Doppler in Obstetrics and Gynecology: Principles and Practice

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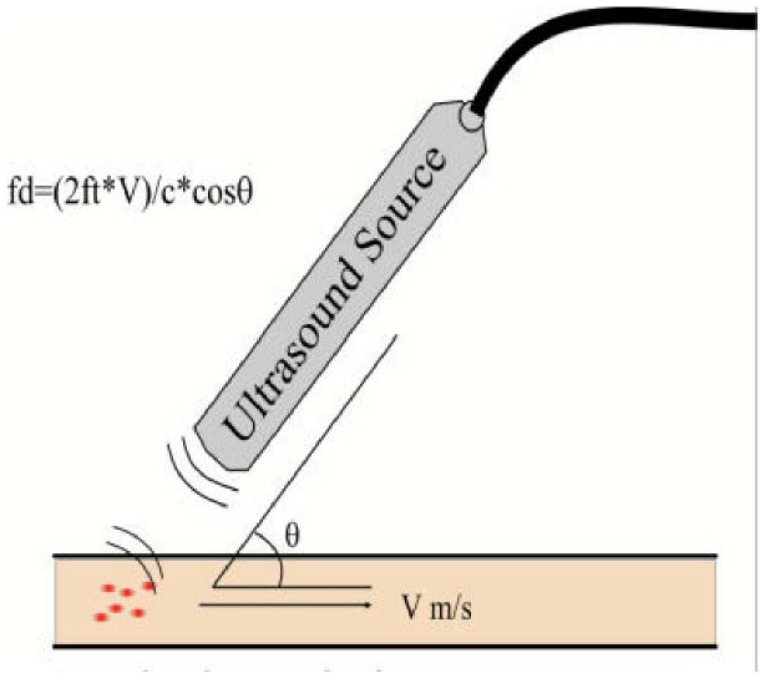
Introduction

The intent of this chapter is to present to the reader the basic principles of Doppler as they apply to Obstetrical and Gynecological practice. We believe that the material presented herein will enable the reader to understand the underlined physiological aspects of utero-placental and fetal circulation. It is important to understand that Doppler is just a tool and not a panacea. Helping us to obtain information regarding the resistance of the various utero-placental and fetal vessels is all about Doppler. How one interprets this information, and more importantly, how one acts or reacts to the meaning of this information is a totally different issue. Doppler has been presented as the perfect diagnostic tool by some and has been blasted as a useless waste of time and money by others. Of course, the truth lies somewhere in between. Obtaining vascular information from the uterine and fetal vessels is not as simple as obtaining information from the aorta, the carotid or the femoral artery in adults. A blocked carotid artery is going to cause certain symptoms to most of the patients who present with the problem. A pathologic uterine artery or fetal umbilical artery may not behave in the same manner. In fact, this is very much the case and understanding the different responses of the above-mentioned vessels in the placental and fetal circulation is of paramount importance. In addition, one has to know what to expect from a pathologic uterine artery or from a fetus with particular problems. We cannot expect from Doppler to predict maternal glycemic control for the same reason that we should not and do not expect an x-ray to tell us about the patient's blood pressure. With this in mind we will try

to enrich your understanding and thus enable you to get the best out of Doppler when used in appropriate Obstetrical and Gynecological procedures.

Basic Concepts of the Doppler Principle

The ***Doppler efect*** is the phenomenon observed during the interaction of a stationary sound receiver and a moving sound source (or the reverse). The stationary receiver perceives the sound emitted by the moving source to be of a different frequency. In addition, this frequency increases constantly as the sound source moves closer to the receiver or declines as the source moves further away from it. The Austrian mathematician and physicist Christian Doppler described this effect first in 1841-43. The change in frequency is called the ***Doppler shift in frequency*** or the ***Doppler shift.*** The layperson experiences the Doppler phenomenon in everyday life at the airport when an airplane lands. As the airplane approaches the airport, the jet engines emit a higher frequency sound and as it passes by and away from the receiver, the jet engines emit a lower frequency sound.



The Doppler phenomenon is observed in medicine when an ultrasound beam encounters a moving sound reflector (target) such as a moving red cell inside a blood vessel (Fig. 1).

Fig. 1: Graphic representation of the Doppler Principle

The Doppler effect can be expressed mathematically by the following formula:

$$f_d = 2f_t * \cos\theta * v/c \qquad (1)$$

f_d: Doppler frequency shift

f_t: frequency of the incident beam (transducer frequency)

θ: the angle between the incident ultrasound beam and the longitudinal axis of the vessel (direction of flow axis)

Cos: the cosine function of the angle θ

v: the velocity of the reflector (red cell)

c: the speed of sound in the reference medium (tissue)

Note: the factor 2 reflects the double Doppler shift because the moving red cell acts first as a moving receiver and subsequently as a moving reflector (source).

From equation (1) we can determine the velocity of the moving red cell by solving the problem for velocity as follows:

$$v = f_d * c/2f_t * \cos\theta \qquad (2)$$

From equation (2) we may estimate the blood flow velocity of the red blood cells in the vessel under examination if we know the angle between the incident beam of sound and the axis of the direction of flow in the reference vessel.

Flow is given by the following equation:

$$Q = A * V \qquad (3)$$

Q = blood flow

A = vessel cross sectional area

V = blood flow velocity

Blood flow is directly proportional to perfusion pressure and inversely proportional to resistance (impedance to flow):

$$Q = \Delta BP/R \qquad (4)$$

Q = blood flow

ΔBP = perfusion pressure

R = resistance (impedance to flow)

In order to evaluate blood flow in the umbilical artery, one needs to calculate the vessel's diameter, a rather difficult and inaccurate task given the size and tortuous course of the umbilical vessels. In addition, calculating the velocity requires that one know the angle of insonation (the angle formed by the vessel axis and the incident beam). This is not possible in the small and tortuous placental and uterine vessels. The perfusion pressure is also unknown, as well as the actual impedance to blood flow. Of all the above parameters that are necessary to calculate fetal blood flow, only the impedance to flow (R) can be estimated with clinically acceptable precision. This has been achieved by in vitro and in vivo experimentation involving direct measurements of blood flow and vascular impedance. Vascular impedance was then correlated with the various so called resistance indices (Fig 2), such as Resistance Index (RI), Pulsatility Index (PI), and Systolic to Diastolic Ratio (S/D).

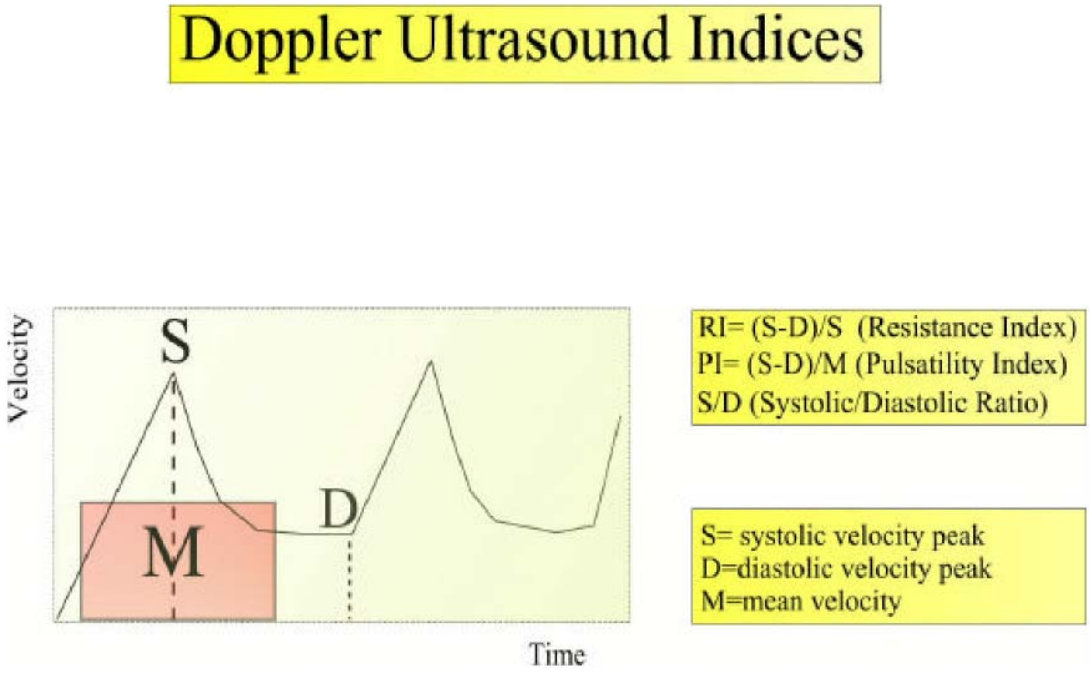


Fig. 2: Methodology for the calculation of the three most commonly used indices to calculate vascular impedance.

All three indices were found to correlate well with the actual impedance to flow. One may use any one index of the three. There are certain considerations to keep in mind regarding the clinical and statistical properties of these indices:

1. When end diastolic velocity is absent (zero), the S/D ratio becomes infinite.
2. The lower the diastolic velocity in the S/D ratio the larger the systematic error.
3. In cases with absent or reverse diastolic flow velocity only the PI can provide us with a measurable entity for future reference.
4. In research, comparisons of S/D ratios should be done with non-parametric statistics since S/D ratio is not normally distributed.

With the above information in mind, when we evaluate the fetal and uterine-placental circulations, we merely get an estimate of the impedance to blood flow, which in part only reflects actual changes in blood flow. Therefore, one should expect Doppler to be wrong in a number of occasions although it may be right in many others. It is imperative that Doppler evaluation of these vessels be only a component of the overall evaluation of the fetal and maternal conditions that may influence each pregnancy's outcome.

Doppler Modalities

Continuous Wave Doppler:

Continuous wave Doppler (CW) utilizes continuous emission and reception of sound. Signals returning from the insonated tissues overlap and are not distinguished as separate entities. If the sound beam crosses more than one vessel, all of them will be displayed simultaneously, and the operator will be unable to determine with reasonable certainty which vessel the signal is coming

from. In regards to the umbilical vessels, this is not much of a problem since these vessels are unique in the maternal body and only during pregnancy (Fig. 3).

In contrast, examination of the numerous uterine vessels can be very confusing (Fig. 4). In fact, this weakness has been the main reason for the highly variable and inconsistent results

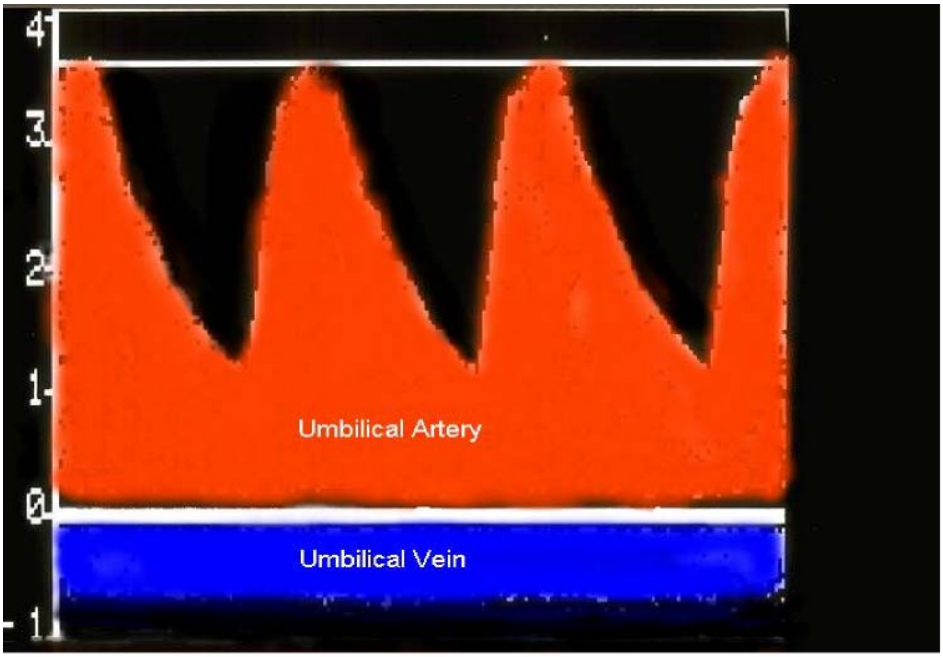


Fig. 3: Normal waveform of the umbilical cord obtained with CW Doppler. Note the simultaneous pulsatile umbilical artery (red) and non-pulsatile umbilical vein (blue).

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in the early clinical studies when single CW was used. The addition of duplex (simultaneous gray scale and CW imaging) has somewhat improved the results. In those early days, patience and considerable skill were necessary to achieve clinically acceptable results.

Pulsed Wave Doppler: Pulsed wave Doppler (PW) has improved our discriminatory abilities substantially. PW emits pulses of sound only for a fraction of time and receives the returning signals the rest of the time. Each returning echo is recognized by its timing and thus the system defines the depth of the structure (Fig. 5). With PW we can define the depth and the size of the area from which returning echoes will be accepted and all other echoes will be rejected. Thus,

with duplex PW Doppler we can see the vessel or the immediate region and then place the PW Doppler range gate over this area. This methodology also has its problems when it comes to the uterine artery since in most patients visualization of the uterine artery with gray scale imaging is extremely inaccurate.

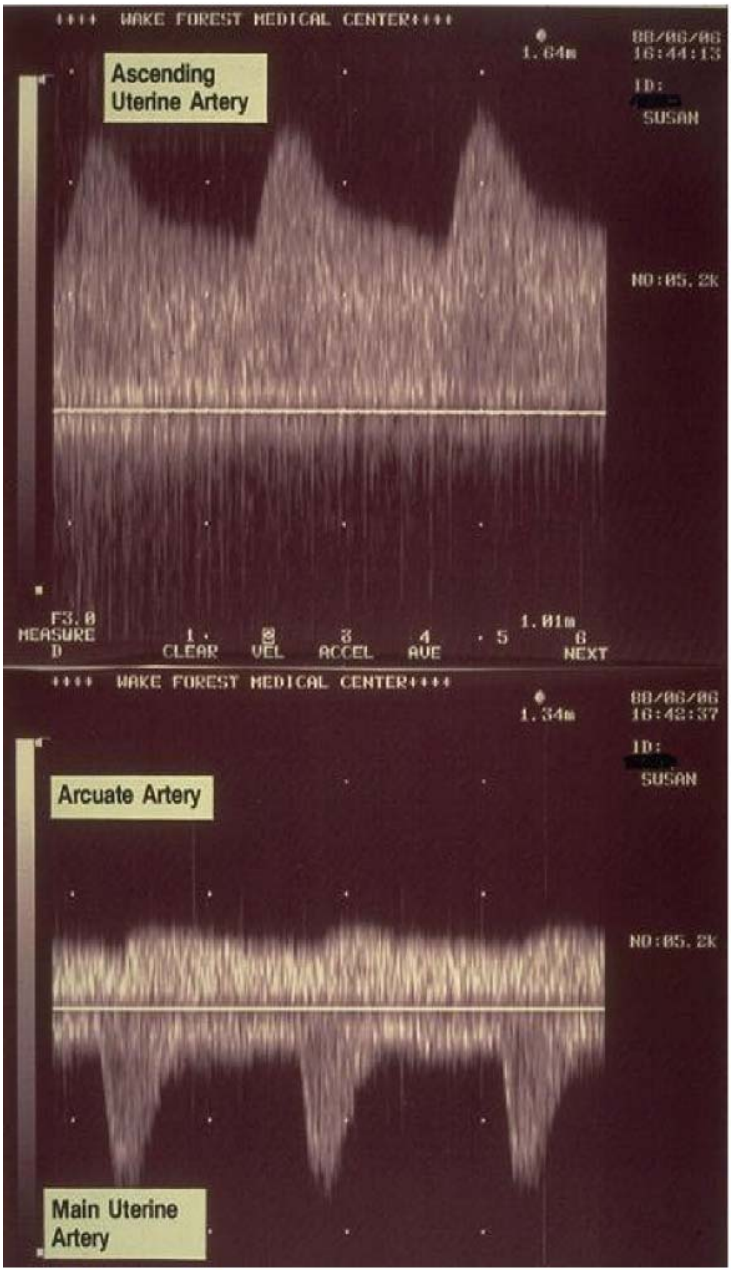

Fig. 4: All three different waveforms can be obtained with the same transducer and at the same insonation path making it impossible to obtain the same vessel with certainty in subsequent visits in long-term follow-up.

Color Doppler imaging:

The addition of color Doppler imaging (CDI) has made obtaining fetal and uterine vessel waveforms considerably easier and accurate. With CDI not only can we see the area of insonation precisely but also to delineate various vascular anatomic structures. CDI is limited, however, by its angle dependence and the inability to distinguish small vessels with low flow velocity, such as, smaller umbilical and uterine branches (Fig. 6).

Power color Doppler:

Power color Doppler (PD) has added to the sonographers capabilities by improving his/hers ability to evaluate smaller vascular structures with low flow

velocities. This is achieved by the fact that PD assesses the entire energy of the Doppler signal and by being angle independent (Fig. 7).

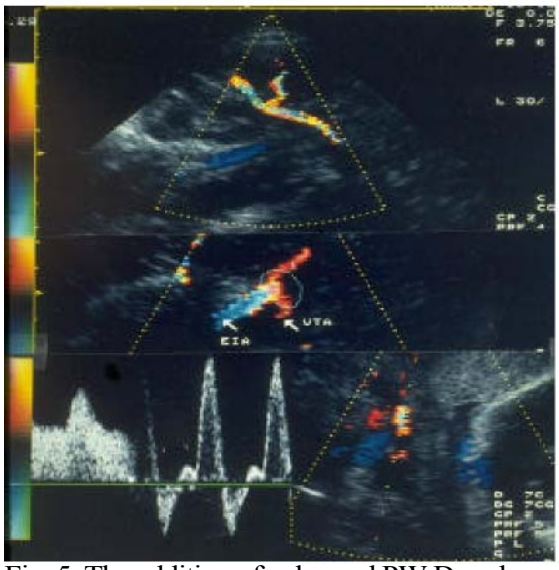

Fig. 5. The addition of color and PW Doppler makes the acquisition of the signals much easier and accurate.

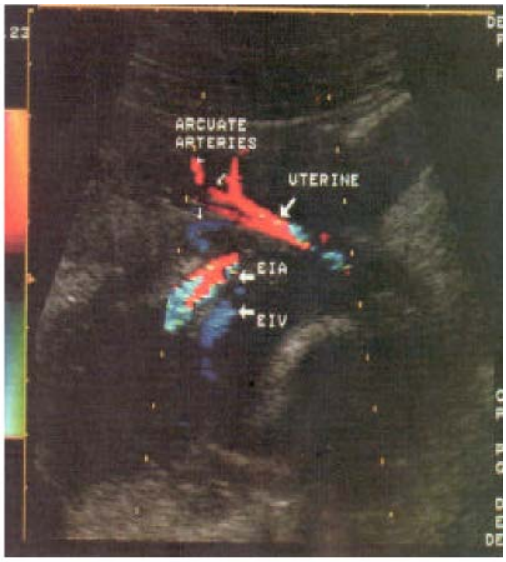

Fig. 6. The quality of imaging with Color Doppler approaches that of angiography.

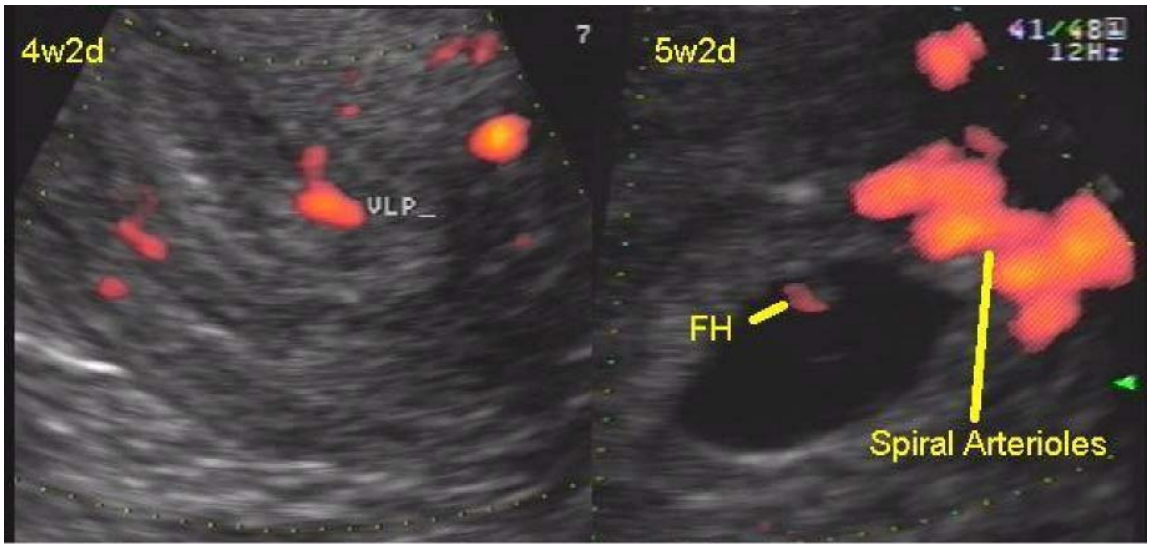

Fig. 7. Power color Doppler imaging has enabled us to visualize the slowest placenta flow pattern as early as 4 weeks gestation. (VLP: vascular leading pole)

Doppler applications in Obstetrics

The Normal Fetal Circulation

Fetal umbilical vessels : The umbilical artery originates within the fetal abdomen and is a branch of the fetal external iliac artery after the origin of the superior vesical artery . In postnatal life it becomes the medial umbilical ligament (one on each side of the neonatal urinary bladder). Likewise, the umbilical vein originates intra-abdominally from the junction of the portal sinus and ductus venosus. In postnatal life the umbilical vein becomes the so-called ligamentum teres. The umbilical arteries take deoxygenated fetal blood to the placental chorionic vessels for oxygenation and this blood returns back to the fetal heart for re-distribution via the umbilical vein. One umbilical vein and two umbilical arteries enter the chorionic plate at the fetal placental surface. From this point on, both vascular structures branch out in a radial fashion towards the placental perimeter. Normally, an arterial branch accompanies each venous branch. Subsequently, and at various intervals smaller branches enter the main stem villus perpendicular to the placental chorionic plate; from this point on extensive branching of these vessels leads to the development of a vast arterio-capillary-venous system which provides the fetal-maternal interface necessary for the exchange of metabolic and gaseous products between the two otherwise independent circulations. It is evident then, that both vascular structures are equally important for the well being of the fetus.
Flow disturbances in the umbilical vein may reflect restriction of venous flow secondary to external compression or intrinsic pathology such as hematoma, varicosity, etc.. In addition, flow in the umbilical vein may be disturbed by changes in the intrathoracic pressure (lung tumors, pericardial or pleural effusion as well as other intrathoracic pathology) or changes in the intracardiac pressures (congenital cardiac disorders, anemia, hydrops etc.).
Flow disturbances in the umbilical artery may reflect a multitude of normal as well pathologic conditions. Oligohydramnios and nuchal cord represent conditions that may be associated with umbilical cord compression and abnormal blood flow waveforms in the umbilical artery in the

absence of intrinsic fetal placental pathology. Fetal conditions that may affect the quality of umbilical artery waveforms include but are not limited to cardiac disease (functional and structural), anemia, hypoxia, cord vessel abnormalities (single umbilical artery, discordant umbilical arteries, cord hematoma, umbilical artery aneurysm etc.) and in most cases fetal chorionic vessel abnormalities. One needs to understand all this before proper interpretation of Doppler and clinical utilization can be implemented.

Ductus Venosus: This structure has been illusive until recently. Color and pulsed Doppler helped us map this vessel's anatomic and functional relationship with the rest of the fetal circulation. From all the evidence (however limited) it seems that this vessel is of significant importance to the maintenance of fetal oxygenation and plays a role in the preferential distribution of oxygenated blood directly into the left atrium with minimal mixing from deoxygenated fetal blood entering the heart via the superior and inferior vena cava (SVC and IVC respectively) (Fig. 8).

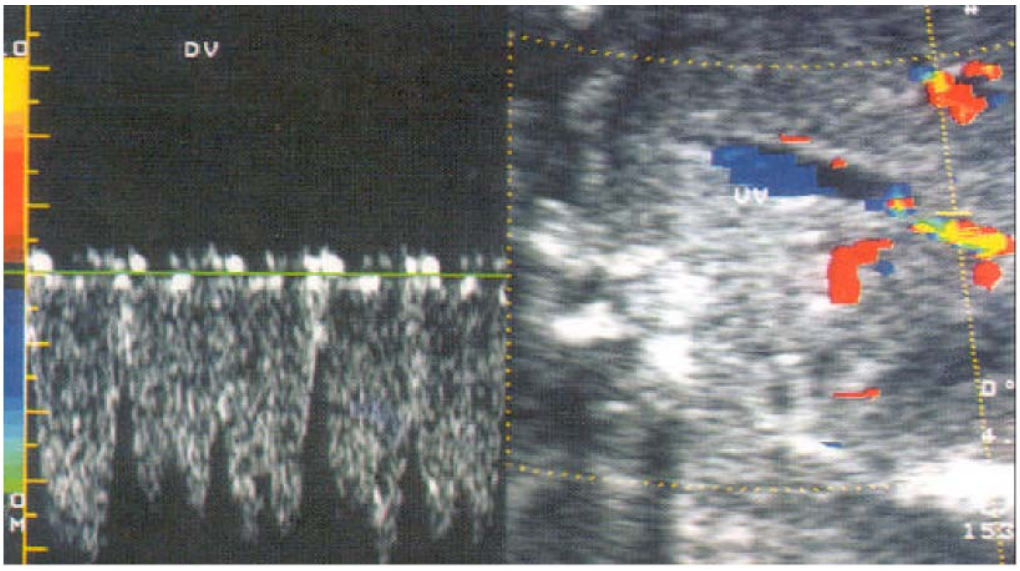

Fig. 8. Normal PW flow pattern in from the ductus venosus. Note the change in color from the blue at the level of the umbilical vein (UV) to bright yellow. This is the result of aliasing from the increase in velocity.

Inferior vena cava: This vessel provides a lot of information due to its proximity to the right atrium. Pressure changes in the fetal right heart (atrium and ventricle) reflect directly into the

IVC and affect its flow velocity waveform (FVW) in ways that we can identify and extract clinically useful information (Fig. 9).

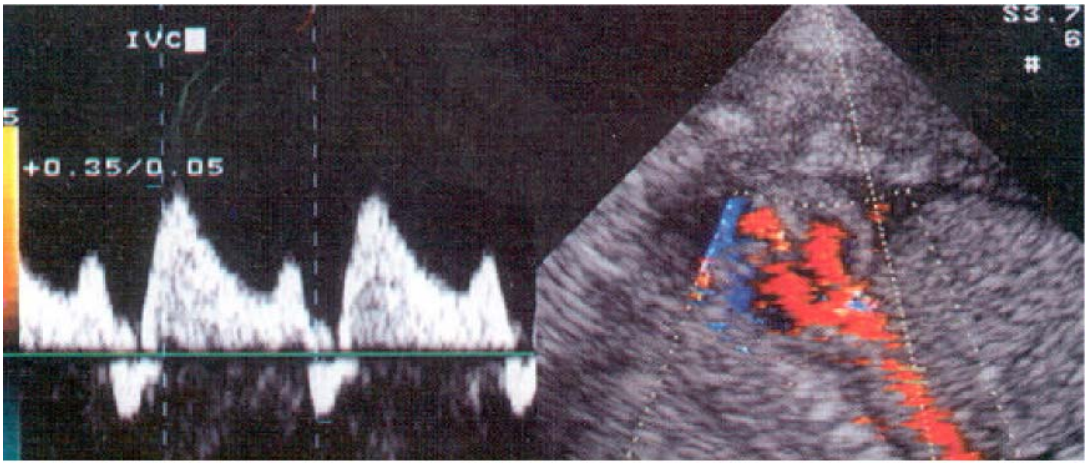

Fig. 9. Note the triphasic PW flow pattern in the fetal inferior vena cava (IVC).

Middle cerebral artery: The middle cerebral artery (MCA) originates from the circle of Willis at the junction with the internal carotid artery and supplies a significant portion of the human brain (Fig. 10). Its main arterial branches include the anterolateral ganglionic, inferior external frontal, ascending frontal, ascending parietal, and parietotemporal arteries. There is little known on the development of the cerebral vasculature of the human fetus after 24 weeks' gestation, although significant changes take place in the cerebral growth and vascular development. Factors such as, fetal heart rate, fetal breathing, and behavioral states can affect the flow velocity waveforms from the MCA significantly.

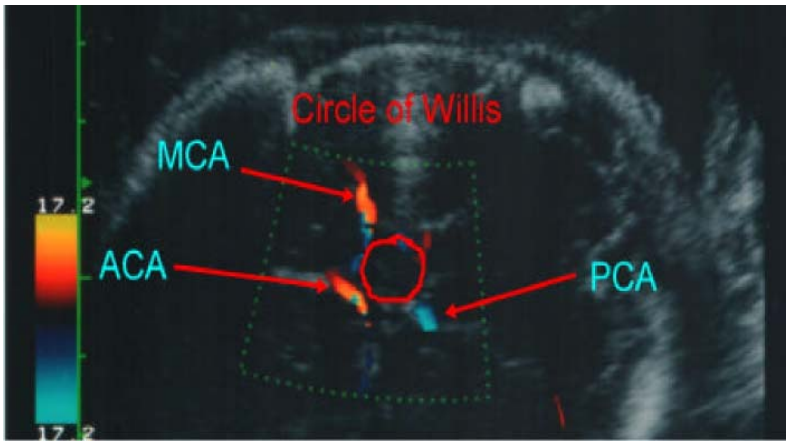

Fig. 10. Color Doppler imaging of the Circle of Willis with the intracranial vessels. MCA: Middle cerebral artery, ACA: anterior cerebral artery, and PCA: posterior cerebral artery.

Ductus arteriosus: The ductus arteriosus (DA) is the main outflow for the fetal right ventricle since fetal pulmonary circulation is underperfused. Through the ductus arteriosus the less oxygenated blood from the right ventricle is directed towards the descending aorta (DsA). Congenital heart defects and iatrogenic causes may lead to altered flow, which in turn may affect the rest of the cardiovascular functions. In utero occlusion of the ductus arteriosus (regardless of cause) may lead to right ventricular dilatation and tricuspid regurgitation. CDI along with duplex CW or PW Doppler can be instrumental in the management of these patients (Fig. 11). The descending aorta is informative in the evaluation of the fetus with growth restriction and blood flow redistribution.

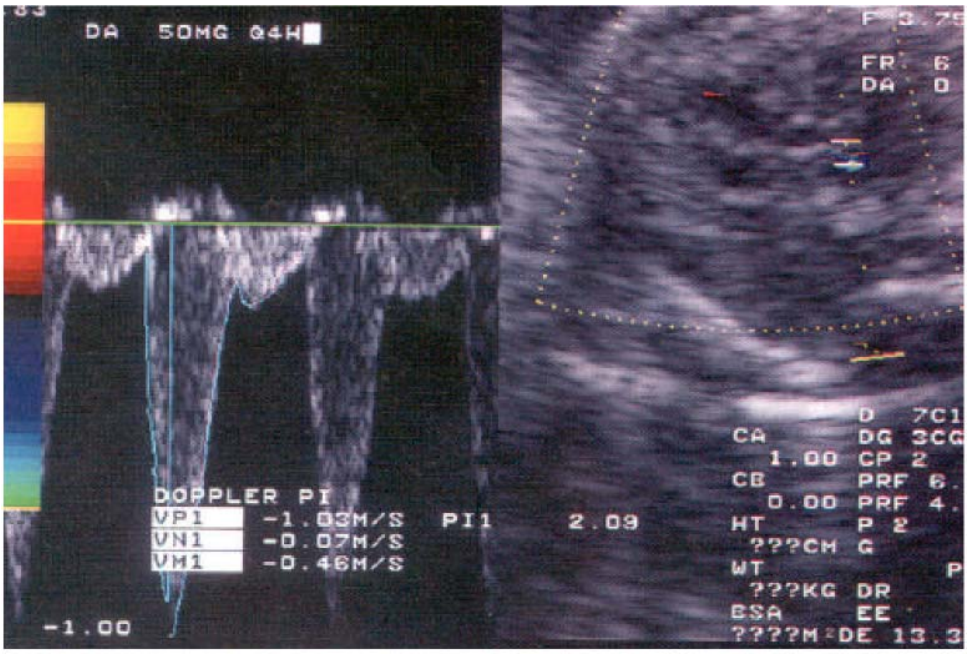

Fig. 11. Normal flow pattern in the Ductus arteriosus in a fetus exposed to Indomethacin for preterm labor treatment. The use of Doppler allows the safe use of this potent and efficacious tocolytic agent.

Normal uterine -placental circulation

Uterine artery: The uterine artery (UtA) originates from the internal iliac artery (Fig. 12). At the level of the isthmus (cervical-uterine body junction) it divides into two branches; the cervical and the ascending uterine artery. After a short convoluted course along the parametrial area, it

gives off several medially directed branches, the arcuate arteries. From the arcuate arteries originate the radial arteries, which travel radially to the uterine surface

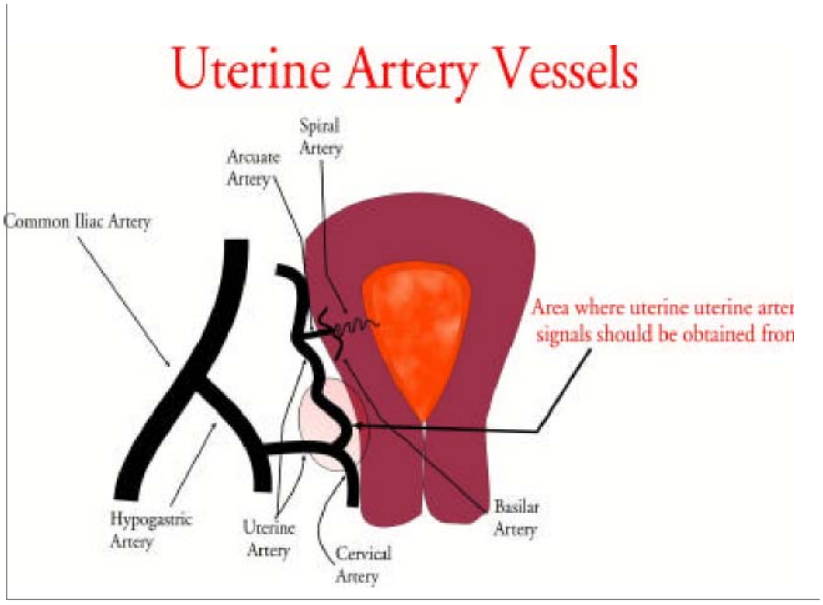

Fig. 12. Graphic representation of the origin of the uterine artery as it branches off of the iliac vessels and hypogastric artery. The uterine artery Doppler signal should be acquired at the pink circular shaded area for accuracy and reproducibility of measurements

perforating the myometrium towards the endometrium. The radial arteries terminate in the form of the spiral arterioles after they give off the basilar branches. The spiral arterioles through a convoluted course perforate the sub-endometrial myometrium and terminate into the most superficial area of the endometrium. At this level, the trophoblast will invade the spiral arterioles and initiate the development of this magnificent organ, the placenta.

The uterine artery is the most misunderstood pregnancy related vessel. Some of the most profound changes take place in the uterine circulation during the course of the normal human pregnancy. Trophoblast invasion of the spiral arterioles leads to a substantial reduction in the impedance to flow in the uterine vessels. The spiral arterioles loose their muscular wall, which is replaced by trophoblastic cells. This renders these vessels incapable of vasoconstriction. This event ensures the lowest possible impedance to flow and continuous blood flow during the diastolic phase of the cardiac cycle. Concurrent hormonal changes (high estrogen and progesterone levels) add to the increase and maintenance of high blood flow to the placental vessels. These dramatic changes reflect in the shape of the uterine flow velocity waveform, which transforms from a high systolic and low or absent diastolic pattern to one of high systolic and high diastolic flow pattern. This assures continuous uninterrupted blood flow under a variety

of adverse conditions. As mentioned earlier, the uterine artery is a difficult vessel to evaluate without color and PW Doppler. This difficulty led to a number of conflicting reports and up until now, few researchers have paid appropriate attention to its clinical significance to the extend that they only evaluate the fetal circulation and ignore the uterine vessels. When the entire pregnancy depends on proper uterine blood supply, how can one be so blind? Improved technology and better understanding will ultimately pay justice to this important vessel. Uterine contractions increase the uterine artery resistance by external compression of the arcuate arteries but mostly by severe constriction of the radial arteries that travel between interlaced "S" shaped uterine myometrial smooth muscle fibers. However, we have shown that all vessels under the placenta are not affected at all by uterine contractility and the constriction of the vessels away from the placenta does not decrease enough the placental perfusion in normal pregnancies to affect pregnancy outcome. In patients with pathologic placentas however, this may be detrimental. This protective effect of the placenta to its underlined vessels is strictly attributed to increased levels of progesterone.

Clinical applications of Doppler methodology in pathologic pregnancies *Intrauterine growth retardation (IUGR):* Significant work has been done regarding the validity and clinical usefulness of Doppler in fetuses with growth retardation. The balk of the studies dealt with the umbilical artery, since this is one of the most important fetal vessels, which connects the fetus with the placenta and the maternal supply-line. Changes in the placental umbilical branches (villous edema, endo-vascular fibrosis, placental infarcts, and fetal arterial thrombosis) increase the peripheral vascular resistance; these changes cause decreased diastolic flow velocity with increased resistance indices (Fig. 13 and Fig. 14).

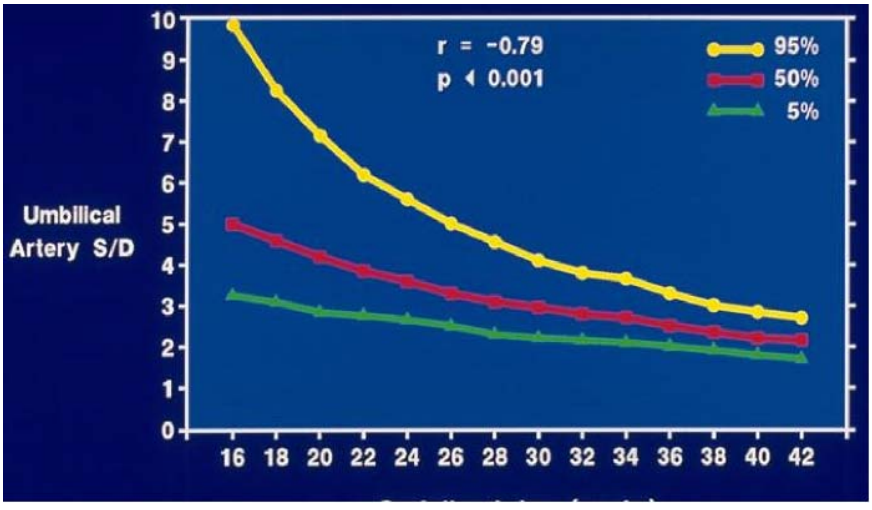

Fig. 13.
The graph to the left represents the normal changes in the impedance of the Umbilical artery (expressed as S/D ratio) during gestation. In pathologic gestations, the impedance remains high and above the 95th %.

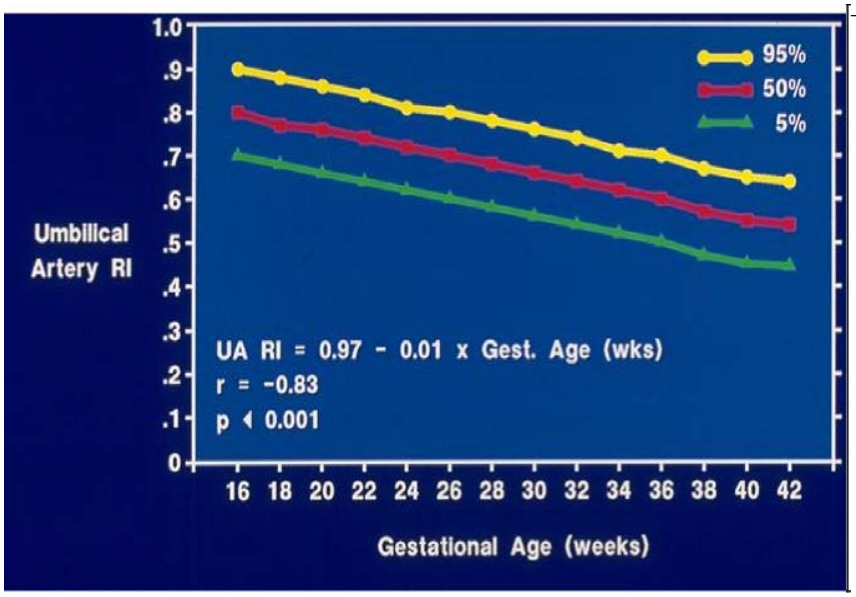

Fig. 14.
The graph to the left represents the normal changes in the impedance of the Umbilical artery (expressed as RI) during gestation.
In pathologic gestations, the impedance remains high and above the 95th %.

In severe cases, the diastolic flow is absent and in the most severe forms of the condition, there is reversal of flow during the diastolic phase of the cardiac cycle. Increased umbilical artery resistance with present diastolic flow velocity is associated with increased incidence of growth restriction of variable degrees; its presence should prompt a thorough clinical and ultrasonographic evaluation to determine the cause and thus intervene to prevent deterioration. In addition, fetal surveillance with the most appropriate means should commence at this point. When there is no diastolic flow or there is reverse flow during diastole, immediate action is mandated in the form of delivery or intense fetal surveillance to prevent fetal compromise or even demise, since this condition has been associated with dismal perinatal outcomes. In general, pathologic fetal heart rate tracings appear approximately 3 weeks after the changes in the umbilical artery Doppler. Usually, mild umbilical Doppler changes (pathologic resistance indices with diastolic flow present) are associated with normal fetal heart rate tracings. As the diastolic flow declines, the chances of pathologic FHR tracings increases. With absent (Fig. 15) or reverse diastolic flow velocity (Fig. 16), it is almost certain that the FHR tracing will be pathologic, suggestive of disturbed fetal acid-base balance. In fetuses with IUGR, the presence of pathologic FHR tracing has been associated with increased incidence of poor postnatal

physical and mental development. In contrast, in fetuses with IUGR, mild pathologic changes in the UA

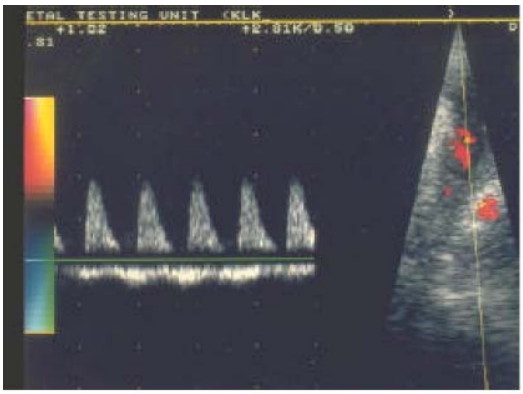

Fig. 15. Abnormal umbilical artery flow velocity pattern with absent end diastolic flow velocity.

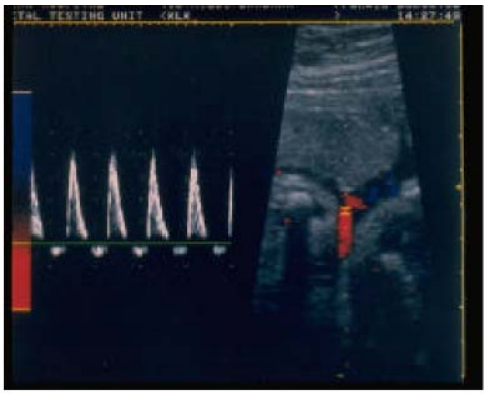

Fig. 16. Abnormal umbilical artery flow velocity pattern with reverse end diastolic flow velocity.

resistance, but normal FHR tracings is associated with normal postnatal development in the great majority of the neonates. Therefore, it becomes evident that Doppler changes should prompt us to take action to prevent the development of pathologic FHR tracing if we are to prevent fetal compromise. In term pregnancies with mild Doppler changes, the decision to deliver the fetus comes easily, since there is nothing for the fetus to gain and a lot to loose. In pre-term pregnancies, however, a fine line is drawn between fetal benefit and fetal risk. In such cases, more sophisticated management is in order with the addition of more involved assessment of the fetus under examination as it will be presented later on, in subsequent sections. It is possible to have IUGR in the presence of normal umbilical artery resistance. This may be seen in genetically small but otherwise normal fetuses. In contrast, normal weight fetuses with pathologic umbilical artery resistance are at risk for compromise since these fetuses may be growth retarded according to their genetic potential despite their apparent normal weight. Another reason for normal umbilical artery in the presence of IUGR is the presence of focal or generalized uterine artery pathology in the presence of intact fetal umbilical circulation. Therefor, knowledge of the status of the uterine artery is important even when the umbilical artery remains normal.

Maternal vascular conditions: There is a significant number of pathologic maternal conditions whereby the uterine artery is the first and only vessel to be abnormal, and as the pregnancy advances, the umbilical vessels start developing abnormal findings. In patients with severe chronic hypertension with vasculopathy, severe early pre-eclampsia, chronic renal disease (nephritis, glomerulonephritis, diabetic nephropathy etc.), collagen vascular diseases, and patients with recurrent unexplained pregnancy losses, pathologic uterine artery is the only Doppler finding early in pregnancy that indicates poor placental development. This is evident as early as 12 to 14 weeks of gestation, at the completion of the first wave of trophoblastic invasion. Intervention at this point may change the pregnancy outcome for the better. Left untreated, this condition eventually will limit the development of the umbilical vessels and lead to variable degrees of placental failure with subsequent fetal consequences (IUGR or fetal loss). In our laboratory, all patients with the above mentioned maternal conditions undergo transvaginal Doppler (color and PW) to evaluate the Doppler waveforms of the uterine arteries. If there is appropriate resistance with high diastolic flow and no evidence of notch, the placental development is considered to proceed normally and if the condition is similar at 24 to 26 weeks gestation (completion of the second wave of trophoblastic invasion) the pregnancy is expected to be uneventful with a minute risk for IUGR and / or pre-eclampsia. To the contrary, if there is abnormally high resistance or more importantly, if there is severe notching (Fig. 17), it is considered that the placental development is not proceeding well and intervention is initiated. The kind of intervention will depend on the underline condition. We usually start all patients on one baby aspirin (81 mg) per day and we may add 10 mg of prednisone po. or 5000 units of heparin subcutaneously according to the overall maternal clinical condition. Follow-up studies are performed in 2 to 4 week intervals depending on the magnitude of the pathology.

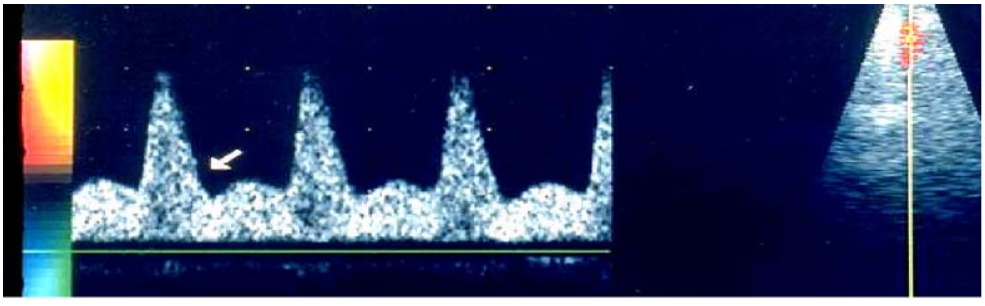

Fig. 17. Abnormal uterine artery impedance with severe notch (arrow), suggestive of poor placental trophoblastic invasion.

Placental degenerative changes: This is a term we use to describe certain placental sonographic findings. One of them is the so-called "placental lakes" or "placental infarcts" (Fig. 18).

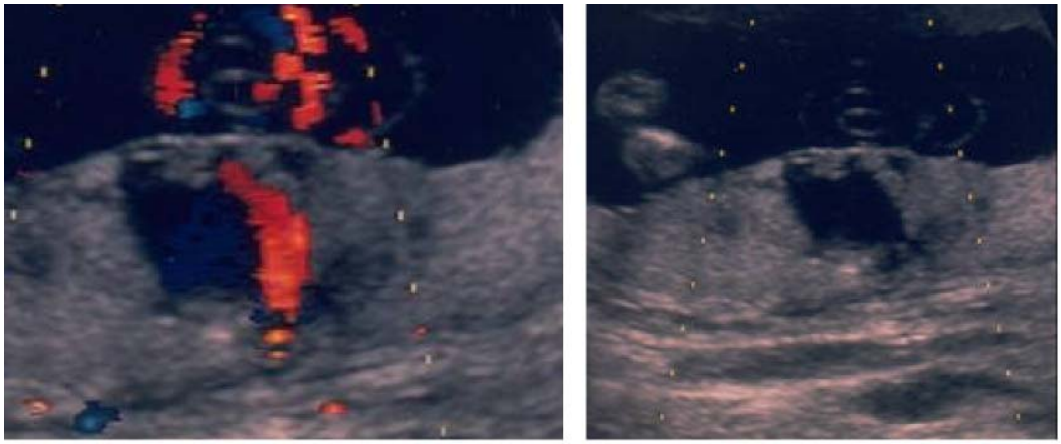

Fig. 18. Evidence of placental thrombosis after primary chorionic villous thrombosis and degeneration. Maternal circulation was active for two weeks after fetal vessel thrombosis was diagnosed on a patient with unexplained MS-AFP elevation.

The term "placental lakes" describes an anechoic segment in the placental parenchyma and is a strictly sonographic term. The term "placental infarcts" is a strictly pathologoanatomic term and describes a segment of the placenta with no active maternal circulation and hyaline deposition with or without the presence of fetal chorionic vessels. Placental lakes are conditions where fetal chorionic villi have been destroyed and the corresponding spiral arterioles perfuse a vacant space. Ultimately, this space will be thrombosed and become an infarct; a red infarct if the placenta is delivered shortly after or a white infarct (hyaline degeneration) if the placenta is delivered remotely in time. We have followed patients with placental lakes of variable onset and documented active spiral arteriolar perfusion up to 3 weeks. At the time of delivery the placenta had a variety of infarcts in all developmental stages, from soft jell-like clots to hard white infarcts with hyaline deposits (Fig. 19).

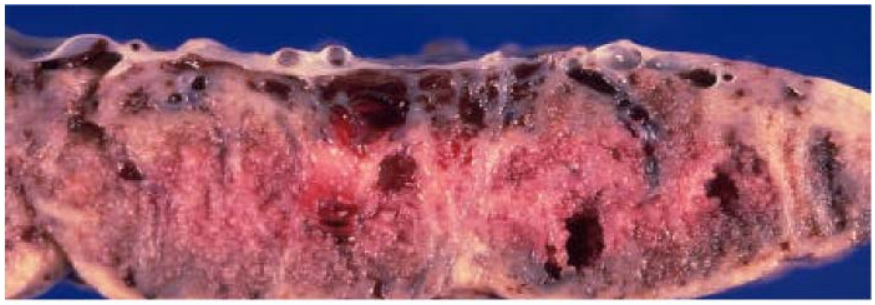

Fig. 19. Severe placental thrombosis with villous degeneration in a case with severe IUGR

We have also been able to document numerous cases with variable degrees of chorionic villi degeneration, which appear on gray scale imaging as variably anechoic placental areas. In vivo needle biopsies in 3 of these cases revealed a number of lesions in the fetal chorionic vessels, such as, endovasculitis, endo-vascular thrombosis, peri-vascular fibrosis and villous edema. These patients have a high incidence of anti-phospholipid antibodies (20 to 30%) and increased incidence of pregnancy loss, IUGR and pre-eclampsia. When we identify placental degenerative changes, in patients who come for routine ultra- sonography in the absence of identifiable maternal disease, we initiate treatment with one baby aspirin and obtain a complete profile of anti-phospholipid antibodies and thrombophilia. If antibodies and any thrombophilic abnormalities are identified, then treatment with prednisone and / or Lovenox is initiated along with proper follow-up as discussed above. The importance of this finding lies with the fact that it is a recurrent finding in subsequent pregnancies in which case early treatment (at conception) with aspirin and Lovenox is indicated. If prednisone is indicated it is not started until after 12 weeks to minimize the risk for fetal anomalies. The Doppler findings in these patients are variable and depend on the primary underlying pathology. In early pregnancy, it is usually the uterine circulation that suffers while the umbilical artery appears normal. With advancing gestation however, the umbilical artery is affected in variable degrees. This is primarily due to the fact that placental quantitative development in early pregnancy is far more advanced than the fetal development. As the fetal demands for growth increase after 20 weeks of gestation, fetal vascular pathology becomes increasingly evident. Only in the most severe of the cases we found pathologic umbilical Doppler prior to 20 weeks gestation. Most of these cases if left untreated, will lead to severely pathologic fetal and uterine artery Doppler findings.

Unilateral placenta: Placental location in the uterine cavity is a random event. The two uterine arteries to equivalent degrees provide uterine blood supply. This has been shown with infusion of colored plastic liquids that form a vascular cast after chemical destruction of the uterine

tissues. The presence of anastomoses between the two uterine arteries has been shown also. However, whether these anastomoses are functional or not has never been proven. We have shown that the presence of unilateral placenta is associated with increased incidence of IUGR and / or pre-eclampsia (threefold). In these patients, the non-placental uterine artery has significantly increased resistance in comparison to the placental uterine artery (Fig. 20).

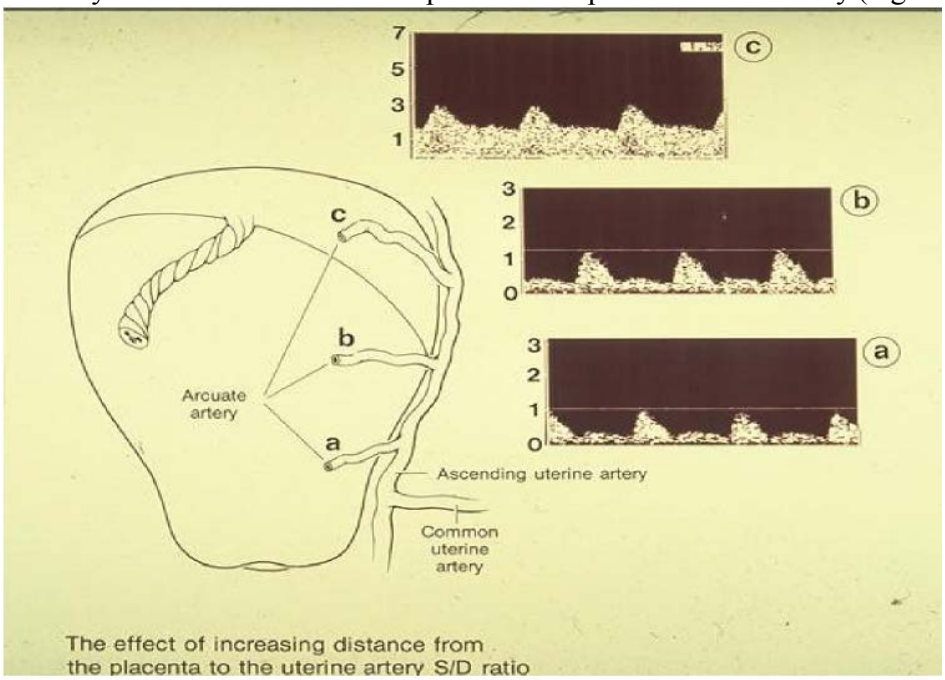

Fig. 20. Graphic representation of the effect of placental location in relation to the impedance of the uterine vessels. The further away from the placenta, the higher the impedance is.

We have published normal values for this condition. On the other hand, in patients with unilateral placenta and normal uterine artery resistance bilaterally, the pregnancy outcome is usually normal. The later happens in approximately 70 % of the patients with unilateral placenta. This indirectly suggests that in most patients the anatomic anastomoses of the uterine arteries are functional whereas in the rest are not. The worst outcomes in patients with unilateral placenta and discordant uterine arteries happen when the placental uterine artery is pathologic with high resistance index or most importantly when it has a notch. Patients with unilateral placenta require close sonographic evaluation for growth and clinical evaluation for development of preeclampsia. In patients with persistent pathologic uterine Doppler at 24 weeks and beyond, we

initiate treatment with one baby aspirin and advise limited physical activity with or without bed rest.

Maternal treatment: When pregnant women are treated for pregnancy complications and the medication in use crosses the placenta, naturally one wonders if this medication has any side effects on the fetus. In cases where the side effects regard the cardiovascular system of the fetus, Doppler evaluation of the fetal cardiovascular system is possible and can elucidate the concerns. Maternal treatment for premature labor with Indomethacin may be the most important case in point. Premature labor not responding to conventional means may require Indomethacin, which is known to cause premature closure of the ductus arteriosus in utero. This can have detrimental effects to the fetal cardiovascular function and may even cause fetal demise. However, not all fetuses respond equally and thus treatment is possible if one has the means and experience required to evaluate ductal flow dynamics. In fact, we have been able to use as much as 100 mg Indomethacin every 6 hours and only after several days of treatment we show a small degree of stenosis which responded to a modest decrease of the dosage. With accumulating experience, we have been able to use Indomethacin even in patients with degenerating leimyomas. It is known that within the first 48 hours of use, Indomethacin does not cause any clinically significant constriction of the ductus. Therefor, if treatment is in need beyond this time limit, fetal evaluation with Doppler is in order every 2- 3 days. The normal PI value for the ductus is between 2 and 3 and is unaffected by gestation. After 34 weeks gestation Indomethacin should never be used due to its profound effect on the ductus. In patients with chronic hypertension and / or chronic cardiovascular conditions who require continuous treatment with cardiovascular drugs that may affect fetal cardiovascular status, treatment may be monitored with Doppler of the fetal and maternal circulations. As our experience expands, we may be able to provide ever more sophisticated care to the fetus.

Clinical applications of MCA Doppler and the "brain sparing phenomenon ": As mentioned previously, fetal heart tracings remain normal for about 3 weeks after the appearance of pathologic fetal umbilical Doppler. As the umbilical artery resistance increases the fetus

responds in an effort to combat the increasingly hostile environment of decreasing blood supply. This adaptational response is carried out by increasing peripheral vascular resistance in structures such as lower and upper extremities, gastrointestinal tract, kidneys and progressively all other structures with the exception of the adrenals, the heart and the brain. This increase in the peripheral resistance allows blood to flow towards the path of least resistance, the adrenals, cardiac structures, and the brain. Of all changes, the ones involving the human brain are best known and studied due to the ease of access of the brain vessels with current Doppler methodology. Studies have shown that when the placental function and ability to supply well oxygenated blood to the fast growing fetus fails, fetal growth declines. The decline in growth however, is not equal in all fetal segments. The brain, the heart, and the adrenals are "spared" so to speak thus the so-called "brain-sparing phenomenon". Increased peripheral resistance with decreased brain resistance leads to preferential supply of the most vital human organ. Brain sparing should be seen as a normal response of a healthy fetus adjusting to an increasingly hostile environment. Unfortunately, the contrary has dominated in the perinatal literature. Brain sparing has been equated with fetal disease. This preferential treatment of the brain has a limit. When this limit is reached, the fetus is in immediate danger for irreparable damage. However, there is a very fine line between successful brain sparing and failed brain sparing. Crossing this line is very easy, since we do not have complete understanding of time related dynamics of this condition. Until further studies allow us to be more precise regarding the timing and accuracy of the measurements, the mere presence of brain sparing in the term fetus should be considered an indication for delivery and in the premature fetus it should constitute an indication of intense conventional monitoring and treatment. Brain sparing is measured by the relationship of the middle cerebral artery resistance with the resistance in the umbilical artery and descending aorta. In our laboratory we use both methods simultaneously, because we believe that they reflect different etiologies for brain sparing.

Fetal anemia of variable etiologies: Anemia is associated with decreased oxygen carrying capacity. The adult as well the fetus, compensate by increased heart rate and increased stroke volume (hyper-dynamic cardiovascular function). This causes the cardiac output to increase and

thus deliver the needed oxygen to the tissues. In the fetus, these changes can be assessed with cardiovascular and uteroplacental Doppler. Progressive anemia (erythroblastosis fetalis of any etiology or anemia from human parvo-virus) causes progressively hyper-dynamic circulatory changes, which in turn cause increased Doppler velocities in the major cardiac inlets and outlets. In addition, cardiac congestion in the more severe cases of fetal anemia is accompanied by changes in the inferior vena cava Doppler flow velocity waveforms. These findings appear before the development of the hydropic changes and if properly used, they can improve fetal care by diminishing the need for invasive and risky fetal monitoring. In fact, we have almost eliminated the need for frequent fetal blood sampling in these cases with appropriate use of Doppler methodology. This method has been very beneficial to fetuses suffering from human parvovirus since in most instances this is a self-limited condition and only a small number of fetuses develop severe anemia to the degree that intrauterine transfusion is required.

Congenital fetal heart disease: Congenital heart disease causes a variety of functional disturbances in the central as well as peripheral fetal vessels. Two-dimensional and M-mode sonography have been instrumental in our ability to diagnose fetal structural and certain functional cardiac anomalies. The addition of all Doppler modalities gave us the ability to make a diagnosis in almost every conceivable fetal cardiac anomaly. In addition, Doppler has given us the ability to evaluate fetal cardiac function in ways that gray scale imaging cannot (Fig. 21).

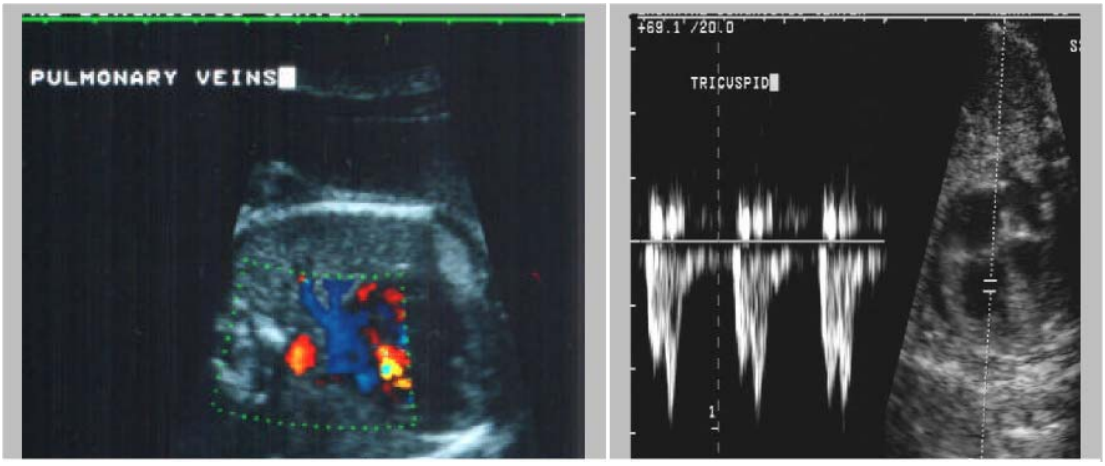

Fig. 21. Color and PW Doppler echocardiography allows us to assess the overall cardiovascular condition of the fetus and thus provide sophisticated management.

Armed with these modern tools, we are able to identify fetuses with congenital cardiac problems and provide them with excellent care. This has improved the perinatal outcomes and coupled with modern cardiac surgical techniques, has opened new opportunities for quality life for thousands of otherwise doomed human lives.

Diagnosis of non-cardiac fetal anatomical lesions: There is a number of fetal structural defects that are vascular in origin and can be best diagnosed by Doppler or simply, Doppler can be instrumental in their diagnosis. It is worth while noting here that in most instances it is the use of color Doppler that is useful for the diagnosis of non-cardiac fetal anomalies. Umbilical cord anomalies such as single or discordant umbilical artery, umbilical artery aneurysm, and umbilical vein varicosities can now be diagnosed with accuracy (Fig. 22).

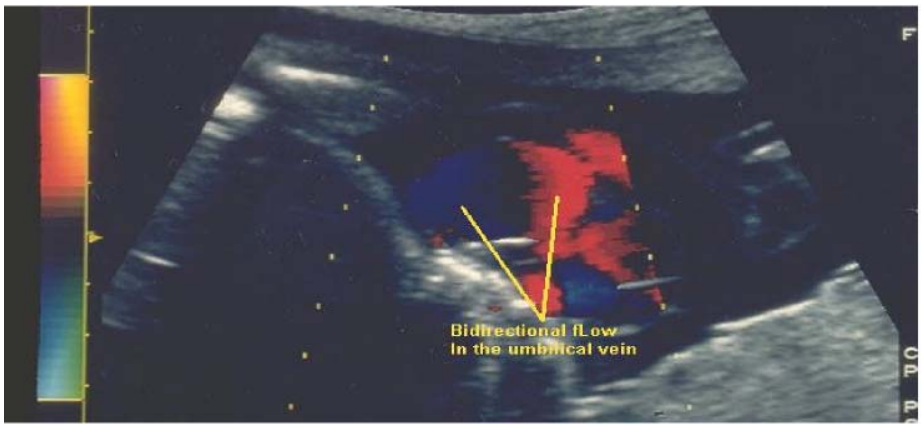

Fig. 22. Note the bidirectional circular flow pattern in the dilated umbilical vein.

Color and pulsed wave Doppler are instrumental in the diagnosis of vascular tumors of the liver and the placenta. Doppler should be used in all fetal cystic lesions in order to differentiate from vascular etiology; for example, the aneurysm of the vein of Galen can never be diagnosed with accuracy without the use of PW or CDI. Color Doppler imaging has been used recently for the diagnosis of arterio-venous anastomoses in placentas of monozygotic twin gestations. Most recently we have started using power Doppler in an attempt to better characterize placental lesions.

Role of Doppler in fetal therapy: Apart from the ability to diagnose certain fetal lesions that contribute to fetal care, the role of Doppler in fetal therapy is limited to only a few indications. We have been using CDI to guide the needle in all cases of fetal blood sampling and fetal intra-vascular transfusions. Of importance also is the use of CDI during amnioinfusion in cases of severe oligohydramnios; the role of Doppler in these cases is to identify compressed loops of umbilical cord and thus avoid unintended puncture. In addition, we evaluate the presence of unobstructed needle out-flow during the initial stages of the infusion.

Doppler applications in Gynecology

Introduction

The amount of research in gynecology pales that of obstetrics. The indications for Doppler in gynecology are limited although they may turn out to be very important. The normal nonpregnant uterus is not a very vascular organ. For Doppler to be useful there must be vessels to be examined. In gynecology, with the exception of normal early pregnancy, the conditions that can be evaluated by Doppler are abnormal. The subject that has been examined the most in gynecology is ovarian cancer with less research devoted to the study of normal follicle and the corpus luteum. Transvaginal color Doppler in combination with PW Doppler is the methodology used in all gynecologic indications.

Clinical conditions in gynecology

Ovarian neoplasias: Ovarian malignancies are the most difficult to diagnose among all gynecologic malignancies. Early diagnosis is essential for best treatment results. The addition of color Doppler on the transvaginal ultrasound has increased our ability to identify ovarian vessels and thus evaluate them for increased flow, which is expected to be present in a malignancy. Neovascularization leads to a significant reduction in the resistance of the vessels that supply the ovarian tissue. Color Doppler is used to identify the particular vessels and PW to obtain flow velocity waveforms and estimate the vascular resistance. Original work was very encouraging and a resistance index (RI) value of 0.41 was considered to be the lowest normal value. When

the RI value was lower than 0.41 the risk for malignancy was increased. Subsequent work has not been so encouraging since there seems to be a significant number of false negative as well as false positive. This is more likely to happen in premenopausal women since they are more likely to have benign pathology that presents with low vascular resistance. It is clear from the current experience that although Doppler may be a useful tool for the diagnosis of early ovarian malignancies, it is equally clear that a lot more work needs to be done. The use of power Doppler may also add to our ability to identify vessels in early stages of the disease and needs to be investigated.

Benign gynecologic conditions: The blood supply to the ovarian follicle increases with increasing follicular maturity and substantially so after ovulation and the formation of the corpus luteum. The development of the new vessels causes a drop in the vascular resistance of the ovarian vessels. Whether these findings will be useful clinically is not clear yet and further research is required. These changes in the normal ovary may be mistaken to be neoplastic in origin in the eyes of the inexperienced. Power Doppler may be useful in the detection of ectopic trophoblastic tissue and improve the use of transvaginal sonography in the early detection of ectopic pregnancies.(Fig. 23) Attention should be paid in the distinction of ectopic trophoblast from the round cystic and highly vascular corpus luteum of pregnancy. Another condition where color Doppler may be found useful is adenomyosis.

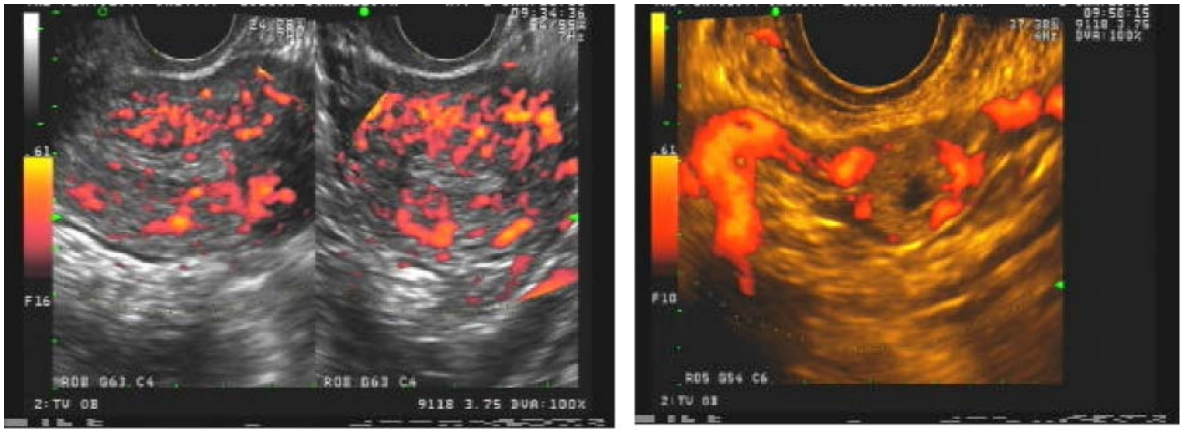

Fig. 23. On the left image, note the abnormal excessive vascularity of the endometrium with no special orientation due to the absence of a gestational sac. On the right image, a gestational sac is noted with trophoblastic flow in the fallopian tube.