Obstetrical Doppler

Mani Montazemi, RDMS

Introduction

The introduction of color Doppler imaging and pulsed Doppler duplex systems has enabled the more detailed examination of the fetal circulation, thereby allowing a greater knowledge of the physiological and pathophysiological changes in the fetus during pregnancy. Doppler ultrasound of fetal circulation allows us to investigate the fetal response to adverse conditions in utero. This information can only help in defining the small baby that is sick and may also be useful in determining when it is better to have the fetus delivered, rather than remain in utero. The primary response observed with fetal Doppler is the "brain sparing" effect which has been demonstrated in both animal and human studies. It has been possible to correlate the development of hypoxia and acidosis with changes in fetal hemodynamics that correspond to the brain sparing effect, whereby the blood supply (and thereby oxygen and nutrients) is preferentially supplied to the fetal heart, adrenal glands and brain, at the expense of the rest of the body. Suspected fetal growth restriction on the basis of placental insufficiency is the major indication for fetal Doppler. Patients with hypertensive complications of pregnancy or those with suspected preeclampsia are at risk for fetal growth restriction as are Diabetic patients with vascular disease. At particular risk for growth restriction are patients with diamniotic monochorionic twin gestations. Use of Doppler in obstetrics requires knowledge of basic principles, instrumentation & examination technique, indications and clinical applications.

Doppler Principles

Doppler technology provides hemodynamic assessment of the arteries and veins. This technique is combined with sonographic imaging (Duplex), which provides the morphologic data. The physics of the Doppler phenomenon is quite different from that of conventional sonographic imaging and must be clearly understood in order to properly perform and interpret Doppler studies. Ultrasound, when reflected from components in soft tissue, generally returns to the transducer at the same frequency as transmitted. However, if the ultrasound beam encounters moving particles, the ultrasound reflected from these particles return to the transducer at a slightly altered frequency. The difference between the transmitted and the received frequency is called Doppler shift.

The Austrian physicist Johann Christian Doppler first formulated the Doppler principle in 1842. The Doppler phenomenon refers to the change in frequency of a sound wave relative to the motion between the source (reflector) and the receiver (transducer). If the particles (red blood cells) are moving toward the transducer the returning echoes will be at a higher frequency that the original transmitted ultrasound waves. The wavelengths of the received ultrasound waves will also be shorter than the original waves. Conversely, if the blood cells are moving away from the transducer, the reflected ultrasound waves will be lower in frequency than the original ultrasound waves and they will have longer wavelengths. This is known as the "Doppler effect". Thus, Doppler systems emit a high-frequency sound (ultrasound) that is reflected off of the moving red blood cells and then returned at a different frequency dependent upon the speed and direction of the moving blood. This frequency change is displayed as waveforms.

The relationship between blood flow and the Doppler shift is represented by the following equation:
[$f_d = (2\ f_t\ v / c).\ \cos.\ \theta$]. The ($f_d$) is the Doppler shift, which is the frequency difference between the reflected frequency and the transmitted frequency. The (2) is found in this equation because a Doppler shift occurs when the ultrasound strikes a red blood cell and another Doppler shift occurs when the ultrasound is reflected from that red blood cell. (f_t) is the transmitted ultrasound frequency and (v) represents the velocity of blood flow. The letter (c) is the velocity of sound in tissue (approximately 1540m/s) and (θ) is the angle between the ultrasound beam and the direction of flow.

The change in blood flow during the cardiac cycle is a temporal pattern of blood flow. Temporal alterations of blood flow can be best characterized with pulsed Doppler. The spectral Doppler waveform is most commonly described using the term pulsatility, which can be defined as the ratio of systolic and end diastolic flow velocities. In clinical practice, several indices are calculated to quantify the pulsatility of flow. If a vessel is insonated from a certain maybe unknown angle, all velocity components in the Doppler spectrum are subject to the same angle correction error. An advantage of using indices for the diagnostic evaluation of Doppler waveforms is that ratios of Doppler frequencies, or of flow velocities, are independent of the Doppler angle, provided that the angle of insonation has not changed over the cardiac cycle under evaluation.

Interpretation of fetal Doppler waveforms must, however, take into account the fact that a variety of factors other than peripheral resistance may influence the appearance of the waveform. These include cardiac factors which include acceleration of blood, heart rate and vascular factors which include vessel length, diameter, wall elasticity, and number of branches. In the second and third trimesters, fetal breathing may also affect systolic and diastolic velocity and pulse rate.

Three indices are in common use: the systolic/diastolic ratio, the resistance index, and the pulsatility index. The Resistive Index (RI) also referred to as Pourcelot Index, as well as the ratio parameters is the simplest resistance parameters. Two points in the waveform, the systolic peak velocity (A) and the end diastolic velocity (B) are used to calculate RI [A-B/A]. The calculation of Ratio, defined as A/B or B/A, is done using the same two points in the waveform. Numerical values for RI vary between 0 and 1, for Ratio A/B between 1 and ∞, and for Ratio B/A between 1 and 0; the first of the two values are indicative for low resistance, the second ones for high resistance. The pulsatility index (PI) is the ratio of the peak systolic frequency shift minus the minimum diastolic frequency shift divided by the mean frequency shift [PSV-EDV]/[mean velocity].

As mentioned earlier the RI, P1 and the SD ratio are angle-independent calculations. This makes these indices useful for assessing flow in small or tortuous vessel where an accurate Doppler angle may not be available. The small tortuous vessels found in tumors, The middle cerebral artery and the tortuous and often moving umbilical cord arteries can be assessed using these indices.

Color Doppler is an important aid in the evaluation of the placenta, umbilical cord, and fetus. Color Doppler yields a vascular map and expedites the location of vessels for pulsed Doppler interrogation. Normal, velamentous and marginal cord insertions are shown as well as abnormalities including nuchal cord, two vessel cords, coiling abnormalities and placenta accreta. Color Doppler of the fetus may aid in the evaluation of such varied abnormalities as abdominal wall defects, umbilical vein varix, vein of Galen aneurysm, pulmonary sequestration, congenital heart disease, twins (cord entanglement, twin-twin transfusion), hemangioma, and tumors.

1st Trimester Pregnancy

In the first trimester of all viable pregnancies, Doppler shows the low impedance vascularity of the corpus luteum. In this setting, a low impedance signal is generally considered any with a resistive index (RI) of 0.5 ± 0.2 or less. This is usually only seen in one ovary unless there has been stimulation of the ovaries by menotropins (Pergonal®) or clomiphene citrate (Clomid®). In such patients, bilateral corpora lutea are usually seen. There is evidence to indicate that absence of luteal flow is inconsistent with a viable first trimester pregnancy.

The uterine vasculature shows relatively little change in the first trimester of pregnancy. Many studies have documented dramatic changes which occur in the second trimester, particularly between the 14th and 18th week of pregnancy. During this time, the high impedance uterine waveform changes to the low impedance flow seen during the late second and third trimesters. This lowered impedance to flow has been correlated histologically with the destruction of the elastic lamina of the maternal spiral arteries, which occurs as a result of the secondary invasion of the trophoblast. Such a change implies that the utero-placental circulation now becomes a low impedance shunt that will receive blood preferentially over any higher impedance circuit perfused by the maternal cardiovascular system.

The trophoblastic ring in early pregnancy normally does not contain a Doppler signal, but pulsatile flow signals with prominent diastolic component are present between outer edge of the throphoblastic ring and inner third of myometrium in both normal and abnormal pregnancy. In cases of missed abortion continuous flow is identified in the trophoblastic ring. With Doppler, cardiac flow is routinely detected at 6-7 weeks, and umbilical cord flow by 7 weeks. In the first trimester, diastolic flow is typically absent in the umbilical artery.

2nd & 3rd Trimester Pregnancy

In the second and third trimesters of pregnancy, the primary use of Doppler ultrasound has been in the assessment of flow in the umbilical, middle cerebral and uterine arteries and, to a lesser extent, in the fetal aorta and carotid arteries. Using pulsed Doppler, most studies have investigated the relationship of changes in the fetal and uteroplacental circulation to conditions associated with fetal growth restriction, maternal hypertension, fetal anemias, and congenital anomalies. Color Doppler now provides a valuable adjunct to real time imaging of the fetus in the second and third trimesters and aids in pulsed Doppler examination. With Color Doppler, the structural information provided by the real time ultrasound image can be combined with the graphic display of fetal, placental, and uterine vasculature, aiding in the determination of normal development and function. A particularly important use of Color Doppler is in the selection of optimal sites for pulsed Doppler sampling within the fetus. The selection of a sampling site for umbilical arterial Doppler sampling has been shown to have a significant influence on the accuracy of measurement of Doppler indices. With Color Doppler, the umbilical cord can be followed from the fetus to the placental insertion and sampling sites and optimal Doppler angles may be selected with ease. The value of Color Doppler in tracing the course of the cord is particularly great when there is oligohydramnios and cord loops are difficult to identify.

Umbilical Artery Blood Flow

Since the first report of Doppler ultrasound evaluating high-risk pregnancies in 1977, the fetal arterial system has been extensively studied to determine if abnormal waveforms identify fetuses at increased risk of perinatal mortality. For clinical purposes, the umbilical artery is the most universally understood and applied fetal arterial vessel since it was one of the earliest circulations studied and is a relatively easy vessel to interrogate. The umbilical artery Doppler velocity waveform is determined primarily by cardiac contractility upstream and by placental impedance downstream. The organ downstream from the umbilical artery is the placenta and analysis of the Doppler waveform is a reflection of placental function and is a true test of placental insufficiency.

Waveform analysis of arterial signals from the umbilical artery is of particular importance in the evaluation of high risk pregnancies. Umbilical artery flow velocity waveforms may be observed and measured by using a pulsed wave Doppler system. No umbilical artery waveform measurements should be made during periods of fetal body movement or fetal breathing since either of these biophysical activities can induce circulatory changes reflected by marked increases in systolic and diastolic pressures. Further, no waveform should be measured during uterine contractions during which the waveform may be altered. A low (50-100 Hz) filter is used to eliminate the low frequencies obtained from movements of the arterial wall. A minimum of three consecutive waveforms should be measured, and the mean result calculated for each of three indices: systolic-diastolic ratio (S/D), pulsatility index (P1), and the resistance index (RI). The sampling site in the cord may affect measurements. Ratios from the fetal end of the cord are significantly greater than distal measurements and a significantly higher percentage of patients would be considered to have an elevated S/D ratio if the waveform were obtained at the fetal end as opposed to the placental end of the cord. The following technical considerations will aid in obtaining an optimal acquisition of cord Doppler:

Spectral Doppler

- Angle of insonation to flow
- Sample volume size & location
- Doppler gain
- Scale (PRF)
- Wall filter
- Sweep speed

Color Doppler

- Angle to flow
- Image size
- Color box size
- Scale (PRF)
- Color gain
- Wall filter

Increasing volume flow in the umbilical circulation is related to a decrease in vascular resistance. Progressive growth of the placental villous tree, together with an increase in fetal cardiac output, increases both systolic and diastolic velocity in the umbilical artery. Approximate values of normal systolic-diastolic ratios are 4.0 at 20 weeks, 3.0 at 30 weeks, and 2.0 at 40 weeks gestation. When waveform values of normal fetuses were compared with values from fetuses suspected of being growth restricted, it was discovered that if the values are elevated for gestational age, the fetus is more likely to have growth restriction. Fetuses with absent end-diastolic velocities in the umbilical artery appear to be at higher risk than the average. These fetuses have an increase in congenital anomalies, perinatal mortality, and delivery by cesarean section, and fetal distress.

Abnormal umbilical artery waveforms have been correlated with pathological placental microvascular anatomy. Placentas of high risk pregnancies in which a high systolic-diastolic ratio was measured were found to have a significantly smaller number of small muscular arteries in the tertiary villi as opposed to placentas examined in pregnancies with normal systolic-diastolic ratios. It is believed, therefore, that the abnormal systolic-diastolic ratio, as an indicator of increased umbilical blood flow resistance, identifies a specific microvascular lesion in the placenta.

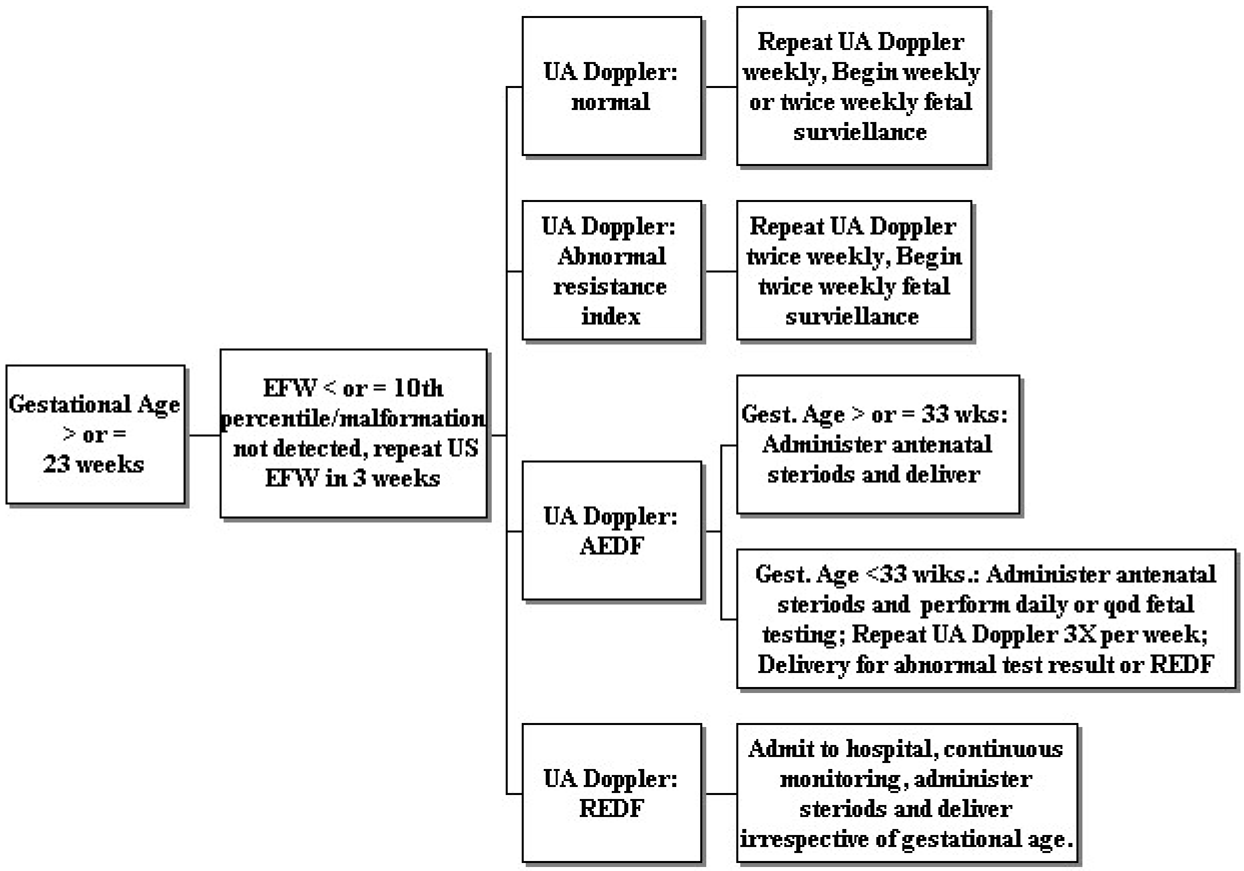
At 22-24 weeks gestation if the fetus is measurably small by ultrasound, several Doppler patterns may occur. The umbilical artery may still have a normal pulsatility index (resistance index or S/D ratio), the middle cerebral artery may have either a normal or abnormal pulsatility index. The second possibility is when the umbilical artery has an abnormal pulsatility index and the middle cerebral artery has either a normal or abnormal value of pulsatility index. The other possibility occurs when both umbilical artery and the middle cerebral artery have an abnormal value of pulsatility index. In this case, there is a severe utero-placental insufficiency. The fetus needs to be monitored very closely. Oligohydramnios may be present at any stage of the above process. Ductus venosus reverse flow and umbilical veins pulsation are present continuously. The fetus starts to lose the brain sparing effect and the biophysical profile becomes abnormal. This sequence of events applies to a growth restricted fetus in cases of insufficiency placental circulation and not to the fetuses who have other causes such as smoking, abruption, and toxic drug exposure who may have a different pathology.

Recent meta-analysis of randomized controlled trials suggests that incorporation of umbilical artery Doppler waveform analysis into management protocols for high risk pregnancies significantly decreases perinatal mortality. Other investigators suggested that the time period between identification of an abnormal umbilical artery Doppler waveform and the development of fetal distress and/or death varies widely – from days to weeks. Studies show that there is a wide variability in the interval between detection of umbilical absent or reverse end-diastolic flow velocities and occurrence of heart rate decelerations. Therefore, the challenge is to identify fetuses at greatest risk for adverse perinatal outcome when abnormal umbilical artery waveforms are present. The effects of Doppler ultrasound in high-risk pregnancies on obstetrical care and fetal outcomes were systematically reviewed. The use of Doppler in pregnancies complicated by hypertension or presumed impaired fetal growth was associated with a trend in reduction of perinatal deaths.

It is worth emphasizing that, screening is only worthwhile if an effective preventive treatment is available. If we could identify the 'at-risk' fetus using the Doppler ultrasound in order to apply clinical interventions, it could result in reduced perinatal deaths and unnecessary obstetric interventions. In many cases, the management consists of early delivery when the fetus is mature or specific interventions for conditions such as pre-eclampsia.

Mani Montazemi, RDMS

The following is a potential management scheme using umbilical artery Doppler information:



Fetal Cerebral Blood Flow

The middle cerebral artery reflects fetal adaptation to hypoxia while the peak systolic velocity correlates with fetal anemia. Evaluation of the flow pattern of the fetal cerebral arteries can be obtained with transcranial Doppler sonography by using either a transabdominal or transvaginal route with a duplex system and color flow imaging. Because of the relative ease of visualization and accessibility, the middle cerebral artery is used in most fetal cerebral circulation studies to obtain Doppler waveforms. By visualizing an axial view of the brainstem, an oblique cross-section of the internal carotid artery at its bifurcation into the anterior and middle cerebral arteries (MCA) can be observed anterior to the cerebral peduncles, on either side of the midline. The middle cerebral artery can be located more caudal to the cerebral peduncles in the section containing the pons and medulla oblongata and greater paired wings of the sphenoid. As with umbilical artery Doppler measurements, the mother should be positioned so as avoid supine hypotension and no measurements should be taken during periods of fetal breathing.

In an effort to obtain an optimal MCA Doppler the following technical considerations should be utilized:

- Follow the spectral & color Doppler recommendations for the cord Doppler
- Use color Doppler to identify circle of Willis
- Zoom image to see entire length MCA
- Angle of insonation should be zero
  - Angle correct to ≤ 10 degrees for most accurate peak systolic velocity
- Sample site
  - Place Doppler gate close to the origin in the ICA
- Measure when fetal breathing and body movements are at a minimum

The MCA is a relatively high resistance circulation compared to the umbilical artery. The typical MCA is characterized by high systolic velocities and minimal diastolic velocities, resulting in high RI values. Low diastolic velocity indicates normal autoregulatory mechanisms limiting brain blood flow. Oxygenated blood is diverted across the interatrial septum by the ductus venosus and on to the ascending aorta and carotid arteries, preferentially sending oxygenated blood to the developing brain. The brain chemoreceptors sense oxygen tension in aortic arch blood and normally maintain high middle cerebral artery vascular resistance (and thus, low diastolic velocities). In situations of low oxygen tension, vascular tone is reduced in the middle cerebral artery, resulting in increased diastolic velocity and reduced RI values. This is known as cerebral blood flow redistribution to fetal brain and is found in the more severe forms of early fetal growth restriction. The relationship between the cerebral and umbilical Doppler values can be expressed as a cerebral/umbilical ratio. This ratio is abnormal if $MCA_{RI} / UA_{RI} \leq 1$.

Value of Cerebral to Umbilical Doppler Ratio:

- As a ratio, it is independent of gestational age which might affect the Doppler value
- A value of 1 is clinically significant for blood flow redistribution
- May indicate an abnormal umbilical artery value that is not apparent
- Compare RI of MCA to RI of UA
- RI of MCA should always be greater than RI of UA. For example, if RI of MCA is .64 and RI of UA is .69: early blood flow redistribution will have occurred and closer fetal surveillance may be warranted.

Uterine Artery

The uterine artery and arcuate arteries comprise the major blood supply to the uterus. During pregnancy, the uterine artery represents the major portion of the anterior division of the internal iliac artery. These vessels run up each side of the uterus and anastomose, such that uteroplacental blood flow is a summation of each arterial supply. In the first half of pregnancy the placental trophoblast invades into the myometrium and establishes a low resistance circulation.

The uterine artery should be sampled immediately after its origin from the hypogastric as it crosses the external iliac artery. Sampling is performed on the side of the placenta. If the placenta is central in location, sampling is performed on each side.

Doppler ultrasound allows non-invasive investigation of the uteroplacental circulation. Uterine blood flow in the non-pregnant woman is 50mL/min and increases to over 700mL/min in the third trimester of pregnancy. The diastolic component of the uterine artery Doppler waveform is, thus

transformed during normal pregnancy from one of low peak-flow velocity and an early diastolic notch, to one of high flow and no diastolic notch by 18 to 22 weeks. Pulsatility index values at 18 to 22 weeks are typically less than 1.45.

Abnormal uterine artery Doppler has been associated with adverse events including development of preeclampsia, fetal growth restriction, and perinatal death. The uterine artery is a low resistance circulation and after the 25th week the S/D ratio should be less than 2.7 and there should be the absence of the diastolic notch. Unilateral or bilateral notching which persists beyond 24 weeks gestation is considered abnormal as well as patients above the 95th percentile RI for gestational age. The latter is usually defined as an RI in the uterine artery above .60.

Conclusion

The addition of pulsed and color Doppler has greatly added to the diagnostic potential for obstetric ultrasound. Doppler aids in the efficient and accurate performance of Doppler spectral sampling and contributes to the evaluation of structural and functional abnormalities of the fetus, umbilical cord, and placenta. Clinical action guided by Doppler US reduces the odds of perinatal death and complications of pregnancy, benefiting the fetus and the mother.