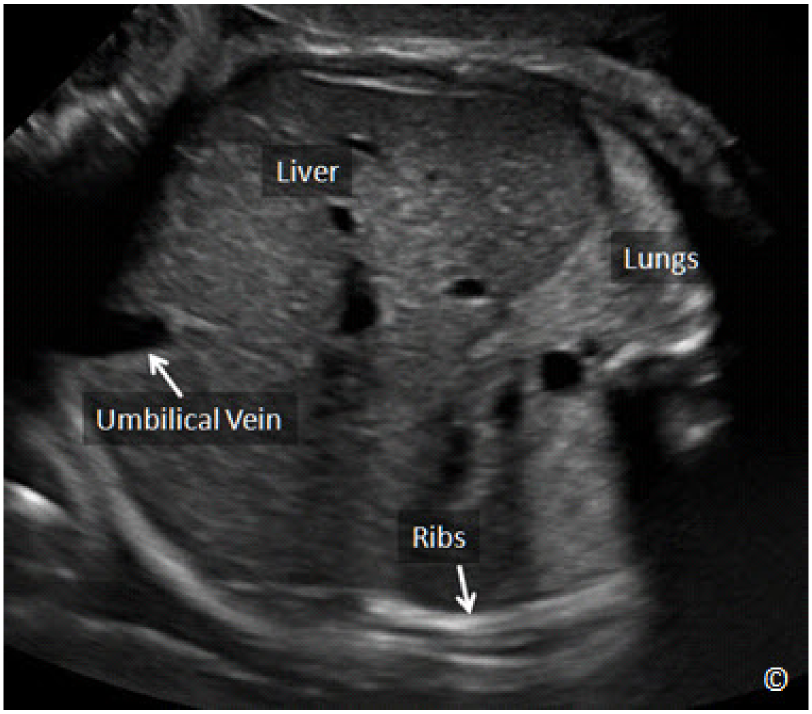

Figure 1.8: Variations in grey scale in a 2D ultrasound image of a fetal abdomen in the second trimester. Note the hyperechoic ribs and lung tissue, hypoechoic liver and anechoic umbilical vein. The intensity of the returning beam determines echogenicity.

TABLE 1.4	Various Ultrasound Echogenicity of Fetal Tissue

Organ System	Anechoic	Slightly Echoic	More Echoic	Echogenic
Bone				√
Brain		√		
Lungs			√	
Stomach	√			
Liver		√		
Intestines			√	
Kidneys			√	
Bladder	√			
Placenta			√	
Amniotic Fluid	√			

M-mode display, which stands for “Motion mode” is a display that is infrequently used in current ultrasound imaging but is specifically used to assess the motion of the fetal cardiac chambers and valves in documentation of fetal viability and to assess certain fetal cardiac conditions such as arrhythmias and congenital heart disease. The M-mode originates from a single beam penetrating the body with a high pulse repetition frequency. The display on the monitor shows the time of the M-mode display on the x-axis and the depth on the y axis (**Figure 1.9**).

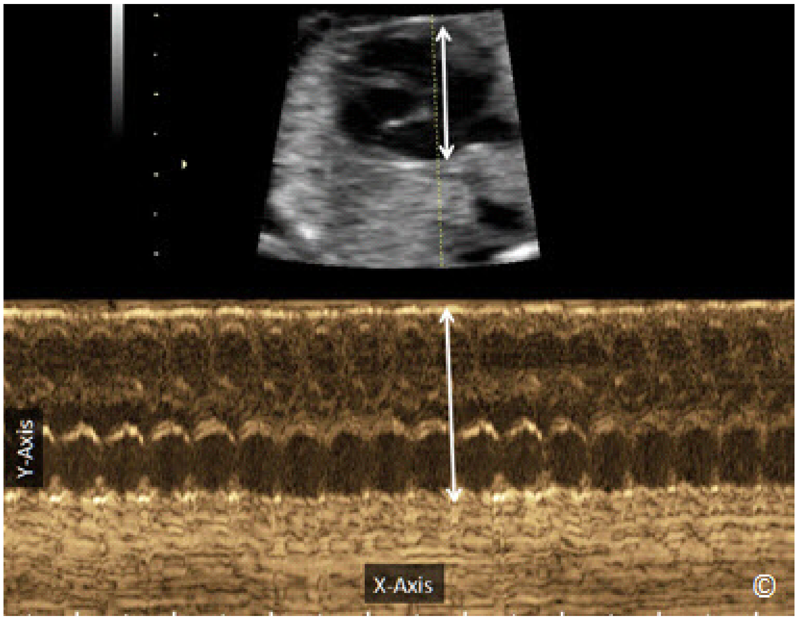

Figure 1.9: M-mode ultrasound of the fetal heart in the second trimester. The M-mode display (in sepia color) corresponds to the single ultrasound beam (dashed yellow line) with the X-axis displaying time and Y-axis displaying depth. Note the display of the heart on B-mode and corresponding M-mode shown by the double-headed arrows.

Color and spectral (pulsed) Doppler modes are dependent on the *Doppler principle (effect).* The Doppler principle describes the apparent variation in frequency of a light or a sound wave as the source of the wave approaches or moves away, relative to an observer. The traditional example that is given to describe this physical phenomenon is the apparent change in sound level of a train as the train approaches and then departs a station. The sound seems higher in pitch as the train approaches the station and seems lower in pitch as the train departs the station. This apparent change in sound pitch, or what is termed the frequency shift, is proportional to the speed of movement of the sound-emitting source, the train in this example. It is important to note that the actual sound of the train is not changing; it is the perception of change in sound to a stationary observer that determines the "Doppler effect". In clinical applications, when ultrasound with a certain frequency (f_o) is used to insonate a certain blood vessel, the reflected frequency (f_d) or frequency shift is directly proportional to the speed with which the red blood cells are moving (blood flow velocity) within that particular vessel. This frequency shift of the returning signal is displayed in a graphic form as a time-dependent plot. In this display, the vertical axis represents the frequency shift and the horizontal axis represents the temporal change of this frequency shift as it relays to the events of the cardiac cycle (**Figure 1.10**). This frequency shift is highest during systole, when the blood flow is fastest and lowest during end diastole, when the blood flow is slowest in the peripheral circulation (**Figure 1.10**). Given that the velocity of flow in a particular vascular bed is inversely proportional to the downstream impedance to flow, the frequency shift therefore derives information on the downstream impedance to flow of the vascular bed under study. The frequency shift is also dependent on the cosine of the angle that the ultrasound beam makes with the targeted blood vessel (see formula in **Figure 1.10**). Given that the insonating angle (angle of incidence) is difficult to measure in clinical practice, indices that rely on ratios of frequency shifts were developed to quantitate Doppler waveforms. By relying on ratios of frequency shifts, these Doppler indices are thus independent of the effects of the insonating angle of the ultrasound beam. Doppler indices that are commonly used in obstetric and gynecologic practice are shown in (**Figure 1.11**).

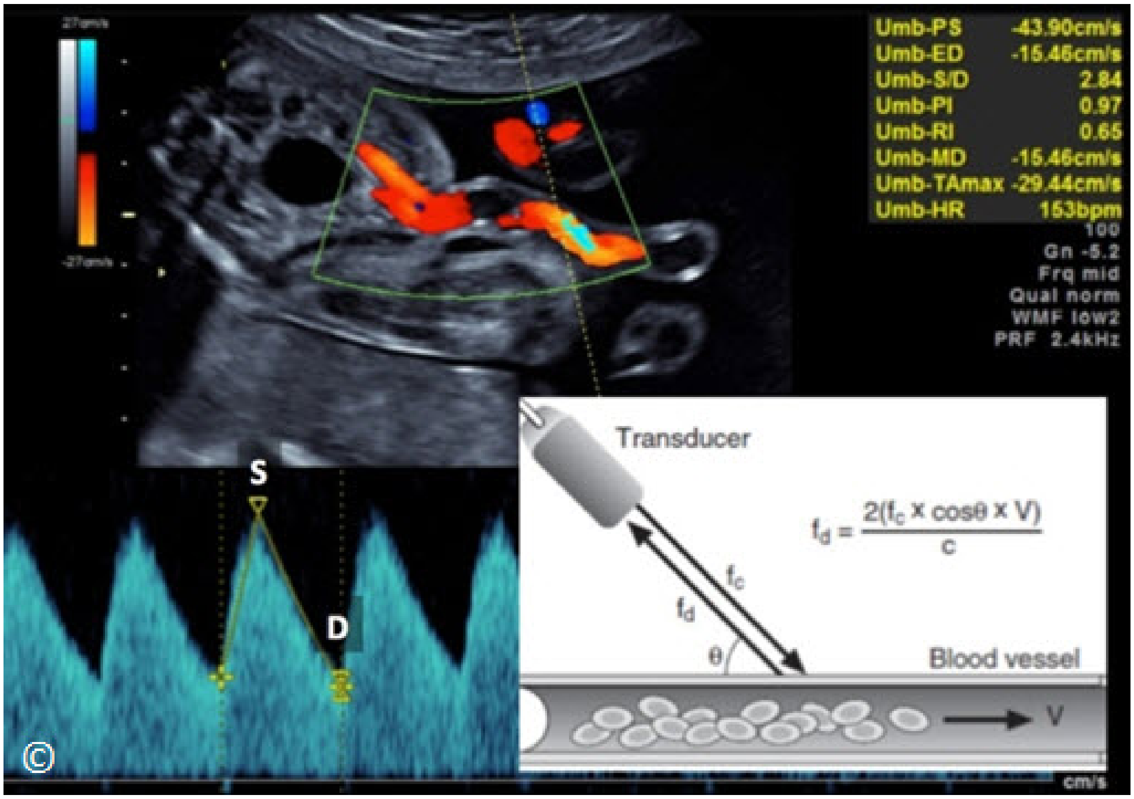

Figure 1.10: Doppler velocimetry of the umbilical artery at the abdominal cord insertion. "S" corresponds to the frequency shift during peak systole and "D" corresponds to the frequency shift during end diastole. The Doppler effect formula is also shown in white background. (Schematic of Doppler formula modified with permission from *A Practical Guide to Fetal Echocardiography Normal and Abnormal Hearts* – Abuhamad, Chaoui, second edition – Wolters Kluwer.

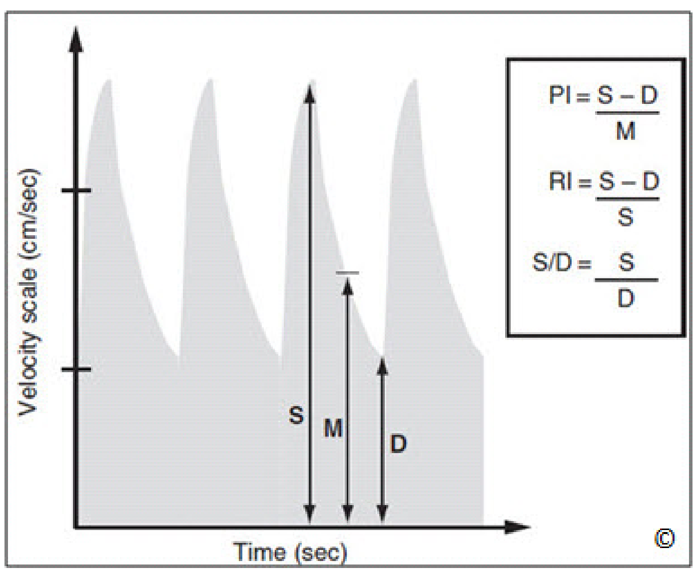

Figure 1.11: Doppler waveforms formulas that are commonly used in obstetrics and gynecology. PI = pulsatility index, RI = resistive index, S = peak systolic frequency shift, D = end diastolic frequency shift and M = mean frequency shift. Reproduced with permission from *A Practical Guide to Fetal Echocardiography: Normal and Abnormal Hearts* – Abuhamad, Chaoui, second edition – Wolters Kluwer.

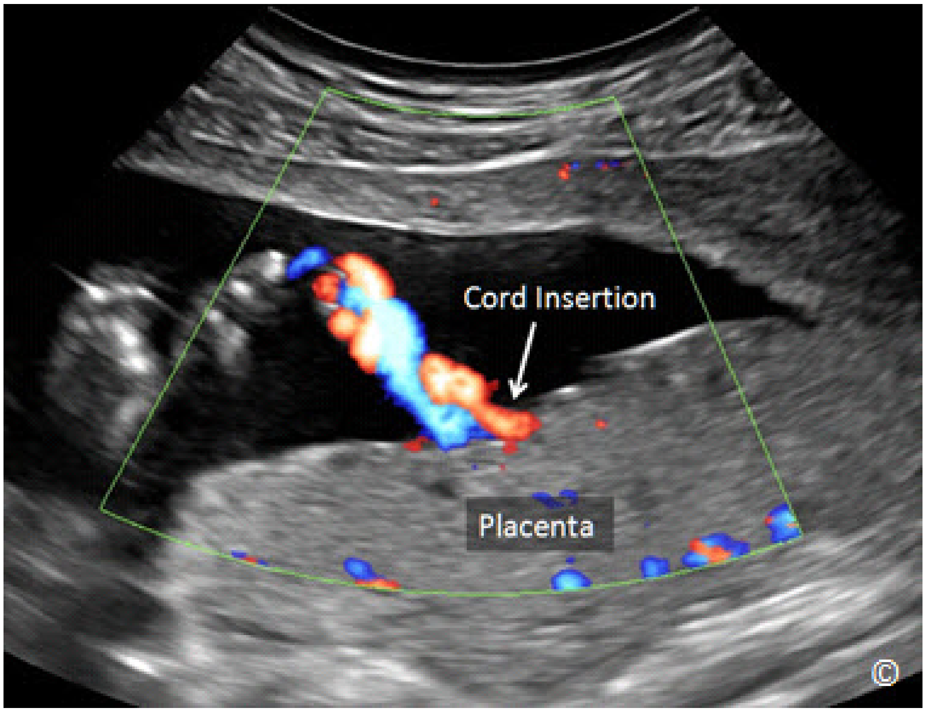

Figure 1.12: Color Doppler mode of the cord insertion into a posterior placenta. Blood in the umbilical vein is colored red (towards the transducer) and blood in the umbilical arteries is colored blue (away from the transducer).

Color Doppler mode or Color flow mode is a mode that is superimposed on the real-time B-mode image. This mode is used to detect the presence of vascular flow within the tissue being insonated (**Figure 1.12**). By convention, if the flow is towards the transducer it is colored red and if the flow is away from the transducer it is colored blue. The operator controls various parameters of color Doppler such as the velocity scale or pulse repetition frequency (PRF), wall filter, size of the area within the field of B-mode and the angle of incidence that the ultrasound beam makes with the direction of blood flow. Low velocity scales and filters are reserved for low impedance vascular beds such as ovarian flow in gynecology (**Figure 1.13**) and high velocity scales and filters are reserved for high impedance circulation such as cardiac outflow tracts **(Figure 1.14)**. In order to optimize the display of color Doppler, the angle of insonation should be as parallel to the direction of blood flow as possible. If the angle of insonation approaches ninety degrees, no color flow will be displayed given that the "Doppler effect" is dependent on the cosine of the angle of insonation, and cosine of 90 degrees is equal to zero (**Figure 1.15**).

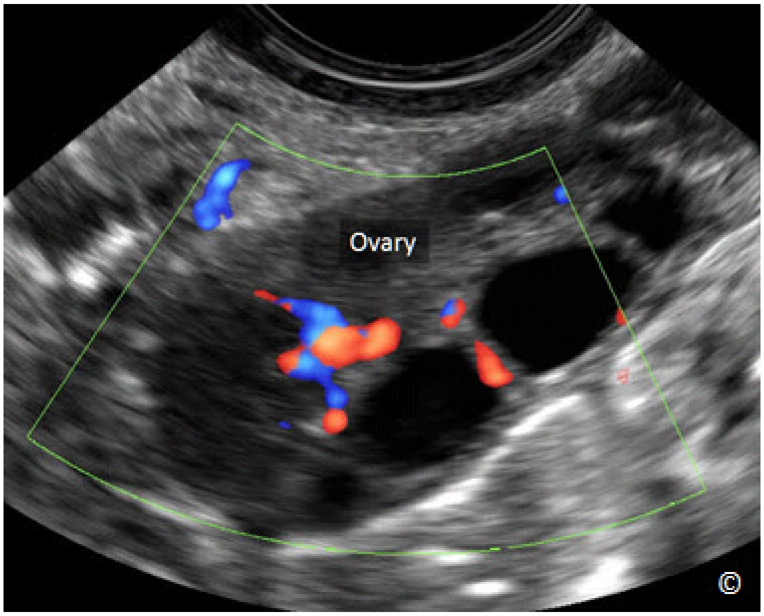

Figure 1.13: Color Doppler mode of blood flow within the ovary (labeled). Typically ovarian flow is low impedance and detected on low velocity scale with low filter setting.

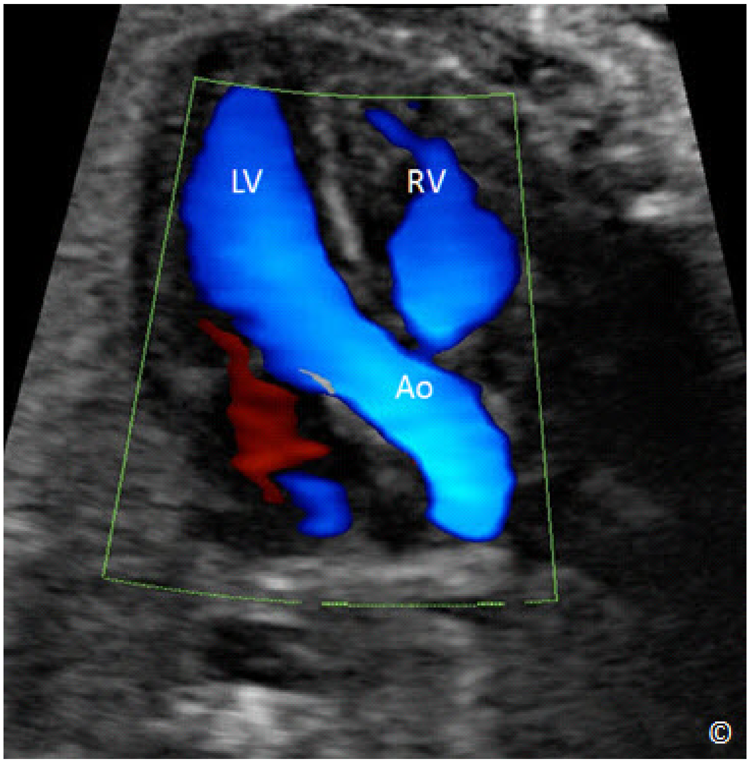

Figure 1.14: Color Doppler mode of left ventricular outflow in the fetal heart. Blood flow in the fetal heart has high velocity and thus is detected on high velocity scale. LV=left ventricle, RV=right ventricle, Ao=aorta.

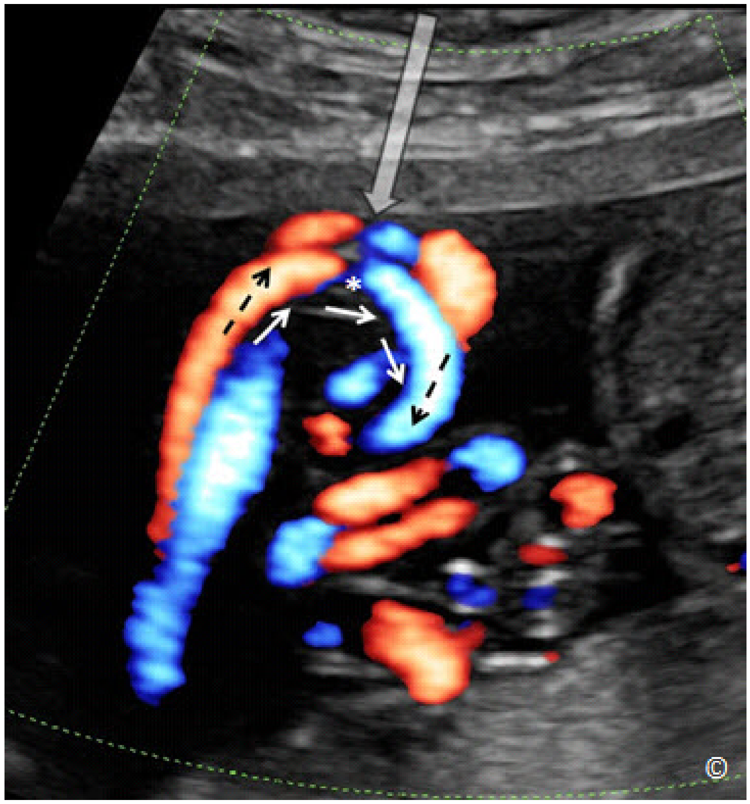

Figure 1.15: Blood flow in an umbilical cord showing the Doppler Effect. White arrows show the direction of blood flow. Note the absence of blood flow on color Doppler (asterisk) where the ultrasound beam (grey arrow) images the cord with an angle of insonation equal to 90 degrees. The black arrows represent blood flow with an angle of insonation almost parallel to the ultrasound beam and thus display the brightest color corresponding to the highest velocities.

In the spectral Doppler mode, or pulsed Doppler mode, quantitative assessment of vascular flow can be obtained at any point within a blood vessel by placing a sample volume or the gate within the vessel **(Figure 1.16)**. Similar to color Doppler, the operator controls the velocity scale, wall filter and the angle of incidence. Flow towards the transducer is displayed above the baseline and flow away from the transducer is displayed below the baseline. In spectral Doppler mode, only one crystal is typically necessary and it alternates between sending and receiving ultrasound pulses.

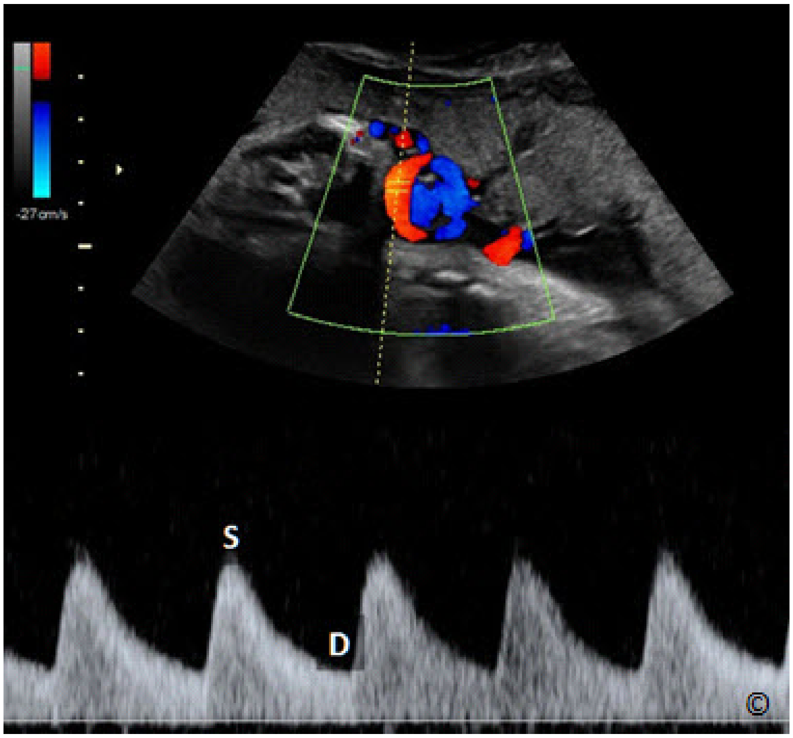

Figure 1.16: Pulsed Doppler mode of the umbilical artery. S corresponds to the frequency shift during peak systole and D corresponds to the frequency shift at end diastole.

Doppler mode, or Energy mode, or High Definition Doppler mode is a sensitive mode of Doppler that is available on some high-end ultrasound equipment and is helpful in the detection of low velocity flow **(Figure 1.17)**. The strength (amplitude) of the reflected signal is primarily processed. Power Doppler mode is less affected by the angle of insonation than the traditional color or spectral Doppler.

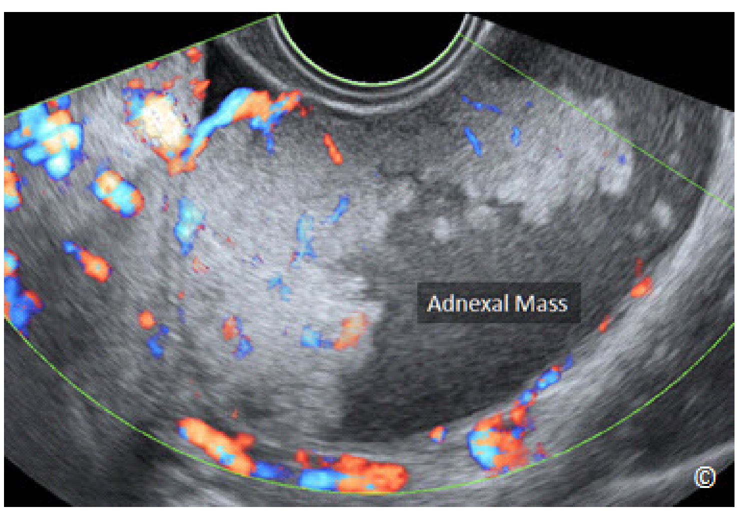

Figure 1.17: Power Doppler mode showing vascularity within a borderline ovarian tumor. Power Doppler mode is helpful in the detection of low velocity flow.

WHAT ARE THE BIOEFFECTS OF ULTRASOUND?

Ultrasound is a form of mechanical energy and its output varies based upon the mode applied. In general B-mode has the lowest energy and pulsed Doppler has the highest energy. Given the presence of a theoretical and potential harm of ultrasound, the benefit to the patient must always outweigh the risk. In general, ultrasound is considered to be a safe imaging modality as compared to other imaging modalities that have ionizing radiation like X-ray and Computed Tomography (CT). There are 2 important indices for measurement of bioeffects of ultrasound; the Thermal Index (TI) and the Mechanical Index (MI). The Thermal Index is a predictor of maximum temperature increase under clinically relevant conditions and is defined as the ratio of the power used over the power required to produce a temperature rise of 1° C. The TI is reported in three forms; TIS or Thermal index Soft tissue, assumes that sound is traveling in soft tissue, TIB or Thermal index Bone, assumes that sound is at or near bone, TIC, or Thermal index Cranial assumes that the cranial bone is in the sound beam's near field. The Mechanical index (MI) gives an estimation of the cavitation effect of ultrasound, which results from the interaction of sound waves with microscopic, stabilized gas bubbles in the tissues. Other effects included in this category are physical (shock wave) and chemical (release of free radicals) effects of ultrasound on tissue.

In 1992, the Output Display Standard (ODS) was mandated for all diagnostic ultrasound devices. In this ODS, the manufacturers are required to display in real time, the TI and the MI on the ultrasound screen with the intent of making the user aware of bioeffects of the ultrasound examination (**Figure 1.18**). The user has to be aware of the power output and make sure that reasonable levels are maintained. Despite the lack of scientific reports of confirmed harmful bioeffect from exposure to diagnostic ultrasound, the potential benefit and risk of the ultrasound examination should be assessed and the principle of ALARA should be always followed. The ALARA principle stands for As Low As Reasonably Achievable when adjusting controls of the ultrasound equipment in order to minimize the risk. Always keep track of the TI and MI values on the ultrasound screen, and keep the TI below 1 and MI below 1 for obstetrical ultrasound imaging.

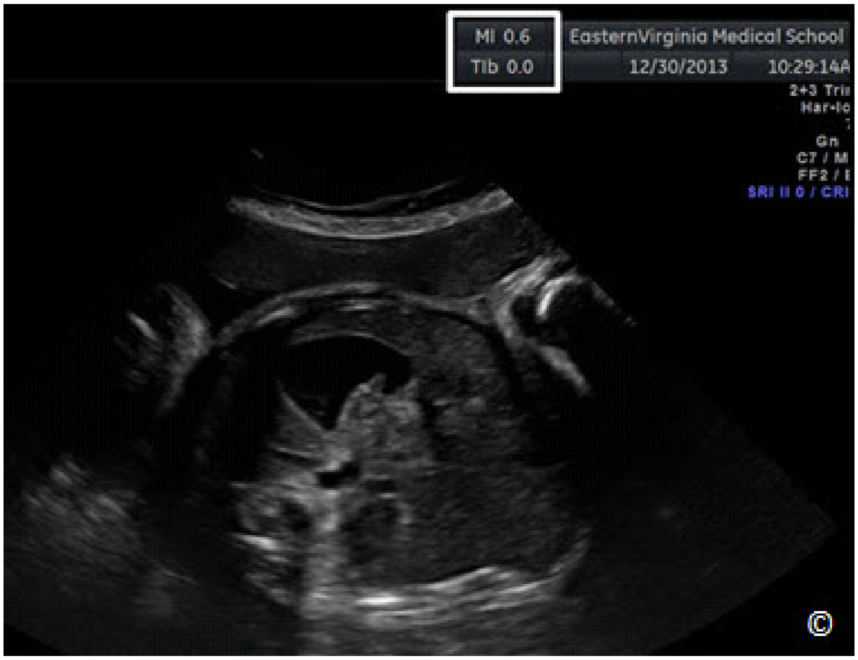

Figure 1.18: An ultrasound examination of the fetal abdomen in the third trimester of pregnancy. Note the display of MI and TIb in white rectangle. MI= Mechanical Index and TIb=Thermal Index bone.

WHAT ARE SOME RELEVANT OFFICIAL STATEMENTS FROM ULTRASOUND SOCIETIES?

Several national and international societies have official statements that relates to the use of medical ultrasound in obstetrics and gynecology. We have assembled in this chapter some of the relevant official statements along with the Internet link to their source. It is important to note that official societal statements tend to be updated from time to time and the reader should consult with the society's website for the most recent version.

International Society of Ultrasound in Obstetrics and Gynecology (ISUOG) (www.ISUOG.org)

ISUOG- Statement on the safe use of Doppler in the 11 to 13+6-week fetal ultrasound examination (1):

1) Pulsed Doppler (spectral, power and color flow imaging) ultrasound should not be used routinely.
2) Pulsed Doppler ultrasound may be used for clinical indications such as to refine risks for trisomies.

3) When performing Doppler ultrasound, the displayed thermal index (TI) should be ≤1.0 and exposure time should be kept as short as possible (usually no longer than 5–10 min) and should not exceed 60 min.
4) When using Doppler ultrasound for research, teaching and training purposes, the displayed TI should be ≤1.0 and exposure time should be kept as short as possible (usually no longer than 5–10 min) and should not exceed 60 min. Informed consent should be obtained.
5) In educational settings, discussion of first-trimester pulsed or color Doppler should be accompanied by information on safety and bioeffects (e.g. TI, exposure times and how to reduce output power)
6) When scanning maternal uterine arteries in the first trimester, there are unlikely to be any fetal safety implications as long as the embryo/fetus lies outside the Doppler ultrasound beam.

ISUOG- Safety Statement, 2000 (reconfirmed 2003) (2):

The thermal index (TI) and the mechanical index (MI) are not perfect indicators of the risks of thermal and nonthermal bioeffects, but currently they should be accepted as the most practical and understandable methods of estimating the potential for such risks.

B-mode and M-mode
Acoustic outputs are generally not high enough to produce deleterious effects. Their use therefore appears to be safe, for all stages of pregnancy.

Doppler Ultrasound
Significant temperature increase may be generated by spectral Doppler mode, particularly in the vicinity of bone. This should not prevent use of this mode when clinically indicated, provided the user has adequate knowledge of the instrument's acoustic output, or has access to the relevant TI. Caution is recommended when using color Doppler mode with a very small region of interest, since this mode produces the highest potential for bioeffects. When ultrasound examination is clinically indicated, there is no reason to withhold the use of scanners that have received current Food and Drug Administration clearance in tissues, which have no identifiable gas bodies. Since ultrasound contrast agents are mostly gas-carriers, the risk of induction and sustenance of inertial cavitation is higher in circumstances when these agents are employed.

Pregnancy
Based on evidence currently available, routine clinical scanning of every woman during pregnancy using realtime B-mode imaging is not contraindicated. The risk of damage to the fetus by teratogenic agents is particularly great in the first trimester. One has to remember that heat is generated at the transducer surface when using the transvaginal approach. Spectral and color Doppler may produce high intensities and routine examination by this modality during the embryonic period is rarely indicated. In addition, because of high acoustic absorption by bone, the potential for heating adjacent tissues must also be kept in mind. Exposure time and acoustic output should be kept to the lowest levels consistent with obtaining diagnostic information and limited to medically indicated procedures, rather than for purely entertainment purposes.

Education

Education of ultrasound operators is of the utmost importance since the responsibility for the safe use of ultrasound devices is now shared between the users and the manufacturers, who should ensure the accuracy of the output display.

ISUOG-Statement on the non-medical use of ultrasound (2009) (3):

The International Society of Ultrasound in Obstetrics and Gynecology (ISUOG) and World Federation of Ultrasound in Medicine and Biology (WFUMB) disapprove of the use of ultrasound for the sole purpose of providing souvenir images of the fetus. There have been no reported incidents of human fetal harm in over 40 years of extensive use of medically indicated and supervised diagnostic ultrasound. Nevertheless, ultrasound involves exposure to a form of energy, so there is the potential to initiate biological effects. Some of these effects might, under certain circumstances, be detrimental to the developing fetus. Therefore, the uncontrolled use of ultrasound without medical benefit should be avoided. Furthermore, ultrasound should be employed only by health professionals who are trained and updated in the clinical usage and bioeffects of ultrasound.

American Institute of Ultrasound in Medicine (AIUM) (www.AIUM.org)

AIUM-As Low As Reasonably Achievable (ALARA) Principle (2008) (4):

The potential benefits and risks of each examination should be considered. The ALARA (As Low As Reasonably Achievable) Principle should be observed when adjusting controls that affect the acoustical output and by considering transducer dwell times. Further details on ALARA may be found in the AIUM publication "Medical Ultrasound Safety.

AIUM-Conclusions Regarding Epidemiology for Obstetric Ultrasound (2010) (5):

Based on the epidemiologic data available and on current knowledge of interactive mechanisms, there is insufficient justification to warrant conclusion of a causal relationship between diagnostic ultrasound and recognized adverse effects in humans. Some studies have reported effects of exposure to diagnostic ultrasound during pregnancy, such as low birth weight, delayed speech, dyslexia and non-right-handedness. Other studies have not demonstrated such effects. The epidemiologic evidence is based primarily on exposure conditions prior to 1992, the year in which acoustic limits of ultrasound machines were substantially increased for fetal/obstetric applications

AIUM-Prudent Use and Clinical Safety (2012) (6):

Diagnostic ultrasound has been in use since the late 1950s. Given its known benefits and recognized efficacy for medical diagnosis, including use during human pregnancy, the American Institute of Ultrasound in Medicine herein addresses the clinical safety of such use:

No independently confirmed adverse effects caused by exposure from present diagnostic ultrasound instruments have been reported in human patients in the absence of contrast agents. Biological effects (such as localized pulmonary bleeding) have been reported in mammalian systems at diagnostically relevant exposures but the clinical significance of such effects is not yet known. Ultrasound should be used by qualified health professionals to provide medical benefit to the patient. Ultrasound exposures during examinations should be as low as reasonably achievable (ALARA).

AIUM-Prudent Use in Pregnancy (2012) (7):

The AIUM advocates the responsible use of diagnostic ultrasound and strongly discourages the non-medical use of ultrasound for entertainment purposes. The use of ultrasound without a medical indication to view the fetus, obtain images of the fetus, or determine the fetal gender is inappropriate and contrary to responsible medical practice. Ultrasound should be used by qualified health professionals to provide medical benefit to the patient.

AIUM-Statement on Measurement of Fetal Heart Rate (2011) (8):

When attempting to obtain fetal heart rate with a diagnostic ultrasound system, AIUM recommends using M-mode at first, because the time-averaged acoustic intensity delivered to the fetus is lower with M-mode than with spectral Doppler. If this is unsuccessful, spectral Doppler ultrasound may be used with the following guidelines: use spectral Doppler only briefly (e.g. 4-5 heart beats) and keep the thermal index (TIS for soft tissues in the first trimester, TIB for bones in second and third trimesters) as low as possible, preferably below 1 in accordance with the ALARA principle.

References:

1) International Society of Ultrasound in Obstetrics and Gynecology official statement on the Safe use of Doppler in the 11 to 13+6 week fetal ultrasound examination. UOG: Volume 37, Issue 6, Date: June 2011, Page: 628
2) International Society of Ultrasound in Obstetrics and Gynecology official statement on Safety. UOG: Volume 21, Issue 1, Date: January 2003, Page: 100
3) International Society of Ultrasound in Obstetrics and Gynecology official statement on Non-Medical use of ultrasound. UOG: Volume 33, Issue 5, Date: May 2009, Page: 617
4) American Institute of Ultrasound in Medicine official statement on http://www.aium.org/officialStatements/39
5) American Institute of Ultrasound in Medicine official statement on As Low As Reasonably Achievable principal; 2008. http://www.aium.org/officialStatements/16
6) American Institute of Ultrasound in Medicine official statement on Conclusions regarding epidemiology for obstetric ultrasound; 2010 http://www.aium.org/officialStatements/34

7) American Institute of Ultrasound in Medicine official statement on Prudent use in pregnancy; 2012. http://www.aium.org/officialStatements/33
8) American Institute of Ultrasound in Medicine official statement on Measurement of fetal heart rate; 2011. http://www.aium.org/officialStatements/43