Basic principles and safety of diagnostic ultrasound in obstetrics and gynecology

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INTRODUCTION — The term "ultrasound" refers to sound waves of a frequency greater than that which the human ear can appreciate, namely frequencies greater than 20,000 cycles per second. For diagnostic ultrasound imaging in obstetrics and gynecology, frequencies of 2 to 12 million cycles per second are used. Ultrasound imaging has been used for medical purposes for several decades and is safe when properly performed [1].

Understanding the physical principles underlying ultrasound technology can help the sonographer optimize image quality, and thus improve diagnostic capabilities. This information is also vital for maintaining the safety of this technology for the woman and, during obstetrical examinations, her fetus.

SOUND WAVES — Sound waves are a type of mechanical vibration. They are described in terms of their frequency, which is the number of repetitions (ie, cycles) per second. The unit for measuring frequency is the Hertz (Hz). Other characteristics of sound waves are wavelength, the distance between excitations; the amplitude of excitation, measured in decibels (dB); and the period, the time it takes for one cycle to occur, measured in seconds.

The speed with which an acoustic wave moves through a medium is dependent upon the density and resistance of the medium. Media that are dense will transmit a mechanical wave with greater speed than those that are less dense. As an example, the acoustic speed of a mechanical wave through air is 331 meters/second; through water, it is 1495 meters/second; through soft tissue, it is 1540 meters/second; and through bone, it is 4080 meters/second [2].

Frequency and wavelength are mathematically related to the velocity of the ultrasound beam within the tissue as indicated by the following equation:

Velocity = Wavelength (mm) x frequency (Hz)

Ultrasound is an ideal means for imaging soft tissues and fluid collections typically evaluated by obstetrician-gynecologists. Given the known speed of sound in water and soft tissue, measuring the transit time between initiation of the mechanical pulse and its return can be used to determine the depth, size, and characteristics of the anatomic structure under study.

INTERACTION OF ULTRASOUND WAVES WITH TISSUES — When an ultrasonic wave travels through a homogeneous medium, its path is a straight line. However, when the medium is not homogeneous or when the wave travels through a medium with two or more interfaces, its path is altered. The relationship between ultrasound waves and tissues can be described in terms of reflection, scattering, refraction, and attenuation. The last three factors all act to decrease the magnitude of the ultrasound wave.

Reflection — When an ultrasound beam "hits" a tissue boundary/interface, a certain amount of the ultrasound is reflected back to the transducer. The magnitude of the reflected wave is dependent on the acoustic impedance of the tissue:

Acoustic impedance = tissue density x propagation velocity

Tissues with increased density reflect a greater proportion of the ultrasound beam. The most intense reflection occurs when air is encountered. Air has an impedance dramatically lower than any other tissue in the body and diagnostic ultrasound imaging is unable to penetrate air-containing structures such as bowel. In contrast, the ultrasound beam is virtually completely transmitted through fluid and few or no echoes are produced.

The magnitude of the reflected beam received by the transducer is also dependent upon the angle between the ultrasound beam and tissue interface. Since the angle of incidence equals the angle of reflection, the "optimal" return of the reflected ultrasound occurs at a 90º (perpendicular) orientation.

Scattering — Small structures, eg, less than 1 wavelength in lateral dimension, result in scattering of the ultrasound signal. Unlike a reflected beam, scattering results in the ultrasound beam being radiated in all directions, with minimal signal returning to the transducer.

Echoes returning to the transducer are "back-scattered" echoes because they are dependent upon reflection and scattering. The degree of strength of the returning echoes is translated into varying shades of brightness, which is the basis for B-mode display of ultrasound data. Gray-scale imaging is vitally dependent upon the relative intensity of these "back-scattered" echoes.

Refraction — Ultrasound waves can be refracted, or deflected, from their orientation as they pass into a medium of different acoustic impedance.

Attenuation — During transmission, ultrasound signal strength is progressively reduced due to absorption of the ultrasound energy by conversion to heat, a process called attenuation. Attenuation is frequency and wavelength dependent. The depth of penetration is limited to approximately 200 wavelengths, corresponding to a depth of 30 cm for a 1 MHz transducer, 12 cm for 2.5 MHz transducer, and 6 cm for a 5 MHz transducer.

Attenuation is also dependent upon acoustic impedance and any mismatch in impedance between adjacent structures. Any tissue with high impedance, such as bone, will lead to increased attenuation of the ultrasound beam. Those tissues with low impedance, such as water, will allow the ultrasound beam to continue to be transmitted, and will result in less attenuation. An easy rule of thumb is that bone absorbs approximately 10 times that of soft tissues, and soft tissues absorb approximately 10 times more than fluids [2].

Artifacts — Given the rules of physics, as noted above, and heterogeneity of human tissue, ultrasound interrogation results in many possible variations in the displayed image. Some of these displayed images will vary based on well-recognized artifacts of ultrasound imaging. Intimate knowledge of how ultrasound interacts with tissue and the artifacts that can occur is fundamental to properly assess ultrasound-generated images. A complete list of artifacts is beyond the scope of this topic, but some of the most important artifacts encountered in obstetrical and gynecologic imaging are briefly described below:

- Shadowing occurs when there is a particularly strong reflector or attenuator leading to a diminished ultrasound beam with the resultant loss of imaging data distal to the reflector or attenuator. This is commonly seen in the third trimester fetus with progressive mineralization of the fetal bones.

- Increased through transmission occurs when there is less attenuation than surrounding tissues, typically due to a fluid-filled structure such as a cyst. Understanding through transmission is essential for differentiating solid versus cystic ovarian masses.

- Reverberation artifacts occur when two or more intensely reflective interfaces cause the ultrasound beam to echo, potentially causing echoes to appear in cystic structures, simulating solid elements. Changing the path of the ultrasound beam may eliminate this artifact.

- Refraction artifacts occur when a change in the tissue being insonated results in non-linear bending of the sound waves. Because the ultrasound software assumes that the beam travels in a straight line, it does not correctly locate the source of the bent wave. The resulting artifact may incorrectly widen the source structure or may cause a false duplication of the source structure.

TRANSDUCERS — Ultrasound waves are generated from piezoelectric crystals, which consistently produce high frequency ultrasound waves when electrically stimulated. Applying an electrical potential to piezoelectric crystals causes the crystals to mechanically deform, and this deformation leads to formation of an acoustic wave. This is known as the piezoelectric effect. Natural crystals, especially quartz, were used for many years to generate ultrasound waves, but now synthetic crystals or ceramics are more commonly used. These crystals have a thickness of less than 1 mm.

Piezoelectric crystals are arranged in various ways at the core of the ultrasound transducer. Each transducer crystal functions as both a transmitter and receiver of mechanical energy. The transmitted mechanical pulse lasts approximately one microsecond, thus 1000 mechanical pulses can be sent in one second. The crystal then waits to receive the returning echoes, which it converts back into electrical energy. The strength of this signal is directly dependent on the amplitude of the returning wave. Display of these returning electrical signals (echoes) creates the images used in diagnostic sonography [2,3].

Two methods of electronic excitation of the crystals are used. Multiplexing involves exciting a crystal or a small group of crystals, and awaiting the returning echoes prior to exciting the next group of crystals. These images are typically rectangular in configuration. With phased array excitation, the crystals are stimulated all at once as a unit with slight delay between each crystal. The image produced is that of a sector scan [2].

The arrangement of the crystals and method of excitation of the crystals alter the image displayed and affect the type of obtainable information. The shape of the transducer also significantly alters the qualities of the image and affects visualization of various tissues. During an ultrasound examination, it may be necessary to use multiple transducers to evaluate different structures of interest [4].

- Linear array transducers display the image in a rectangular shape, mimicking the long, slender appearance of these transducers. These transducers are optimal for evaluating structures in the near field.

- Sector scanners display the obtained image in a pie shape with the tip towards the transducer. They are generally rather narrow and small in configuration. As the near field is quite narrow, sector transducers are better at evaluating deeper structures, especially when there are impediments to viewing in the near field, such as ribs.
- Vector transducers are similar to the sector transducers, but have the pie shaped tip removed. This transducer allows more visualization in the near field than the sector scanner.
- Curved array transducers are a combination of the linear array and vector transducers. These transducers are wide with a narrow curve. They allow a larger near field with a retained large far field.

RESOLUTION — Resolution refers to the ability to distinguish between two closely related structures and varies directly with the frequency and inversely with the wavelength. Diagnostic ultrasound uses wavelengths of 0.1 to 1.5 mm. If two separate structures are closer than one wavelength apart, then they will not be identified as separate. Therefore, smaller wavelengths are associated with improved resolution [2]. High frequency, short wavelength ultrasound can separate objects that are less than 1 mm apart.

Given the interrelationship of acoustic speed, wavelength, and frequency, smaller wavelengths with improved resolution are associated with higher frequencies. The downside of the better resolution achieved with higher frequencies is lack of penetration of the ultrasound beam. Therefore, the sonologist chooses the transducer with the highest frequency that has the penetration necessary to visualize a particular anatomic structure. Frequencies of ultrasound probes that are used in medicine range from 1 to 20 MHz, with those in obstetrics and gynecology typically in the 2 to 12 MHz range.

Resolution is described as axial or lateral:

- Axial resolution is the ability to distinguish between two structures that are in the same direction as the acoustic wave. The axial resolution is equal to half of the spatial pulse length. Any adjacent structures that are closer than half of the spatial pulse length will not be able to be distinguished as separate structures. Axial resolution will be improved if the pulse frequency is increased, if there is a decrease in wavelength, or number of cycles in a single pulse.
- Lateral resolution refers to distinguishing between two closely located adjacent structures that are perpendicular to the acoustic wave. Lateral resolution is equal to the diameter of the ultrasound beam. This distance can vary with the depth from the transducer. A structure that is smaller than the beam diameter may be detected, but its exact location within the ultrasound beam will not be able to be determined. A smaller beam diameter will improve lateral resolution. Increasing frequency can also improve lateral resolution [5].

DISPLAY — The electrical signals of the echoes are amplified and displayed on a monitor. There are various methods for displaying these data, but ultrasound in obstetrics and gynecology relies on the use of B-mode. The display can be static or in real-time. Static images show the distance from the transducer to various interfaces or tissues, the spatial locations of specific interfaces, and the physical or anatomic characteristics of the specific interfaces. Real-time imaging also provides temporal relations of these interfaces [6].

A-mode — A-mode, or amplitude modulation, has not been widely used in ultrasound in obstetrics and gynecology. The returning echo causes a vertical deflection whose amplitude is used to calculate the depth of the interface.

A-mode is the oldest and most basic imaging modality. A cathode ray tube is used to display the position of the boundaries of the insonated tissue. As this technique only displays data in one dimension, it has limited uses. As an example, ophthalmologists may use it for determining the thickness of the cornea.

B-mode — B-mode imaging, or brightness modulation, is the basis for imaging in obstetrics and gynecology. Instead of the vertical deflections used in A-mode, B-mode displays the varying intensities of the returning echoes as varying degrees of brightness. The brightness of the amplitudes in B-mode is represented as pixels. Echoes with greater intensity are displayed with greater degrees of brightness. B-scans use B-mode data and display it in two dimensions, providing a static gray-scale ultrasound image.

Static B-scans have been replaced in modern usage by real-time imaging, which has the advantage of much more rapid acquisition of images, and the ability to evaluate movement. The transducer can be moved to whichever position can obtain the best image, and there is no need for the exact position of the transducer to be known to obtain an image as with static B-scan. A single image or frame can be obtained with ease. Frame rates of at least 15 per second are generally considered a minimum for real-time imaging [2].

M-mode — M-mode, or motion modulation, is useful in cardiology, as well as in obstetrics and gynecology. M-mode imaging is B-mode with a continuous update of the returning echoes. This forms a sequence of B-mode that shows changes over time. Evaluation of the heart is especially amenable to this type of imaging. (See "Echocardiography essentials: Physics and instrumentation".)

Compact, portable ultrasound systems — Over the past decade, ultrasound units have progressively become smaller and are now available as laptop-sized and hand-held systems [7]. These portable ultrasound systems can be used easily at the bedside, and make ultrasound more available to users in low resource settings [8,9]. Their performance has also compared favorably with full-size ultrasound units [10].

Of potential concern is the relative lack of data regarding the safety of these newer units and the knowledge and training of those who are novel users. Duration of examinations, power output, and a thorough understanding of the physics of ultrasound use are a few of the issues that demand further attention commensurate with the increased availability and use of these compact systems.

ENERGY OUTPUT MEASUREMENT — The concept of using the lowest amount of energy possible for obtaining the necessary diagnostic information from diagnostic ultrasound is the ALARA principle (as low as reasonably achievable) [11]. The acoustic output of modern ultrasound machines can be measured via two measurements displayed on the monitor: TI and MI [12].

TI — TI is an estimate of the degree of temperature elevation. A TI of 1 indicates a power causing a temperature increase of 1ºC. If TI is below 1.0, then temperature elevation is not a significant factor. If TI is above 1.0, there is a chance for temperature elevation of the insonated tissue. For this reason, special care should be taken in febrile patients since the effects of ultrasound heating and fever are additive.

The World Federation for Ultrasound in Medicine and Biology concluded a diagnostic exposure that produces a maximum temperature rise of no more than 1.5ºC above normal physiological levels (37ºC) may be used without reservation on thermal grounds [13,14]. To be considered potentially hazardous on thermal grounds, it appears that a diagnostic ultrasound exposure must elevate embryonic and fetal in situ temperatures to the following temperatures for approximately the corresponding durations [15]:

- 39 ºC (2 degrees above normal), 60 minutes
- 40 ºC (3 degrees above normal), 15 minutes
- 41 ºC (4 degrees above normal), 4 minutes
- 42 ºC (5 degrees above normal), 1 minute
- 43 ºC (6 degrees above normal), 0.25 minutes

As the presence of bone will greatly affect the calculation of the TI, three different subsets of the TI have been developed. Of the three, Thermal index soft tissue (TIS) and Thermal index bone (TIB) are important in ultrasound examinations in obstetrics and gynecology.

TIS is the soft tissue TI and is used in the absence of bone. TIB is the bone TI and is used when bone is at or near the focus, or the area of interest. Thermal index cranial (TIC) is the cranial TI and is used when the ultrasound probe is close to bone, as during intracranial examinations. The TIC is typically only displayed during adult transcranial examinations.

As bone is an important factor in the conversion of ultrasound waves to thermal energy, the TIS would be used for the early embryo of less than 10 weeks menstrual age because of the lack of calcification of the early bone. After this time, the TIB should be used throughout pregnancy. As the early embryo is undergoing a rapid degree of cell division and differentiation during embryogenesis, great care during ultrasound examinations should be maintained for this time period.

MI — MI is an estimate of the compressive and decompressive mechanical effects of ultrasound pulses, which can potentially result in cavitation. An MI of less than 1.0 is not a concern. If MI is greater than 1.0, then adverse effects may result [12]. The FDA imposes an upper limit of 1.9 for the MI. Given that there is a lack of gas within human fetuses, the risk for cavitation, as indicated by the MI, is thought to be negligible [16].

Temperature rise is dependent on tissue type and is particularly dependent on the presence of bone, where the temperature increase is highest. Exposure can be reduced by either reducing the TI or MI using output controls or by reducing the dwell time, the amount of time that the transducer remains in one place.

When the ultrasound probe is not actively being used to obtain medical information, it should be removed from the patient. The image should also be frozen if not in active use. Local heating of ultrasound probes can be a factor, especially with transvaginal sonography in early pregnancy. If a transvaginal probe produces noticeable heat, its use during early pregnancy must proceed with caution.

The power output from transducers especially affects tissue in close proximity to the transducer. This fact makes insonation of the early pregnancy with a transvaginal ultrasound probe a situation of particular significance. Although temperature increases at depths greater than one centimeter are likely to be clinically insignificant [17], unnecessary examinations during early pregnancy should be avoided.

External fetal heart rate monitors — For fetal heart rate monitors, the maximum attainable value of spatial average, temporal average intensity at the transducer face should be less than 20 mW/cm2 for continuous wave devices and the maximum attainable value of the spatial average, pulse average intensity at the transducer face should be less than 20 mW/cm2 for pulsed devices [15]. With these limits for fetal heart rate monitors, a TI display would not generally be required under the ODS.

SAFETY — Almost as soon as ultrasound began being used in pregnancy, concerns of its safety for the fetus were raised. Studies applying extreme levels of ultrasound exposure to rodents suggested potentially harmful effects [18]. No significant adverse effects have been identified in children followed for several years after birth [19]. Nevertheless, continuing review of safety issues is important. The use of ultrasound in pregnancy should be reserved for clear indications for its performance and the scans should be performed over the shortest time and with the lowest output possible to permit adequate diagnostic acuity [20].

Theoretical concerns about thermal effects, cavitation, and vibration — The primary concerns of the use of ultrasound technology are with respect to thermal effects of the insonated tissue, and cavitation of tissue due to the production of gas-filled bubbles [21-23]. The temperature increase with diagnostic ultrasound is less than one degree Celsius at typical acoustic output levels as long as the Thermal Index (TI) is maintained below 1.0. This level of increase is not felt to be clinically significant. Similarly, diagnostic ultrasound used for medical imaging does not appear to cause cavitation at usual obstetrical acoustic output levels as long as the Mechanical Index (MI) is kept below 1.0 (see 'Energy output measurement' above) [12,23].

The ultrasound wave affects the tissue through which it travels by mechanical vibration and heating of this tissue. Mechanical vibration can result in cavitation or the formation of gas bubbles. This is an effect that typically occurs at the interface of tissues and gas. Because there is no gas within the uterus, this is not thought to be a significant factor in obstetrical sonography at the currently used levels of diagnostic sonography.

Thermal effects have the greatest potential for adversely affecting the fetus. Routine B mode, as is used for typical two-dimensional (2D) imaging, does not increase the temperature above the 1 to 1.5 degree Celsius range that is thought to be safe for fetuses, especially those early embryos at the time of embryogenesis. Spectral Doppler ultrasound, however, uses higher energy and focuses the acoustic energy that is created on a much smaller volume of tissue than typical 2D imaging does, and can result in changes in tissue temperature, especially at bone-tissue interfaces. For this reason, Doppler ultrasound should be used with great care, especially early in pregnancy [21,24]. (See "Doppler ultrasound of the umbilical artery for fetal surveillance", section on 'Modalities of Doppler ultrasound'.)

The intensities used in transvaginal examinations are generally lower than those in transabdominal examinations. However, thermal risk can only be assessed by determining the thermal index (TI) in each case.

Effects in humans — The World Health Organization (WHO) systematically reviewed 61 publications reporting data on the safety of B mode or Doppler ultrasound in human pregnancy [25]. These data showed that ultrasonography during pregnancy was **not** associated with adverse maternal/fetal/neonatal outcome, impaired physical or neurological development, increased risk of childhood malignancy, impaired cognitive ability, or mental disease. There was an unexplained weak association between ultrasound and non-right handedness in boys. The weak association with non-right handedness has also been reported in a meta-analysis of follow-up data of 8865 children aged 8 to 14 years from three randomized trials on routine ultrasonography at 15 to 20 weeks of gestation [26].

There were limitations to the WHO data, which prevent a firm conclusion about safety [27]. For example, the studies were observational and assessing bioeffects was not the primary objective, the intensity of ultrasound exposure was not usually measured, ultrasound technology changed over the period these studies were performed, and subtle and longer-term changes could have been missed. Nevertheless, the data are reassuring.

There is no independently confirmed peer-reviewed evidence that in utero exposure to clinical ultrasound can cause development of autism spectrum disorders in childhood [28].

Statements of major organizations

American Institute of Ultrasound in Medicine — With regard to clinical safety, the American Institute of Ultrasound in Medicine has stated, "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" [29].

The American Institute of Ultrasound in Medicine has also acknowledged that "the epidemiologic evidence is based on exposure conditions prior to 1992, the year in which acoustic limits of ultrasound machines were substantially increased for fetal/obstetric applications" [30]. The issue of safety is even more critical currently, as many more applications for ultrasound are being found, and industry is producing more "technically sophisticated devices that provide more diagnostic information" [31]. Continued vigilance for adverse effects through research must be a priority, as the power outputs from ultrasound machines have increased in an attempt to improve visualization, resolution, and diagnostic capabilities.

GUIDELINES FOR CLINICAL USE — A voluntary scheme for on-screen labeling of diagnostic ultrasound devices, known as the output display standard (ODS) was adopted by the American Institute of Ultrasound in Medicine (AIUM) in conjunction with the National Electrical Manufacturers' Association [32]. The fetus may be exposed to higher allowable maximum derated intensity (ie, the attenuation of sound waves in tissue compared to water) when the equipment has a visual indicator of the likelihood of risk of producing biological effects because the allowable maximum derated intensity when such indicators are available is higher than in equipment that does not have an output display (720 mW/cm^2 versus 94 mW/cm^2).

It is the responsibility of the ultrasound operator to be aware of the output displays (MI and TI) and to scan using output levels that are as low as reasonably achievable. Fetuses are increasingly being scanned in the first trimester to identify structural defects. As the first trimester is a time of organogenesis, particular attention must be paid to the thermal and mechanical indices. During first trimester fetal echocardiography, the TI progressively increases from B-mode, to color Doppler, to pulsed-wave Doppler of the fetal heart. Mechanical indices in this same population have maximal acoustic outputs greater than 1 while using B-mode and color Doppler, and vary by the type of ultrasound equipment [33] Therefore, all modes of ultrasound use require constant consideration of the output displays, especially with increased scanning in the first trimester [34].

B-mode and M-mode — B-mode and M-mode imaging operate at acoustic outputs that do not produce harmful temperature rises, therefore, temperature increases are typically not a concern. The lowest available power should be used for the minimum duration of time. If the MI can exceed 1, then, for devices to comply with the ODS, the MI must be given in B-mode.

Doppler — The use of pulsed wave spectral Doppler and color Doppler imaging has become vital for the evaluation of some pregnancies. In contrast to B-mode and M-mode, the use of spectral and color (including power) Doppler ultrasound diagnostic equipment has greater time-averaged intensities, and therefore, the potential to produce biologically-significant temperature rises, particularly in the vicinity of bone. With the increased acoustic output comes more concern for fetal risk. It is particularly important that sonologists who perform Doppler imaging of first trimester pregnancy understand the thermal and mechanical indices involved [35].

Recognizing the importance of the safe use of Doppler sonography in pregnancy, the International Society of Ultrasound in Obstetrics and Gynecology (ISUOG) Clinical Standards Committee (CSC) developed Practice Guidelines and Consensus Statements to provide healthcare practitioners with a consensus-based approach for diagnostic imaging [36,37]. A key point of the guidelines is that, when performing Doppler imaging in the first trimester, the displayed thermal index (TI) should be ≤1.0 and exposure time should be kept as short as possible, usually no longer than 5 to 10 minutes and not exceeding 60 minutes. The minimal power output and duration of Doppler insonation required to obtain diagnostic information from the fetus should be recognized among all sonologists using Doppler imaging as per the ALARA principle discussed above.

The following points will optimize imaging while limiting risks for the fetus [38,39]:

- Doppler ultrasound should be used with caution in febrile mothers because of the increased risks of potentially harmful heating.
- Examinations using Doppler ultrasound in the first trimester of pregnancy should be restricted to medically indicated diagnostic purposes with a reasonable expectation of beneficial outcome.
- The use of contrast agents in obstetrical patients should be avoided because of the risk of nonthermal cavitational effects. Ultrasound contrast should not be used in pregnancy even in the absence of use of Doppler.
- The high acoustic absorption of bone and the potential for heating adjacent tissues should be recognized when using Doppler ultrasound in these areas, especially in the second and third trimesters.
- The use of transvaginal ultrasound can be associated with localized heating of adjacent tissues.
- Use the minimum output and duration of Doppler insonation consistent with obtaining the required diagnostic information on the fetus. The effects of elevated temperatures may be minimized by keeping the time during which the beam passes through any one area as short as possible.

NONMEDICAL USE — There is consensus among national/international medical societies and regulatory bodies that prenatal ultrasonography should not be performed for nonmedical reasons, such as solely for parents to have a keepsake picture/video of the fetus or learn the sex of the fetus without a medical indication or for commercial demonstration purposes, such as trade shows [1,40,41]. Likewise, Doppler ultrasound stethoscopes are available by prescription and should not be provided to parents to listen to the fetal heartbeat at home without a medical indication and guidelines for use [1].

The American College of Obstetricians and Gynecologists has also added that nonmedical ultrasonography may falsely reassure women. Abnormalities may not be detected in these settings. Furthermore, these nonmedical providers are not prepared to discuss and provide follow-up of worrisome findings [41].

TECHNIQUES AND INDICATIONS — Techniques and indications for ultrasound examination in obstetrical and gynecological patients, as well as routine prenatal ultrasound screening, are reviewed separately. (See "Ultrasound examination in obstetrics and gynecology" and "Routine prenatal ultrasonography as a screening tool".)

SUMMARY AND RECOMMENDATIONS

- For diagnostic ultrasound imaging in obstetrics and gynecology, frequencies of 2 to 12 million cycles per second (MHz) are used. (See 'Resolution' above.)

- The shape of the transducer significantly alters the qualities of the image and affects visualization of various tissues. Similarly, the arrangement of the piezoelectric crystals within the transducer affects the displayed image. During an ultrasound examination, it may be necessary to use multiple transducers to evaluate different structures of interest. (See 'Transducers' above.)

- Real-time B-mode imaging, or brightness modulation, is the basis for imaging in obstetrics and gynecology. (See 'Display' above.)

- The temperature increase with diagnostic ultrasound is less than one degree Celsius at typical acoustic output levels as long as the Thermal Index (TI) is maintained below 1.0. This level of increase is not felt to be clinically significant. Similarly, diagnostic ultrasound used for medical imaging does not appear to cause cavitation at usual obstetrical acoustic output levels as long as the Mechanical Index (MI) is kept below 1.0. (See 'Energy output measurement' above.)

- Available data show that ultrasonography during pregnancy is **not** associated with adverse maternal/fetal/neonatal outcome, impaired physical or neurological development, increased risk of childhood malignancy, impaired cognitive ability, or mental disease. (See 'Safety' above.)

  Nevertheless, prenatal ultrasonography should be used only when clinically indicated, for the shortest amount of time, and with the lowest level of acoustic energy compatible with an accurate diagnosis.

- In contrast to B-mode and M-mode, the use of spectral and color (including power) Doppler ultrasound diagnostic equipment has greater time-averaged intensities, and therefore, the potential to produce biologically-significant temperature rises, particularly in the vicinity of bone. Therefore, specific precautions should be employed when performing Doppler ultrasound. (See 'Doppler' above.)

- Prenatal ultrasonography should not be performed for nonmedical reasons. (See 'Nonmedical use' above.)

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