Doppler Ultrasound in Obstetrics

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Current Use of Doppler Ultrasound in Obstetrics and Gynecology
• Uteroplacental Circulation
• Fetoplastic Circulation
• Fetal Anatomy
• Multifetal Gestations
• Abnormal Placentation
• Fetal Anemia
• Adnexal/Ovarian masses
• Ectopic Pregnancy

Principles of Doppler Ultrasound
• Doppler waveforms reflect blood velocity and flow
• Doppler Ultrasound is used for the noninvasive assessment of circulation (maternal/fetal)
• Doppler waveform analysis can yield information on:
  ▫ Presence and direction of flow
  ▫ Velocity of flow
  ▫ Volume of flow
  ▫ Impedance to flow
Physics of Doppler Ultrasound

- The doppler frequency shift refers to the scattering of the US wave when it encounters circulating RBCs causing a frequency shift proportional to the speed of RBC movement (velocity).
- This relationship is expressed in the Doppler Equation which forms the basis of the clinical application of doppler ultrasound.

FitzGerald DE, BMJ, 1977
Maulik D, Am J Cardiol, 1984

Modalities of Doppler US

- Continuous Wave
  - Used in obstetrics for determining the presence of fetal cardiac activity and monitoring the FHR during the antepartum and intrapartum period
  - External FHR monitors
  - Handheld Dopplers for FHR

- Pulsed Wave (Spectral Doppler)
  - Provides analysis of flow at a specific site in the targeted vessel
  - Allows calculation of velocity and indices (Pulsatility index, Resistance index, Peak velocity)
  - Analysis of flow wave forms (measure of changing velocity throughout the cardiac cycle)

Modalities of Doppler US

- Color Flow Imaging/Mapping
  - Uses different colors to depict presence and direction of flow
  - Identifies target vessels for PW doppler interrogation
  - Identifies circulatory anomalies
  - Provides beam/vessel angle correction for velocity measurements

- Power Doppler (Amplitude or Doppler Angiography)
  - Produces real-time color-coded images of blood flow
  - No information on flow velocity or direction
  - Enables visualization of slower flow in smaller vessels
Modalities of Doppler US

- **Tissue Doppler Imaging**
  - Analyzes Doppler frequency shifts generated by tissue movement or strain
  - Can assess the myocardium during the cardiac cycle
  - Useful for assessing global and regional myocardial function

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**Pulsed Wave (Spectral) Doppler Indices**

- Peak Systolic velocity

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**Doppler Imaging of the Circle of Willis**

- **Power Doppler**
- **Color Flow Doppler**
Real-Time B Mode Imaging with Color Flow Imaging and PW Doppler
"Triplex Imaging"

Safety of Doppler Ultrasound

- Ultrasound (US) produces sound waves that have the potential to cause thermal and mechanical effects in tissue and bone
- These effects increase as energy output is increased
- US has been found to be safe for mothers and fetuses, but there has been a general trend towards higher energy output per exam because of the expanded use of Doppler US and the higher energy output capabilities of modern US equipment

WHO, 2009
ACOG, AUEM, 2016
ACR, SRU, 2016

Safety of Doppler Ultrasound

- Acoustic energy output increases as the US modality moves from B Mode — Color Flow Doppler — Spectral (Pulsed Wave) Doppler
- Since 1976, the FDA has required either a limit on the acoustic output of an US machine or an Output Display Standard (ODS)
- The Output numbers pertinent to Obstetrical US are Thermal Index soft tissue (TIs) or Thermal Index bone (T Ib)

WHO, 2009
ACOG, AUA, 2016
ACR, SRU, 2016
Safety of Doppler Ultrasound

- The Thermal Index (TI) denotes the potential for increasing the temperature of the tissue being insonated
- The TI is determined by the machine settings and the US modality used
- A TI of 1.0 indicates the potential of for increasing the temperature of the tissue by 1 degree Celsius
- It is the responsibility of the sonographer to monitor the ODS and use safe levels of energy output

WHO, 2009
ACOG, AIUM, 2016
ACR, SRU, 2016

“Ultrasonography is safe for the fetus when used appropriately and should be used when medical information about a pregnancy is needed; however, ultrasound energy delivered to the fetus cannot be assumed to be completely innocuous, and the possibility exists that such biological effects may be identified in the future.

Thus, ultrasonography should be performed only when there is a valid medical indication and, in all cases, the lowest possible ultrasound exposure settings that obtain adequate image quality and gain the necessary diagnostic information should be used, following the as-low-as-reasonably-achievable (ALARA) principle.”
“Aligned with the ALARA principle, spectral or “flow” Doppler should not routinely be used to “auscultate” the fetal heart rate in the first trimester because of its higher energy delivery; instead, adequate documentation of viability can be obtained with use of M-mode scanning or conventional two-dimensional real-time ultrasonography.”


- In keeping with the ALARA principle, spectral Doppler ultrasound should not be used unless clinically indicated
- The promotion, selling, or leasing of ultrasound equipment for making “keepsake fetal videos” is considered by the U.S. Food and Drug Administration to be an unapproved use of a medical device. Use of a diagnostic ultrasound system for these purposes, without a physician’s order, may be in violation of state laws or regulations
- A thermal index for soft tissue (TIs) should be used at <10 weeks’ gestation and a thermal index for bone (T Ib) should be used at ≥10 weeks gestation when bone ossification is evident

Uterine Artery Doppler Velocimetry in Pregnancy

- Impedance to flow (resistance) in the uterine artery (UA) decreases with advancing gestational age (decreased EDF, low RI, low PI)
- Transformation of the high resistance arterial system (nonpregnant state) into a low resistance, high flow system (pregnant state), is thought to be related to trophoblastic invasion of the myometrium and spiral arteries
- Increased impedance to flow in the 1st or 2nd trimesters reflects abnormal trophoblastic invasion and failure of transformation of the uterine vasculature into a low resistance system
Uterine Artery Doppler Velocimetry in Pregnancy

- Persistence of high resistance/impedance to flow in the U.A. has been associated with and increased risk of fetal growth restriction (FGR), preeclampsia and perinatal loss
- UtA waveforms most commonly studied in association with adverse obstetric outcome include the presence of a diastolic notch (unilateral or bilateral), decreased end-diastolic flow (EDF), elevated resistance indexes including the systolic/diastolic ratio (S/D), resistance index (RI) and pulsatility index (PI)

Liu, Obstet Gynecol. 1995
Papageorghiou, B&O, 2005
Chien, B&O, 2009

Uterine Artery Doppler Blood Flow Velocity Waveform

2nd Trimester UtA Doppler Waveforms

Normal 2nd trimester UtA doppler waveform with high EDF and low resistance
Decreased EDF
Diastolic Notching
Uterine Artery Doppler Velocimetry in Pregnancy

- The utility of UtA doppler is limited by:
  - Poor reproducibility and large interobserver variation (Bewley, 1991)
  - Low PPV and LR in low risk populations for SGA, pre eclampsia and perinatal loss
  - Higher PPV and LR in high risk populations but no consensus on timing of screening, parameters to use or intervention to improve outcome
  - Combining UA doppler with maternal risk factors and biochemical assessment improves the prediction of SGA, but limits the clinical applicability due to complexity and need for multiple screening intervals

Myatt, Obstet Gynecol, 2012
Sciscione, Am J Obstet Gynecol, 2009
Parry, Am J Obstet Gynecol, 2017

- “At this time, the evidence does not support routine screening with uterine artery Doppler in any particular group of patients”
- “Because standards for the study technique, gestational age, and criteria for an abnormal test are lacking, uterine artery Doppler studies should not be considered to be a required medical practice in low or high risk populations”

Sciscione (for SMFM), AJOG, 2009

SMFM Clinical Guideline, AJOG, 2012

Doppler of the Fetoplacental Circulation

- Arterial
  - Umbilical Artery
    - Fetal Growth Restriction (FGR)
    - Preeclampsia
  - Middle Cerebral Artery
    - FGR
    - Fetal Anemia
- Venous
  - Ductus Venosus
  - Umbilical vein
Doppler of the Fetoplacental Circulation
Factors Affecting Waveform in Spectral Doppler

- Maternal position
  - Slight lateral tilt avoids IVC compression

- Gestational Age
  - With advancing EGA EDV increases and Impedance indices decrease

- Fetal Respiratory Motion
  - Doppler interrogation should be done during fetal apnea and when fetus is not moving

- Technical Factors
  - Location of doppler interrogation (placental or fetal site)

Doppler of the Fetoplacental Circulation
Factors Affecting Waveform in Spectral Doppler

- Angle of Insonation (angle between the doppler US beam path [cursor] and the axis of the blood vessel)
  - The higher the angle, the smaller the waveform
  - Preferable to keep the angle of insonation as close to zero as possible

Doppler of the Fetoplacental Circulation

- Umbilical artery (UA)
  - Assesses resistance to blood flow in the fetoplacental unit
  - Low impedance permits continuous forward flow throughout the cardiac cycle
  - Maternal/Fetal conditions that obliterate the placental villous vasculature result in a progressive decrease in end-diastolic flow (EDF)
Doppler of the Fetoplacental Circulation

- Umbilical artery (UA)
  - As placental dysfunction worsens, UA bloodflow resistance increases and transfer of substrates, oxygen and fetal waste products become impaired
  - Obliteration of 30% villous vasculature results in reduced EDF and increased S/D ratio
  - Obliteration of 60-70% villous vasculature results in absent EDF (AEDF) or reversed EDF (REDF)

Baschat, J Perinat Med, 2010

Doppler of the Fetoplacental Circulation

- Umbilical artery (UA)
  - The use of Umbilical Artery Doppler evaluation in cases of suspected FGR has been consistently shown to reduce:
    - Perinatal mortality (RR 0.71, 95% CI 0.52-0.98)
    - Unnecessary deliveries in preterm fetuses (RR 0.89, 95% CI 0.80-0.99)
    - Cesarean deliveries (RR 0.90, 95% CI 0.84-0.97)

Alfrevic, Cochrane Database Syst Rev, 2010
SMFM, 2012

Doppler of the Fetoplacental Circulation

- Umbilical artery (UA)
  - Systolic/diastolic ratio (S/D) and Pulsatility Index (PI) are commonly used and either is sufficient to manage suspected FGR
  - Normal or reduced EDF (normal or increased S/D; EDF present) is infrequently associated with perinatal morbidity or mortality
  - Elevated S/D warrants more frequent fetal surveillance to observe for progression of fetal compromise
Doppler of the Fetoplacental Circulation

- Umbilical artery (UA)
  - AEDF or REDF indicates an advanced degree of placental dysfunction and is associated with a 4-5 fold increase in perinatal mortality

Vasconcelos, Fetal Diagn Ther, 2010

Umbilical Artery Waveform Patterns with Progressive Increase in Placental Vascular Resistance

- Normal UA Doppler Waveform
- Absent End-Diastolic Flow
- Reversal of End-Diastolic Flow

Doppler of the Fetoplacental Circulation

- Middle Cerebral Artery (MCA) : Fetal Growth Restriction (FGR)
  - Under normal conditions, the cerebral circulation is a high impedance circulation with continuous forward flow throughout the cardiac cycle (low EDF, High PI)
  - In the presence of impaired placental function and fetal hypoxemia, central redistribution of blood flow results in increased blood flow to the brain, heart and adrenals (“brain-sparing reflex”)
  - This vasodilatation of cerebral vessels and increased flow is characterized by increased EDF and low PI
Circle of Willis
Middle Cerebral Artery

Middle Cerebral Artery Doppler Waveforms

MCA Doppler with high impedance to flow, low EDF and normal Resistive Index (RI)

MCA Doppler with low impedance to flow, increased EDF and low RI
“Brain-Sparing Reflex”

Doppler of the Fetoplacental Circulation

- Middle Cerebral Artery (MCA): FGR
  - Abnormal MCA velocimetry may identify a subset of FGR fetuses at increased risk for cesarean delivery, neonatal acidosis and poor neurodevelopmental outcome (Severi, Ultrasound Obstet Gynecol, 2002)
  - MCA Velocimetry has not been tested in randomized trials and no specific interventions have been shown to improve outcome (SMFM Clinical Guidelines, AJOG, 2012)
  - “…these flow measurements have not been shown to improve perinatal outcome, and the role of these tests in clinical practice remain uncertain” (ACOG Practice Bulletin 204, 2019)
Doppler of the Fetoplacental Circulation

Cerebroplacental Ratio (CPR)

- Developed as a method to quantify redistribution of cardiac output in placental insufficiency ("brain sparing reflex")
- MCA PI (or RI) divided by the UA PI (or RI)
- Reflects both placental status and fetal response
- More sensitive doppler index for predicting adverse perinatal outcome than UA alone
- CPR < 1.0 or 1.08 or < 5th percentile have been associated with an increased risk of death, poor neurologic outcome
- Different indices, categorical cutoffs and unclear effect of gestational age make comparisons of studies difficult and limit the current use of this test in assessment of fetuses with placental insufficiency

Flood, AM J Obstet Gynecol, PORTO study, 2014
Morales, Ultrasound Obstet Gynecol, 2014

Doppler of the Fetoplacental Circulation

- Middle Cerebral Artery (MCA): Fetal Anemia
  - Anemia in the fetus can be caused by RBC alloimmunization, viral infections, fetomaternal hemorrhage, TTS in multifetal gestations, hemolytic disease
  - Fetal anemia has been associated with increased blood flow velocity in the cerebral circulation due to increased CO and decreased blood viscosity
  - Middle Cerebral Artery Peak Systolic Velocity (MCA-PSV) is the most common noninvasive method used to follow fetuses at risk for anemia

- MCA-PSV increases with gestational age
- MCA-PSV > 1.5 MoM for EGA is indicative of moderate to severe fetal anemia
  - Sensitivity 88-100%
  - Specificity 87-89%
  - PPV 53-65%
  - NPV 98-100%

Mari, NEJM, 2000
Pretlove, BJOG, 2009
Zimmerman, 2002
Arrows point to where Doppler gate should be placed for MCA-PSV.


Doppler of the Fetoplacental Circulation

- **Ductus Venosus (DV)**
  - Doppler waveforms in the venous circulation of the fetus reflect the physiologic status of the right ventricle (increased right heart pressures)
  - The normal venous flow velocity is triphasic reflecting pressure volume changes in the atria (systole: s-wave, diastole: d-wave, atrial systole: a-wave)
  - The ductus venosus originates from the umbilical vein as it enters the fetal liver and the DV then ascends steeply to empty into the IVC just below the right atrium
Ductus Venosus

SITE DUCTUS VENOSUS

Doppler Waveform of the Fetoplacental Circulation
Ductus Venosus Doppler Waveform

- S: Peak systolic velocity
- D: Peak diastolic velocity
- a: Atrial contraction
Doppler of the Fetoplacental Circulation

- **Ductus Venosus (DV)**
  - Abnormal Doppler waveforms in the fetal venous circulation usually follow abnormalities in the fetal arterial circulation by 1-3 weeks.
  - In general, Doppler velocimetry of the fetal venous circulation helps identify fetuses with FGR at an advanced stage of compromise.
  - Previous reports have indicated increased rates of perinatal mortality and morbidity, fetal acidemia with absent or reversed flow of the a-wave in late diastole.

Baschat, Ultrasound Obstet Gynecol, 2003
Turan, Ultrasound Obstet Gynecol, 2011

Ductus Venosus Doppler Waveforms

- Normal Ductus Venosus Doppler Waveform
- Abnormal DV Doppler Waveform with Absent a Wave
- Abnormal DV Doppler waveform pattern with reversal of the a-wave

Doppler of the Fetoplacental Circulation

- **Umbilical Vein (UV)**
  - Continuous forward flow throughout the cardiac cycle
  - Reflects RV afterload and myocardial function
  - The presence of UV pulsations indicate increased RV pressures and myocardial failure
  - UV pulsations have been associated with acidemia/acidosis, and increased morbidity and mortality in growth restricted fetuses
  - Not currently recommended as part of standard doppler assessment (standardization of measurements, correlation with outcome)

Schwarze, Ultrasound Obstet Gynecol, 2005
Hofstaetter, Early Hum Dev, 2001
Umbilical Vein Velocity Waveforms

**Top:** High flow velocity with no impedance and no pulsations or changes with cardiac cycle

**Bottom:** Umbilical vein pulsations seen with moderate increase in placental resistance to flow

Doppler Ultrasound in Assessment of Fetal Anatomy

- Umbilical Cord
- Renal
- Fetal Echocardiography

Documenting the Presence of a 3 Vessel Cord

2 umbilical arteries noted branching around the fetal bladder
Unilateral renal agenesis with absence of renal artery (upper arrows) and empty renal fossa. Contralateral kidney is present with normal renal artery demonstrated by color flow doppler ultrasound (small arrowheads).

Doppler Ultrasound in the Assessment of Multifetal Gestations

- Anatomy (3 VC; renal artery)
- Fetoplacental Circulation in pathologic conditions:
  - Discordant fetal growth
  - TTTS (Twin-Twin Transfusion Syndrome)
  - TRAP (Twin Reversed Arterial Perfusion Sequence)
  - TAPS (Twin Anemia-Polycythemia Sequence)
- Placental Cord Insertion

TTTS: Quintero Staging

- Stage I: Oligohydramnios and polyhydramnios sequence, and the bladder of the donor twin is visible. Dopplers on both twins are normal.
- Stage II: Oligohydramnios and polyhydramnios sequence, the bladder of the donor is not visualized. Dopplers on both twins are normal.
- Stage III: Oligohydramnios and polyhydramnios sequence, nonvisualized bladder, and absent Dopplers. There is absent/reverse end diastolic velocity in the umbilical arteries, reversed flow in the ductus venosus, or pulsatile flow in the umbilical vein in the donor twin.
- Stage IV: One or both fetuses show signs of hydrodrops.
- Stage V: One or both fetuses have died.
Twin Reversed Arterial Perfusion (TRAP)

- Occurs in <1% of Monochorionic twin pregnancies
- Normal twin (called the “pump” twin), perfuses twin with absent or nonfunctioning heart (“acardiac” twin) through shared placental vasculature
- Unequal vascular perfusion from the pump twin results in a variety of structural anomalies in the recipient (“acardiac monster”)
- The pump twin may develop high-output cardiac failure, polyhydramnios, hydrops
- 50% mortality for pump twin
- Management includes cord occlusion of acardiac twin, indicated preterm delivery
Twin Reversed Arterial Perfusion (TRAP)

Use of Doppler Ultrasound in Multifetal Gestations: Placental Cord Insertion Site

Doppler Ultrasound in the Assessment of Abnormal Placenta

- Placenta Accreta Spectrum (PAS)
- Vasa Previa
- Chorangioma
Doppler Ultrasound in the Assessment of Abnormal Placentation Placenta Accreta Spectrum (PAS)

- Risk factors include previous uterine surgery or curettage, previous C/S, placenta previa, multiparity, advanced maternal age
- Prenatal diagnosis allows counseling, planning of delivery, optimization of care and referral to Level III or IV maternal care facility
- Color doppler imaging is useful as part of the US diagnosis of PAS, and is frequently used as an adjunctive tool

Ultrasound findings associated with PAS include:
- Multiple placental lacunae
- Loss of the normal hypoechoic zone between placenta and myometrium
- Retroplacental myometrial thinning (<1mm)
- Abnormalities of the uterine serosa-bladder interface (placental “bulge”; abnormal vascularity; disruption of hyperechoic “bladder line”)
- Exophytic mass (representing invasion of placental villi through the uterine serosa into adjacent organs)

Findings with Color Flow Imaging include:
- Turbulent and high flow velocity in lacunae
- Increased vascularity and flow in the retroploental space
- Aberrant vessels crossing between the placenta and uterine serosa (“bridging vessels”)
- Hypervascularity at the uterine serosa-bladder interface
PAS: Abnormal Vascularity in Retroplacental Space

For comparison, color Doppler of the lower uterine segment in a patient with placenta previa and no accreta. Note the vascular structures between the placenta and the bladder wall. The flow appears normal, without turbulence and there is no crossing of vessels into the placental tissue.
PAS: Abnormal Vascularity in Retroplacental Space

Doppler color mapping demonstrates abnormal vasculature that bridges from placental mass to uterine-bladder interface and sometimes beyond (arrows).

PAS: Abnormal Vascularity at the Uterine-Bladder Interface
PAS: Abnormal Vascularity at the Uterine-Bladder Interface

PAS-"Placental Bulge" at Uterine-Bladder Interface

Placenta Accreta Spectrum

- 2013 Systematic Review of the performance of US overall in the detection of PAS:
  - Sensitivity 90.8%
  - Specificity 96.9%
- Color Doppler Imaging:
  - Sensitivity 91.2%
  - Specificity 91.9%
- Assessment of individual US findings should be viewed with caution. Observation of one sign is likely to increase the chance of detecting others, because the signs are not looked for in isolation.

D’Antonio, Ultrasound Obstet Gynecol, 2013
Berkley, J Ultrasound Medicine, 2013
“Although ultrasound evaluation is important, the absence of ultrasound findings does not preclude a diagnosis of PAS; thus, clinical risk factors remain equally important as predictors of PAS by ultrasound findings.”

“IT is unclear whether MRI improves diagnosis of PAS beyond that achieved with ultrasonography alone. Accordingly, MRI is not the preferred recommended modality for the initial evaluation of possible PAS.”

**Doppler Ultrasound in the Assessment of Abnormal Placentation Vasa Previa**

- Fetal vessels (unprotected by Wharton’s jelly) in the membranes covering (or near) the internal cervical os
- Risk factors: velamentous cord insertion, low-lying placenta, placenta previa, succenturiate or bilobed placenta, IVF, multifetal gestation
- Doppler US can aid in diagnosis via color flow imaging and pulsed wave doppler

**Doppler Ultrasound in the Assessment of Abnormal Placentation Vasa Previa**

- Doppler US
  - Identify vessel fixed in lower uterine segment near (within 2 cm) or over internal cervical os via color flow doppler
  - Identify the vessel as fetal via pulsed wave doppler (arterial)
Doppler Ultrasound in the Assessment of Abnormal Placentation

**Chorangioma**

- Benign neoplasm of the placenta
- Vascular or cellular
- Fetal risks include nonimmune hydrops, anemia, cardiac failure, UV thrombosis, and fetal death
- Complications are usually seen with size > 5 cm and increased vascularity
- Doppler US can assess degree of vascularity and assess fetus for anemia and heart failure
An excessive temperature increase can result in toxic effects in mammalian systems. The biological effects observed depend on many factors, such as the exposure duration, the type of tissue exposed, its cellular proliferation rate, and its potential for regeneration. Age and stage of development are important factors when considering fetal and neonatal safety. Temperature increases of several degrees Celsius above the normal core range can occur naturally. The probability of an adverse biological effect increases with both the duration and the magnitude of the temperature rise.

In general, adult tissues are more tolerant of temperature increases than fetal and neonatal tissues. Therefore, higher temperatures and/or longer exposure durations would be required for thermal damage. The considerable data available on the thermal sensitivity of adult tissues support the following inferences:

1. For exposure durations up to 50 hours, there have been no significant adverse biological effects observed due to temperature increases less than or equal to 1.5 °C above normal.

2. For temperature increases between 1.5 °C and 6 °C above normal, there have been no significant adverse biological effects observed due to temperature increases less than or equal to $6 - \frac{(log_{10}(t/60))/0.6}{t}$ where $t$ is the exposure duration in seconds. For example, for temperature increases of 4 °C and 6 °C, the corresponding limits for the exposure durations $t$ are 16 minutes and 1 minute, respectively.

3. For temperature increases greater than 6 °C above normal, there have been no significant adverse biological effects observed due to temperature increases less than or equal to $6 - \frac{(log_{10}(t/60))/0.3}{t}$ where $t$ is the exposure duration in seconds. For example, for temperature increases of 9.6 °C and 6.0 °C, the corresponding limits for the exposure durations $t$ are 5 and 60 seconds, respectively.

4. For exposure durations less than 5 seconds, there have been no significant adverse biological effects observed due to temperature increases less than or equal to $9 - \frac{(log_{10}(t/60))/0.3}{t}$ where $t$ is the exposure duration in seconds. For example, for temperature increases of 18.3 °C, 14.9 °C, and 12.6 °C, the corresponding limits for the exposure durations $t$ are 0.1, 1, and 5 seconds, respectively.

Acoustic output from diagnostic ultrasound devices is sufficient to cause temperature elevations in fetal tissue. Although fewer data are available for fetal tissues, the following conclusions are justified:

In general, temperature elevations become progressively greater from B-mode to color Doppler to spectral Doppler applications.

For identical exposure conditions, the potential for thermal bioeffects increases with the dwell time during examination.

For identical exposure conditions, the temperature rise near bone is significantly greater than in soft tissues, and it increases with ossification development throughout gestation. For this reason, conditions in which an acoustic beam impinges on ossifying fetal bone deserve special attention due to its close proximity to other developing tissues.
7. The current US Food and Drug Administration regulatory limit for the derated spatial-peak temporal-average intensity (ISPTA) is 720 mW/cm². For this exposure, the theoretical estimate of the maximum temperature increase in the conceptus may exceed 1.5°C.

8. Although an adverse fetal outcome is possible at any time during gestation, most severe and detectable effects of thermal exposure in animals have been observed during the period of organogenesis. For this reason, exposures during the first trimester should be restricted to the lowest outputs consistent with obtaining the necessary diagnostic information.

9. Ultrasound exposures that elevate fetal temperature by 4°C above normal for 5 minutes or more have the potential to induce severe developmental defects. Thermally induced congenital anomalies have been observed in a large variety of animal species. In current clinical practice, using commercially available equipment, it is unlikely that such thermal exposure would occur at a specific fetal anatomic site provided that the thermal index (TI) is at or below 2.5 and the dwell time on that site does not exceed 4 minutes.

10. Transducer self-heating is a significant component of the temperature rise of tissues close to the transducer. This may be of significance in transvaginal scanning, but no data for the fetal temperature rise are available.

11. The temperature increase during exposure of tissues to diagnostic ultrasound fields is dependent on: (1) output characteristics of the acoustic source, such as frequency, source dimensions, scan rate, output power, pulse repetition frequency, pulse duration, transducer self-heating, exposure time, and wave shape; and (2) tissue properties, such as attenuation, absorption, speed of sound, acoustic impedance, perfusion, thermal conductivity, thermal diffusivity, anatomic structure, and the nonlinearity parameter.

12. Calculations of the maximum temperature increase resulting from ultrasound exposure in vivo are not exact because of the uncertainties and approximations associated with the thermal, acoustic, and structural characteristics of the tissues involved. However, experimental evidence shows that calculations are generally capable of predicting measured values within a factor of 2. Thus, such calculations are used to obtain safety guidelines for clinical exposures in which direct temperature measurements are not feasible.

13. However, in some applications, such as fetal examinations in which the ultrasound beam passes through a layer of relatively unattenuating liquid, such as urine or amniotic fluid, the TI can underestimate ΔTmax by up to a factor of 2. (4,5)

*The thermal indices are the nondimensional ratios of attenuated acoustic power at a specific point to the attenuated acoustic power required to raise the temperature at that point in a specific tissue model by 1°C. (6)
Prudent Use in Pregnancy

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.

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