Transvaginal Color Doppler Ultrasonography in the Evaluation of Placental Circulation: A Review

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Transvaginal Color Doppler Ultrasonography in the Evaluation of Placental Circulation

A Review

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Transvaginal color Doppler sonography has provided the capability to qualitatively evaluate blood flow in small branches of the uterine arteries, umbilical cord arteries, and intraplacental fetal arteries in early pregnancy. Accurate identification of these small vessels and analysis of their flow characteristics have improved our understanding of the physiology and pathophysiology of early pregnancy that alters the umbilical-uteroplacental circulations. Further development of this technique may help to predict fetal outcome in high-risk pregnancies and in pregnancies with complications, such as intrauterine growth retardation, preeclampsia, and trophoblastic invasion.

Key words: transvaginal sonography, color Doppler, placental, circulation.

Transvaginal sonography is a technique that has become widely accepted as a diagnostic tool in obstetrics. The development of the transvaginal probe has allowed the use of higher frequencies, improving both axial and lateral resolution, providing better visualization of the female pelvic organs, and allowing very early diagnosis of normal or abnormal pregnancies. In 1977, Fitzgerald et al[1] were the first to use Doppler ultrasound to record flow velocity wave forms in pregnancy and to make observations in fetal umbilical vessels. An exciting recent development in the field of diagnostic ultrasonography in obstetrics is transvaginal color Doppler sonography, a technique that facilitates assessment of umbilical–uteroplacental circulation.

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PRINCIPLES OF COLOR DOPPLER ULTRASOUND

Color Doppler sonography, also called color flow mapping, detects mean Doppler frequency shifts created by movement of acoustic interfaces and assigns a color according to the mean direction and magnitude of the motion. In the majority of commercially available scanning equipment, blood flow toward the transducer is encoded in red, and blood flow away from the transducer is encoded in blue. Flow velocity is proportional to color brightness. Turbulence is encoded as green and yellow mixed with red or blue, resulting in a mosaic appearance. A diagnosis can rarely be made solely

on the basis of the information obtained by color Doppler, but it facilitates a more complete assessment of the vascularity of a particular organ or region than is possible with conventional duplex scanning.[2]

The major advantage of color Doppler is a display of blood flow within the entire scanning plane, as compared with the one line of sight shown by conventional pulsed Doppler ultrasound techniques. Color doppler can provide fast and easy orientation to vessels, and can add to a more detailed analysis of flow velocity patterns by pulsed Doppler. Moreover, using multigated, multisample pulsed Doppler and color coding, small vessels beyond the resolution of conventional ultrasound can now be visualized.[3] This is particularly advantageous in the analysis of flow in thin vessels that are extremely difficult to identify with pulsed Doppler.

PHYSIOLOGY OF PLACENTAL CIRCULATION

The blood supply to the pregnant uterus is derived chiefly from the uterine arteries, and to a lesser extent from the ovarian arteries. The main uterine artery, derived from the internal iliac artery, branches within the uterus to form the arcuate arteries. The arcuate arteries are arranged in a circular fashion in the myometrium and are the source of radial arteries that penetrate deeply into the myometrium. The spiral arterioles branch off the radial arteries and pass through the endometrium into the uterine decidua to feed the intervillous space. The uterus is drained by the uterine veins.

In placental circulation, blood enters the placenta from the fetus via the paired umbilical arteries. The blood is distributed throughout the chorionic plate to the chorionic villi, where it passes through villous capillaries and into a network of veins that are parallel to the arteries. Exchange of oxygen, carbon dioxide, nutrients, and waste products occurs across the villous capillaries. The blood is returned to the fetus via the umbilical vein (Figure 1).

The umbilical cord is the crucial intrauterine link between fetal and placental circulation. It consists of an outer layer of amnion containing two arteries and a single large vein ensheathed in Wharton's jelly for protection.

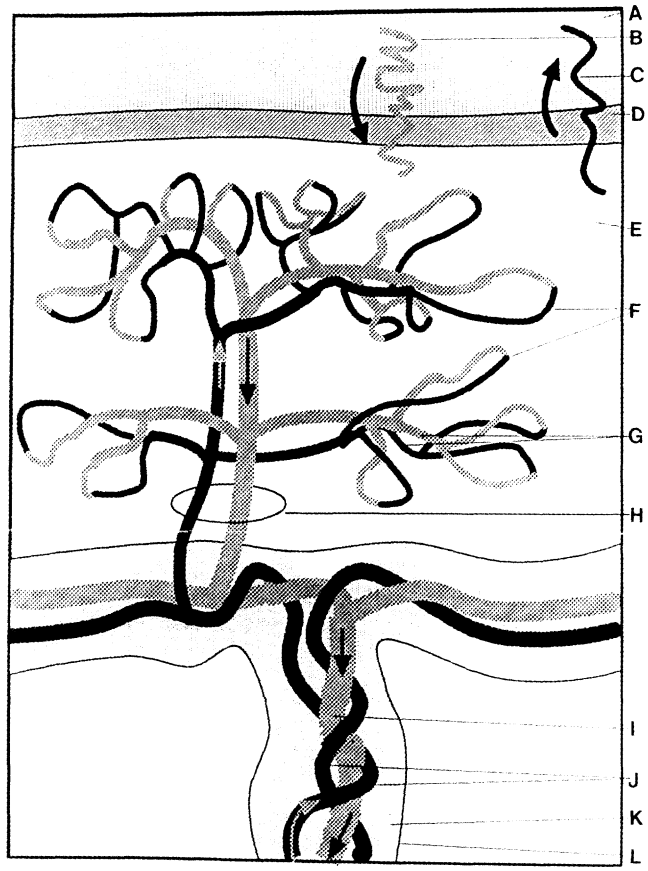

FIG. 1. Illustration of fetal-placental circulation. A = myometrium; B = maternal arteriole; C =maternal venule; D = decidua basalis (placenta); E = chorion (placenta); F = chorionic villi; G = fetal blood vessels; H = main stem villus; umbilical cord: I = umbilical vein; J = umbilical arteries, K = Wharton's jelly; L = amnion.

ULTRASONOGRAPHIC FINDINGS

Until recently the only noninvasive methods of evaluating placental circulation in humans were radioisotope placentography and nitrous oxide dilution studies.[1] The advent of transvaginal color Doppler ultrasonography has provided a new, noninvasive method for the *in vivo* study of placental circulation.[4,5] In healthy nonpregnant women, radial arteries are rarely seen and spiral arteries cannot be demonstrated. However, in early pregnancy, these vessels show pregnancy-induced changes that facilitate their detection by transvaginal color Doppler ultrasound. Jurkovic et al[6] described that, in a normal early pregnancy at 4 weeks to 8 weeks of gestation, the blood flow velocity wave forms from the subplacental vascular area had low resistance, high turbulence, and characteristic spiky outline. This type of wave form

is indicative of a tortuous vessel with an irregular wall, and correlates well with the anatomical features of spiral arteries in a very early pregnancy. Moreover, a significant and progressive decrease in resistance from the uterine artery, through the radial artery, to the spiral artery is consistent with branching in the circulation and an increased total cross-sectional area. Trudinger, et al[7] found a weak relationship between arcuate artery flow velocity and abnormal pregnancy outcome, and attributed this to the effect of adjacent vessels and increasing maternal heart rate on the arcuate arteries. It may be preferable to use flow velocity wave forms from the uterine artery in diagnosis, as these are representative of a greater part of the uteroplacental circulation.

In uteroplacental circulation, studies have documented a physiologic decrease in impedance and increase in blood velocity from the first trimester of pregnancy.[4,8,9] These findings provide indirect evidence of improvement of the blood supply to meet the demands of the developing conceptus. The rapid decrease in resistance over the course of gestation supports the hypothesis of trophoblastic invasion of arterial vessels that result in low impedance flow and low resistance index values.[10] There is an exponentially increasing peak systolic velocity of uterine artery blood flow after 14 weeks of gestation.[6] Increased impedance to flow in uteroplacental circulation at 18 weeks to 22 weeks of gestation has been associated with the development of preeclampsia and intrauterine growth retardation.[11] The flow characteristics of the fetal circulation have not been as extensively studied. Hsieh et al[3] indicate that intraplacental fetal arteries, possibly fetal arteries in main stem villi, are usually found in the upper two-thirds of the placenta beneath the chorionic plate, and flow from the chorionic plate toward the central part of a cotyledon. The vascular resistance of the intraplacental fetal arteries decreases as gestation progresses, and moreover, there is a significant "resistance gradient" between the intraplacental fetal arteries and the umbilical artery.[3] The systolic-diastolic ratio and pulsatility index of the umbilical artery are highest at the fetal side, become progressively lower toward the placental side, and are lowest in the fetal arteries within the placenta. The physiological significance of such a downstream resistance gradient remains unknown. Intraplacental fetal artery velocimetry and flow imaging using transvaginal color Doppler, however, may give further insights into umbilical-placental circulation.

Most of the recent studies of umbilical-placental circulation have focused on the umbilical artery. Transvaginal color flow mapping successfully demonstrated flow in the umbilical artery starting at 6 weeks of gestation.[10] Arduini et al[12] reported that the umbilical artery velocity wave forms were recorded for 214 low-risk pregnancies between 7 weeks and 16 weeks gestational age by means of transvaginal color and pulsed Doppler ultrasound examination. In all the cases studied, end diastolic velocities were absent until the tenth week of gestation. From this age onward, end diastolic velocities were present in a percentage of pregnancies, which progressively increased with gestational age and reached 100% at 15 weeks of gestation. Fetuses with an absence of end diastolic blood velocity in the umbilical artery after this gestational age are at risk of perinatal and neonatal mortality.[13] Provided care has been taken to exclude common technical errors, this finding is associated with a perinatal and neonatal mortality rate of up to 53%, and this rate ranged from 60% to 100% for newborns who were small for gestational age.[1] A significant relationship between an abnormal umbilical artery pulsatility index and growth retardation has been demonstrated.[14] An abnormally high umbilical artery pulsatility index recorded between 26 weeks and 28 weeks of gestation has been reported to be a good predictor of intrauterine growth retardation.[15]

DISCUSSION

Table 1 and Table 2 summarize some normal and abnormal transvaginal color Doppler sonographic findings in placental circulation.

Transvaginal color Doppler can be used successfully in the assessment of placental circulation. It has shown potential for predicting fetal outcome in high-risk pregnancies and in pregnancies with other complications. The opportunity to analyze flow velocity and flow characteristics in placental circulation has improved our understanding of the pathophysiology of various pregnancy disorders. The early suggestion of abnormal hemodynamic features in placental circulation is very important information in the hands of the sonographer, the obstetrician, and the neonatologist. The diagnostic capabilities of transvaginal color Doppler may

TABLE 1. *Normal Transvaginal Color Doppler Sonographic Findings in Placental Circulation*

Circulation	Gestational age (weeks)	Flow velocity wave forms	Hemodynamic findings
Maternal			
Uterine artery	4–12	High peak systolic velocity laminar flow	Progressive fall in resistance from uterine artery to spiral arteries
Radial artery Spiral artery		Low resistance, high diastolic flow, turbulence flow	Decrease in impedance and increase in blood velocity with gestation
Fetal			
Umbilical artery	6–10	A physiologic absence of end diastolic flow	Vascular resistance decreases as gestation progresses
	10–15	End diastolic flow are progressively present, reaching 100% at 15 weeks	The systolic-diastolic ratio and pulsatility index of umbilical artery are highest at fetal side, lower toward placental side, lowest in intraplacental fetal arterioles
Intraplacental fetal arterioles	18–40	Low resistance turbulence flow	

TABLE 2. *Abnormal Transvaginal Color Doppler Sonographic Findings in Placental Circulation*

Circulation	Gestational age (weeks)	Hemodynamic findings	Prediction
Uterine artery	after 14	Rapid fall in resistance with gestation Exponential increase in peak systolic velocity	Trophoblastic invasion
	18–22	Increase impedance to flow with gestation	Preeclampsia, intrauterine growth retardation
Umbilical artery	after 15	Absence of end diastolic flow	A risk of perinatal and neonatal mortality
	26–28	Abnormally high pulsatility index	Intrauterine growth retardation

increase the reliability of ultrasound diagnosis in certain pathologic conditions, may reduce the need for other procedures, and may be of help in making clinical decisions. Transvaginal color Doppler sonography has undoubtedly provided new information on the physiology and pathophysiology of pregnancy and placental circulation. Further work is required, however, before this information may be used in clinical practice.

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