The use of pulsed-wave Doppler in prenatal diagnosis. An update

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Summary

Pulsed wave Doppler ultrasound of fetal vessels confirms the similarity of human fetal circulation to the experimental animal physiology. The result of a multitude of research articles in this field is the clinical use of various components of fetal circulation in perinatal medicine. Umbilical, uterine and fetal cerebral arteries as well as the fetal venous circulation show the potential of Doppler ultrasonography.

Following studies on instrumented fetal sheep preparations, Doppler ultrasonography was introduced into clinical obstetric practice over 20 years ago.
During fetal Doppler ultrasonography's infancy in the 1980s, we were mainly focused our interest on the best use of the technique to detect and record blood velocity waveforms from various fetal and maternal vessels and to correlate these waveforms to physiological and pathological events in fetal circulation.
The human fetal circulation shows similarity to the experimental animal physiology, but with important differences. The human fetus seems to circulate less blood through the placenta, shunt less through the ductus venosus and foramen ovale, but direct more blood through the lungs than the fetal sheep (1).
The shift of the focus in Doppler ultrasonography from research to clinical use in obstetrics took place in the last decade. This article summarizes the current opinion and state of art regarding the prenatal role of pulsed-wave Doppler ulrasonography.

Umbilical artery

Doppler umbilical studies identify the fetus at risk in pregnancies complicated by placental vascular disease. Abnormal development of the placental vasculature is the common denominator and origin of common obstetrical complications such as pre-eclampsia and intrauterine growth restriction (IUGR). Worsening of intrauterine growth restriction is associated with typical changes of blood velocity waveform. The diastolic velocity of the waveform decreases and eventually disappears. The absent or reverse end-diastolic flow (ARED flow) is associated with high risk of intrauterine demise and adverse perinatal outcome.
In recent years, meta-analyses of randomized clinical trials have shown that incorporation of Doppler velocimetry into clinical practice will reduce perinatal mortality in high risk patients. Review of randomized controlled trials of Doppler ultrasonography of the umbilical artery in high-risk pregnancies (2) showed a significant reduction in the number of antenatal admissions, inductions of labor, and cesarean sections for fetal distress in the Doppler group. The clinical action guided by Doppler ultrasonography reduces the odds of perinatal death by 38%. The reduction in perinatal deaths was observed stillbirths, neonatal deaths, deaths of normally formed babies, normally formed stillbirths, and deaths of normally formed neonates. A more strictly defined analysis of 13 randomized controlled studies have shown by stratification that only in pregnancies with suspected intrauterine growth restriction and/or hypertensive disease of pregnancy will the use of umbilical artery Doppler velocimetry reduce the number of perinatal deaths and unnecessary obstetric interventions (3).
Absent (AEDV) or reversed (ARED) flow detected in the late second or early third trimester in the umbilical artery signifies a marked warning signal of fetal distress in high-risk pregnancies (4). Neonates displaying ARED flow before birth are growth restricted, acidemic at delivery and are at high risk of developing bronchopulmonary dysplasia and intestinal complications (5). Since age at delivery has a significant impact on short-term morbidity, prolongation of pregnancy with Doppler velocimetry monitoring is recommended to reduce morbidity. In fetuses with AEDV, delivery before decompensation may improve the perinatal mortality and morbidity (6).
On the other hand, published trials among unselected or low risk populations have found no beneficial effect (7). Therefore routine use of the umbilical Doppler cannot be recommended.
In conclusion, umbilical artery Doppler velocimetry proved to be beneficial in high risk pregnancies , especially those affected by placental vasculopathy and growth restriction. The benefit is not only by reduction of perinatal mortality but also in significant reduction in elective delivery, intrapartum fetal distress, and hypoxic encephalopathy (2).

Uterine artery

Obliteration of the vascular channels in the form of thrombotic placental vasculopathy is followed by Doppler finding in the umbilical circulation. However, in a model presented by Thompson and Trudinger (8) 60-70% of the small arterial channels would need to be obliterated before the umbilical artery indices of resistance became abnormal. Uterine artery Doppler has proved useful in identifying women at high and low risk for developing complications of uteroplacental insufficiency (9), it can identify women in whom biochemical markers (such as HCG, PAPP-A, Placental Protein 13, Activin-A, Inhibin-A) should be measured in order to develop screening tests and aid in evaluation of the pathophysiology of impaired placentation and pre-eclampsia (10-12).
Increased uterine artery pulsatility and resistance indices with or without notching of the waveform are the typical Doppler findings that were correlated with adverse outcome: pre-eclampsia, growth restriction and stillbirth (13).
Screening for pre-eclampsia by uterine artery pulsatility index can be improved by measurement of biochemical markers.

Venous circulation

Reference values for ductus venosus (DV), inferior vena cava (IVC) and hepatic vein flow velocities and indices were established for the second and third trimester of pregnancy (14). Blood flow velocities are highest in the ductus venosus and lowest in the right hepatic vein. The ductus venosus shows a pulsatile flow pattern consisting of a systolic and diastolic forward component without a late diastolic reverse component as demonstrated in the inferior vena cava.
During early pregnancy (12-15 weeks of gestation) (15), combined trans-vaginal and trans-abdominal Doppler ultrasound allows reproducible blood flow velocity recordings at venous level with relatively high velocities in the ductus venosus compared with the umbilical vein and inferior vena cava.
The ductus venosus acts as a transmission line to the umbilical vein for pulse waves generated in the heart. These waves, reflecting cardiac function, are substantially influenced by the local variation of impedance and compliance (16). Blood flow through the ductus venosus is sensitive to changes in umbilical venous pressure, and to an active sphincter-like mechanism of this vessel. The relationship between umbilical artery pulsatility index (UAPI) and IVC pulsatility index for veins (PIV) and DV PIV remained constant throughout gestation (17).
The fetal consequences of placental vascular pathology include rise in the venous pressures because of right heart afterload, increased end diastolic pressure in the right ventricle, and later hypoxemic depression of cardiac contractility. Doppler studies of ductus venosus and inferior vena cava reflect these hemodynamic changes. Placental blood flow resistance least influences the IVC PLI (pro-load index) while the converse is true for the PIV in both veins. Atrioventricular Doppler ratios may be useful in detection of elevated placental blood flow resistance (17). IVC, DV, and UV Doppler parameters in combination provide the best accuracy in predicting acid-base status in IUGR neonates (18). Venous Doppler precede fetal heart rate late decelerations in the compromised fetus (19). Decrease of the late diastolic flow component in the ductus venosus waveform and the presence of umbilical venous pulsations are distinct alterations, which have been detected before cardiotocogram deterioration occurs.

Cerebral circulation

The intracranial circulation becomes visible as early as the 8th week of pregnancy: arterial pulsation can be detected on an axial view of the embryonic skull.
Flow velocity waveforms from the fetal middle cerebral artery are highly pulsatile, and the presence of end-diastolic frequencies becomes more common with advancing gestation (20) and are present in all fetuses examined after 34 weeks' gestation. A significant decrease in the PI was observed in the middle cerebral artery especially after 36 weeks (21, 22). These results suggest that with advancing gestation there is redistribution of the fetal circulation, with decreased impedance to flow to the fetal brain, presumably to compensate for the progressive decrease in fetal blood pO_2. Doppler flow studies in twins without growth retardation or discordance demonstrated changes throughout pregnancy similar to those in singletons (23).
A reflex of centralization of the fetal circulation has been established in fetal hypoxia (24). As in animal models, the redistribution of cardiac output and increased peripheral vascular resistance, with the aim of maintaining cerebral blood flow, resulted in the "brain-sparing" effect (25).
In growth-restricted pregnancies, pulsatility in all of the major intracranial arteries was significantly reduced compared with normal pregnancy, suggesting participation in a brain-sparing effect in the presence of chronic fetal hypoxia (20, 24-27).
Despite this universal response of redistribution, conflicting findings preclude the clinical use of cerebral Doppler alone as predictor of growth retardation. Umbilical artery PI remains the best single indicator for the SGA (small for gestational age) fetus (27).
Fetal anemia. Blood redistribution provides a diagnostic tool for the detection and follow up of fetal anemia. Vyas and colleagues (28) found mean blood flow velocity in the fetal middle cerebral artery to be increased with anemia. They suggest that the hyperdynamic circulation is a consequence of decreased blood viscosity. Increased peak systolic velocity in the middle cerebral artery (MCA-PSV) was found to be reliable in detecting anemia in pregnancies complicated by maternal blood group immunization (29). This is a sensitive tool that can safely replace invasive testing for both the evaluation of fetal anemia of other etiologies (such as placental chorioangioma, twin transfusion syndrome, acute feto-maternal hemorrhage and Parvovirus B9 infection) and response to treatment.
Intracranial venous circulation has shown to be pulsatile in the dural sinuses and non-pulsatile in the vein of Galen in normal pregnancies (30).

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Doppler changes in placental vasculopathy and fetal growth restriction illustrate the sequential involvement of maternal and fetal vascular compartments. Obliteration of placental vascular channels results in increased impedance in the umbilical circulation and followed by increased afterload on the fetal right ventricle of the heart. Circulatory redistribution follows to maintain oxygen delivery to fetal vascular beds. Reduced impedance and pulsatility in the middle cerebral artery and coronary arteries are manifestation of this redistribution. Depressed ventricular ejection is demonstrated by flow in the aorta and renal or mesenteric arteries.

Increased venous pressure because of the high right heart afterload and later hypoxemic depression of myocardial function is reflected by ductus venosus and inferior vena cava flow velocity waveforms.

In conclusion, pulsed wave Doppler is the best modality to study the hemodynamic

consequences of vascular pathology and plays an important role in clinical practice.

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