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Applications of Doppler ultrasound during labor

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Abstract

The information provided by Doppler ultrasound examination during labor permits the understanding of the mechanisms regarding the physiology and pathophysiology of feto-placental exchange and the fetal adaptive systems. There are certain technical difficulties related to intrapartum Doppler ultrasound examination. The investigated sites are the uterine arteries, umbilical arteries, fetal circulation. In diastole, when intrauterine pressure exceeds maternal diastolic pressure, the perfusion pressure of the uterine artery blood flow is no longer present. A progressive decrease in the diastolic component is seen along with an increase in intrauterine pressure from 10 to 60 mmHg. During premature birth or preeclampsia, there are particular changes in the uterine blood flow. A remarkable stability of the umbilical resistance index is found during labor, which shows the permanent presence of feto-placental exchange. Certain correlations can be established between fetal heart rate changes in labor and Doppler ultrasound aspects at the level of umbilical arteries. Doppler examination confirms the concept of reduced cerebral blood flow by the compression of the fetal skull as a cause of decelerations occurring during labor. The decision regarding the extraction of the fetus can only be made by correlating the results of Doppler ultrasound with the other paraclinical methods for the monitoring of the intrapartum fetal status.

Keywords: Doppler ultrasound, labor, fetal heart rate

Rezumat

Informaţiile oferite de examenul Doppler în cursul travaliului permit înţelegerea şi aprofundarea mecanismelor privind fiziologia şi fiziopatologia schimburilor feto-placentare şi a sistemelor de adaptare ale fătului. Există anumite dificultăţi tehnice ale examinării Doppler intrapartum. Situsurile explorate sunt: arterele uterine, arterele ombilicale, circulaţia fetală. În diastolă când presiunea intrauterină depăşeşte tensiunea diastolocă maternă, presiunea de perfuzie a fluxului arterei uterine nu mai este prezentă. Se constată o scădere progresivă a componentei diastolice în paralel cu creşterea presiunii intrauterine de la 10 la 60 mmHg. În cursul naşterii premature sau a preeclampsiei există modificări particulare ale fluxului vascular uterin. Se constată o remarcabilă stabilitate a indicelui de rezistivitate ombilical în cursul travaliului, ceea ce denotă o derulare permanentă a schimburilor feto- placentare. Se pot stabili anumite corelaţii între modificările ritmului cardiac fetal în travaliu şi aspectele ecografiei Doppler la nivelul arterelor ombilicale. Examinarea Doppler confirmă conceptul de reducere a fluxului sanguin cerebral prin compresiunea craniului fetal ca şi cauză a decelerațiilor survenite în cursul travaliului. Decizia privind extragerea fătului poate fi luată numai corelând rezultatele ecografiei Doppler cu celelalte metode paraclinice de monitorizare a stării fetale intrapartum.

Cuvinte cheie: ecografie Doppler, travaliu, ritm cardiac fetal

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The results of Doppler ultrasound (US) examination during labor allow the understanding of the data regarding the physiology and pathophysiology of feto-placental exchange and the fetal adaptive mechanisms. Intrapartum Doppler velocimetry is a non-invasive investigation method, useful for the evaluation of the pathophysiological mechanisms underlying fetal heart rate (FHR) changes. Under certain circumstances, it allows, along with other investigation methods, to detect acute fetal

asphyxia, as well as its effects on fetal hemodynamics.

There are currently few studies regarding the utility of Doppler examination during labor, due to certain technical particularities and difficulties of intrapartum Doppler examination. The most significant problems related to the exploration technique under labor conditions can be synthesized as follows [1]:

- Uterine contractions (UC) during labor cause changes in the maternal circulation parameters.
- Maternal respiratory movements, which are ample and more frequent during uterine contractions, make difficult the continuous recording of the Doppler signal.
- The volume of amniotic fluid is reduced in term pregnancy, particularly after the rupture of membranes, causing difficulties of the Doppler examination of fetal vessels.
- Uterine contractions change the aspect of the abdominal wall, the position of the transducer and the fetus, which can result in the loss of the Doppler signal.
- In the case of a fetal skull deeply engaged in the pelvic excavation, there are difficulties in recording transabdominal Doppler waves of the fetal cerebral vessels.

The sites explored by intrapartum Doppler ultrasound are uterine arteries, umbilical vessels, fetal circulation.

Intrapartum Doppler ultrasound examination of uterine arteries

Examination technique

The ascending branch of the uterine artery is identified by color Doppler US, and pulsed Doppler for recording the Doppler spectrum. Peripheral resistance is assessed by the aspect of telediastolic flow (fig 1). When the angle between the vessel and the Doppler signal is constantly maintained, telediastolic flow is proportional to uterine perfusion, supposing that the low flow velocities that contribute to the spectrum are uniformly distributed and consequently, they should not be taken into consideration when evaluating a relative change in perfusion [2]

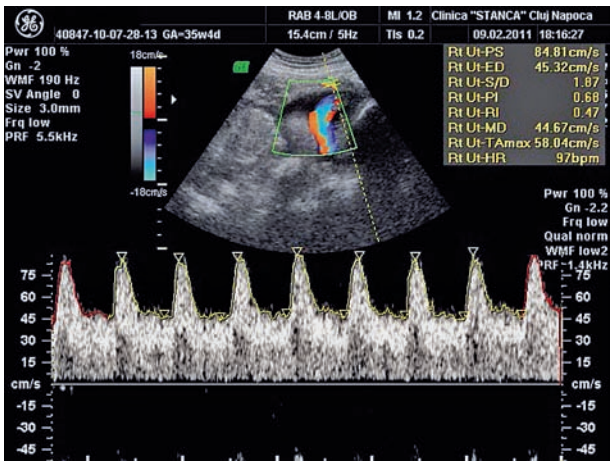

Fig 1. Normal pulsed and color Doppler of uterine artery (37 WG)

For the quantification of the blood flow impedance, the resistance index (RI) or the systolic-diastolic index (S/D) is used [2].

Uterine blood flow changes during uterine contractions

During normal pregnancy, there is a progressive increase in uteroplacental blood flow related to the trophoblast invasion of spiral arteries. This process occurs in two stages: the first stage after 12 weeks of amenorrhoea (WA), and the second one after 18 WA, the process being considered completed at 22 WA. At the end of the trophoblast invasion, the endothelial cells from the distal portion of the intervillous space arteries will also be replaced by trophoblast cells. The increase in diastolic blood flow is related to the vascular compliance and uteroplacental bed development [3,4].

The normal uterine spectrum is defined by the increased residual blood flow in diastole (about 40% of maximum systolic blood flow) and systolic peak with a vertical ascending phase and a less abrupt descending phase, followed by a second change in the descending slope to a pseudoplateau. So, the ascending and the descending parts of the systolic phase are not symmetrical [5-8].

A mean 40-60% reduction in blood flow velocity was reported compared to the initial value, for a maximum intrauterine pressure of approximately 60 mmHg. The systolic peak decreases by only 25%, while the diastolic peak is extremely low or absent. This aspect was explained by a significant reduction in the perfusion pressure of the uterine artery blood flow at the maximum pressure of the uterine contraction. The perfusion pressure during systole is approximately 60-70 mmHg, when intrauterine pressure is 50-60 mmHg [9]. In diastole, when intrauterine pressure exceeds maternal diastolic pressure, the perfusion pressure of the uterine artery blood flow is no longer present. A progressive decrease in the diastolic component is found in parallel to an increase in intrauterine pressure from 10 mmHg to 60 mmHg [9].

An obvious correlation between the reduction of diastolic blood flow and the intensity of uterine contraction was evidenced [10]. Diastolic flow decreases to 0 (null diastolic flow), when intrauterine pressure reaches

80 mmHg, without other changes in the spectrum (protodiastolic notch). However, systolic blood flow can be evidenced up to an intrauterine pressure of 130 mmHg [11].

These aspects suggest that uterine diastolic flow reflects the blood flow from arcuate and spiral arteries during uterine contraction. The compression of these vessels during normal labor under the influence of uterine contractions results in reduction or even disappearance of the diastolic component [12]. During the uterine contraction test (oxytocin test), there are similar uterine blood flow changes to those of spontaneous labor [13].

Uterine blood flow changes during premature delivery

During uterine contractions occurring before term or during premature labor, there is a non-physiological reduction in uterine blood flow. These changes, which can result in the suppression of diastolic flow or the aspect of reversed diastolic flow can develop even when the patient does not perceive uterine contractions as painful. The increase in vascular resistance in uterine arteries confirms uterine hyperactivity in the context of premature delivery, being an obvious argument for tocolytic treatment [14-16]. Systolic blood flow present up to an intrauterine pressure of 130 mmHg confirms the presence of a sufficient minimum blood flow in the intervillous space [11,17].

Intrapartum uterine blood flow changes in patients with preeclampsia

In the case of preeclampsia, the trophoblast invasion of uterine spiral arteries is limited and incomplete, affecting only their decidual segment, which results in a diminution of uteroplacental vascularization.[18]

During pregnancies complicated by severe preeclampsia, the reduced diastolic flow and the presence of the protodiastolic notch are related to a compliance defect of uterine vessels [19]. Under the conditions of preeclampsia, the disappearance of diastolic blood flow or the aspect of reversed flow can be found. The spectral aspect with maximum systolic velocity and reversed diastolic flow is similar to that of the right iliac artery [1,20].

The blood flow in the intervillous space during uterine contractions is almost completely maintained. This phenomenon is caused by the unchanged systolic flow velocity, through the increase in the perfusion pressure determined by maternal arterial hypertension. These considerations recommend caution in the use of aggressive antihypertensive therapy in patients with preeclampsia [7,19]. In cases with abnormal uterine velocimetry prior to labor, a higher increase in vascular resistance is found during labor compared to normal pregnancy, determining a reserved fetal prognosis [12].

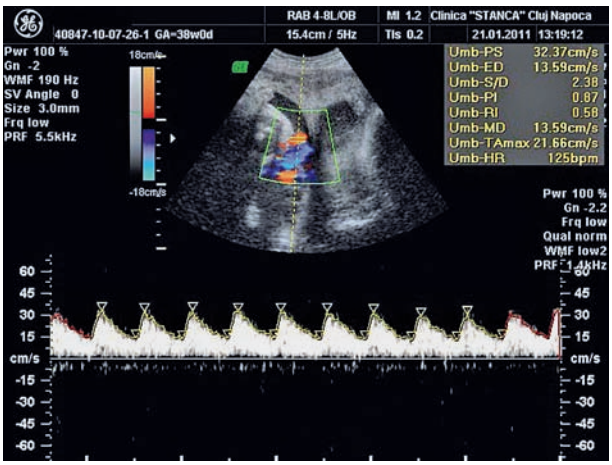

Fig 2. Normal pulsed and color Doppler of umbilical artery (38 WG)

Intrapartum Doppler ultrasound examination of umbilical vessels

The umbilical artery, the first vessel explored by Doppler ultrasound in obstetrics, is the last vessel before the "placental obstacle". As the placenta is the only organ downstream of this vessel, the umbilical artery is the privileged site of exploration of "placental resistances" [21].

Examination technique

The umbilical cord is preferably visualized at its placental insertion (lower mobility area). The pulsed Doppler window is fixed at the level of one of the umbilical arteries under a favorable angle (below 60°) with an opening of approximately 5 mm, incorporating the vessel [7].

Doppler ultrasound examination of umbilical arteries during labor

The aspect of the spectrum of the umbilical artery corresponds to a vessel supplying an organ with relatively low vascular resistance, diastolic flow representing about 30% of the systolic flow value (fig 2).

Residual diastolic flow increases during normal pregnancy [22]. When the amniochorionic membranes are intact and the amount of amniotic fluid is normal, the uterus can be considered as an empty sphere as in the model proposed by Kunzel et al [23]. According to this model, pressure in umbilical vessels increases in response to uterine contraction. Consequently, the perfusion pressure in the placental vascular tree is unchanged. This state is maintained after the rupture of membranes until a certain moment, because the fetal head covers the cervical orifice during labor [10].

It is considered that umbilical Doppler spectrum undergoes no obvious changes as long as the fetal heart rate is maintained within normal limits (120-160 beats/minute) [1]. There is a remarkable stability of umbilical RI values during labor, which shows the permanent presence of feto-placental exchange during this period. Umbilical circulation maintains a certain independence in relation to the active phenomena of delivery.

The aspect of umbilical diastolic flow can be assessed in four stages of uterine contraction: outside uterine contraction, in the ascending phase of uterine contraction, in the peak phase of uterine contraction, and in the descending phase of uterine contraction. Umbilical RI values undergo no significant changes during these phases of uterine contraction [24]. In patients with ruptured membranes or those with oxytocin-induced labor, no significant variations in placental resistances were found, while the fetal heart rate was maintained within normal limits [13]. The position of the patient (dorsal decubitus or left lateral decubitus) at the time of examination does not influence the values of umbilical RI or the accuracy of the measurements [21].

Correlations between fetal heart rate changes in labor and Doppler ultrasound aspects in umbilical arteries

At the level of the umbilical cord and in fetal vessels, direct mechanical effects due to vascular compression under the influence of uterine contractions should be differentiated from other causes of acute changes in vascular resistance.

There are studies that attempt to establish certain correlations between fetal heart rate (FHR) variations and umbilical RI values [24]. The most frequent aspects of FHR during labor are normal trajectory, early decelerations, late decelerations, variable decelerations, prolonged decelerations, accelerations, bradycardia [22,25].

A progressive diminution in the umbilical diastolic flow is found during intrapartum decelerations and in fetal bradycardia, tending to become null, if the fetal heart rate decreases to less than 80 beats/minute. Fetal bradycardia with less than 100 beats/minute is associated with a significant prolongation of diastolic flow, as a compensation mechanism. This aspect of prolonged diastole is obvious in a normal fetal heart rate trajectory and less obvious in a changed trajectory, or imperceptible in a null diastolic flow record. In cases with reversed diastolic flow, the volume of the reversed flow will be theoretically increased, due to prolonged diastole (fig 3).

The umbilical diastolic flow variation in labor under conditions of altered FHR is rather cardiogenic in origin and is less influenced by the temporary increase in placental resistances. The cardiac ejection volume (represented by systolic peak) and placental resistance (represented by residual diastolic flow) remain stable in spite of the increase in intrauterine pressure from 10 mmHg to 60 mmHg during UC [25,26].

In cases in which reversed diastolic flow is found during decelerations, this reversed flow can have different aspects:

- The reversed diastolic flow formed at the beginning of diastole may reflect very high placental resistance and umbilical artery occlusion.
- The reversed holodiastolic flow, which tends to increase in telediastole, will be interpreted as a compensating flow from the peripheral expansion chamber (the placenta) and indicates an umbilical vein occlusion.

The probability of an isolated umbilical vein occlusion or mixed umbilical vein and artery occlusion exists in the case of an acute reversed diastolic flow. In both cases, the outcome is the suppression of feto-placental perfusion, with the presence of an inefficient movement of fetal blood flow in umbilical arteries [27].

Experiments in animals have demonstrated that the oxygen supply to the fetus remains almost constant even at a 50% reduction in umbilical artery blood flow, but the oxygen supply decreases exponentially when the umbilical blood flow decreases to less than 50%. Intrapartum Doppler ultrasound is a valuable method for the assessment of variable FHR decelerations, which are associated with reversed diastolic flow, indicating an obvious decrease in oxygen supply [27]. Under the conditions of the association of pathological FHR decelerations with reversed diastolic flow in the spectrum of umbilical arteries, the risk of fetal hypoxia and acidosis increases.

Because fetal oxygen supply significantly decreases

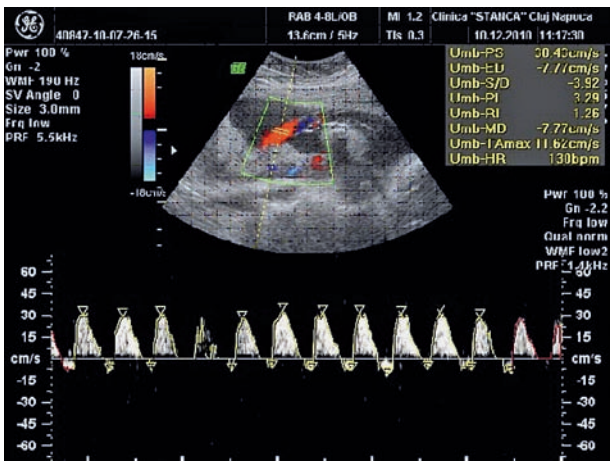

Fig 3. Abnormal pulsed and color Doppler of umbilical artery with reversed flow (36 WG)

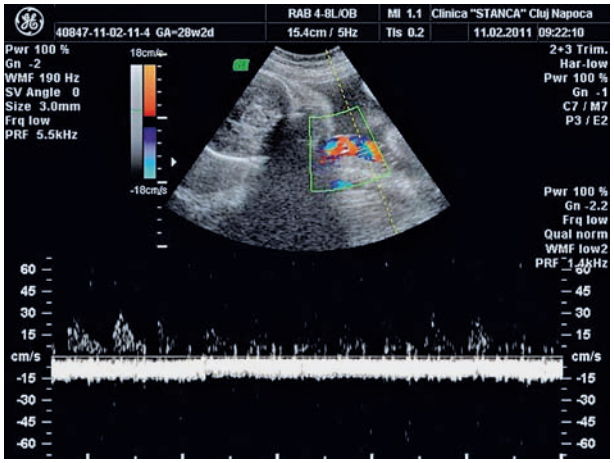

Fig 4. Normal pulsed and color Doppler of umbilical vein (37 WG)

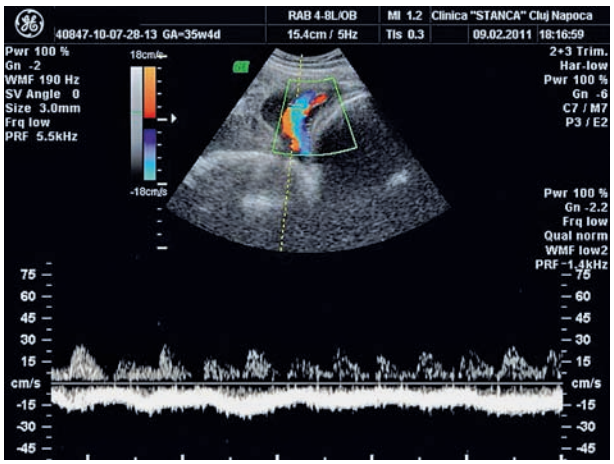

Fig 5. Abnormal pulsed and color Doppler of umbilical vein with pulsations (36 WG)

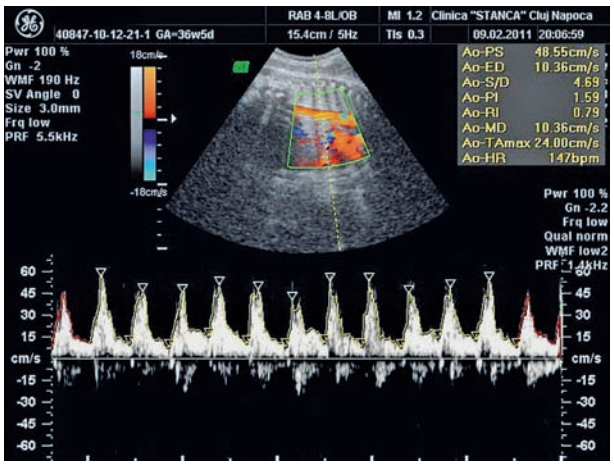

Fig 6. Normal pulsed and color Doppler of fetal aortic artery (37 WG)

when umbilical blood flow is reduced by more than 50% of the initial value, each deceleration should be considered as fetal ”stress”, particularly in fetuses with null or reversed diastolic flow. Considering these aspects, it can be stated that spontaneous or (oxytocin) induced labor should be avoided in the case of a pregnancy with antepartum null or reversed diastolic flow in the umbilical arteries.

Uterine contractions might cause a dangerous decrease in the oxygen supply to the intervillous spaces, and decelerations might determine a reduction in the umbilical blood flow, which can all result in severe fetal hypoxia [28]. The establishing of possible effects of fetal asphyxia on the umbilical artery blood flow have been attempted. One minute of asphyxia has been found to cause an approximately 35% decrease in the umbilical artery blood flow, mainly due to the decrease in FHR [10].

However, Doppler velocimetry could not demonstrate acute fetal hypoxia in animal models. These results are not surprising if we consider the fact that placental perfusion cannot acutely change, probably because of the lack of innervation of intraplacental arteries, although perfusion might be affected by fetal epinephrine levels [28,29]. In the case of pregnancies with a risk for developing intrapartum fetal hypoxia, Doppler waves reflect a chronic increase in resistance in feto-placental circulation, due to either defective placentogenesis or an occlusion of the placental vascular tree. In fetuses with late decelerations and signs of hypoxemia in the intrapartum period, Doppler velocimetry in umbilical arteries can detect a high S/D index, both during and between UC [30]. In 90% of the fetuses with late decelerations, umbilical vein pulsations were evidenced during UC, which indicates a possible short duration overloading of the right heart (fig 4, fig 5) [31,32].

In cases with normal FHR, the umbilical vein blood flow was unchanged during labor. These findings demonstrate that acute hypoxia also affects fetal venous blood flow [33,34].

Intrapartum Doppler ultrasound examination of fetal circulation

Fetal aortic artery

During normal pregnancy, a progressive increase in aortic blood flow is found until 36 WA, followed by a slight decrease starting with 39 WA. The aortic blood flow is characterized by a diphasic aspect with a sharp systolic peak, with increased amplitude, followed by a diastole, which starts with a protodiastolic notch, more obvious with the increase in gestational age (fig 6). The diastole is constantly positive due to the permanent open-

ing of the arterial duct on the one hand, and to the low downstream resistances on the other hand [21,35].

In the case of normal FHR, UC do not cause significant changes in Doppler waves at the level of the fetal aorta. In contrast, decelerations result in a decrease in telediastolic aortic flow [36].

Acute fetal hypoxia is considered to have no direct effect on the fetal aorta spectrum. On the other hand, a redistribution of fetal heart blood flow in favor of cerebral perfusion can have an indirect effect on the aortic spectrum, which is demonstrated by experiments in animals [11]. The major vasoconstriction of the aorta exposes the fetus to an increased risk of ulcero-hemorrhagic enterocolitis. The increased vascular resistance in the fetal aorta can induce a dilation of the arterial duct, pulmonary hypertension, with right heart decompensation and decreased cardiac blood flow, which precede fetal agony. There is an obvious correlation between aortic velocimetry on the one hand, and fetal venous pH, the importance of fetal hypoxia, hypercapnia and acidosis on the other hand [37].

Fetal cerebral arteries

The Circle of Willis, the site of the anastomoses of the main cerebral vessels, is visualized by using color Doppler. The section plane of the biparietal diameter allows to evidence the main components of the Circle of Willis (fig 7) [38].

In normal pregnancies, the cerebral vascular system has an increased resistance, the value of the telediastolic flow being approximately 16% of that of maximum systolic flow (fig 8).

There are only a few studies that have evaluated the changes in fetal cerebral vascularization during labor. The pressure of the transducer on the fetal head can cause a reduction of telediastolic flow velocity, and obvious pressure may induce null or reversed diastolic flow. These reductions in diastolic velocity have also been evidenced in oligohydramnios [39]. As long as the heart rate is maintained within normal limits, during UC the blood flow in the middle cerebral artery undergoes no obvious changes.

Studies have evidenced a slight increase in vascular resistance in the internal carotid artery during the initial phase of the dilation period. As the skull descends, due to the pressure exerted by UC on the skull and to the increased intracranial pressure, the S/D index increases from 3.5 to 5.5 during UC [40].

A normal fetus is considered to respond to a drastic heart rate decrease during isolated decelerations by a reduction in residual velocity at the level of cerebral circulation. This diminution of telediastolic velocity is purely cardiogenic in origin. Thus, Doppler examination has confirmed the concept of the reduction of cerebral blood

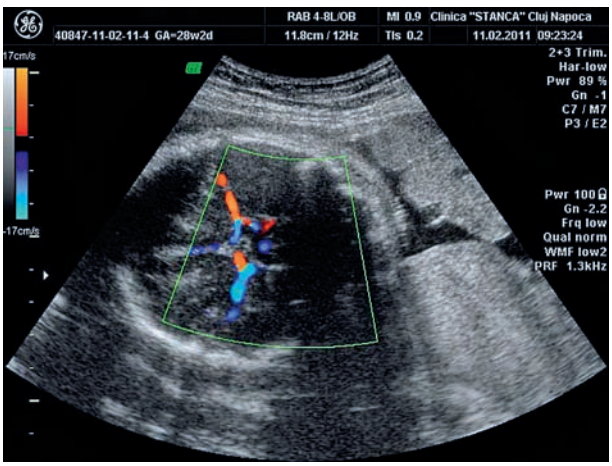

Fig 7. Color Doppler – the Circle of Willis (38 WG)

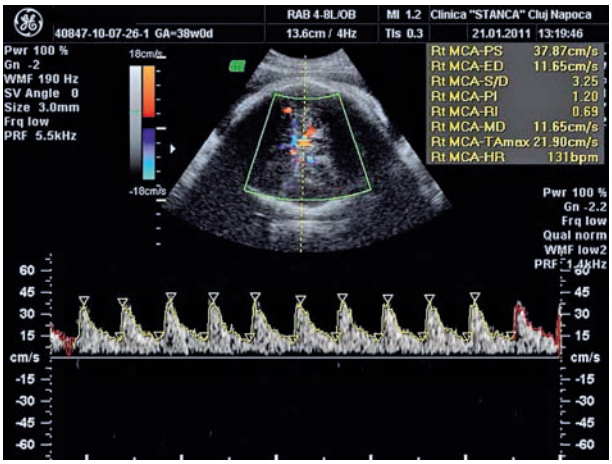

Fig 8. Normal pulsed and color Doppler of middle cerebral artery (37 WG)

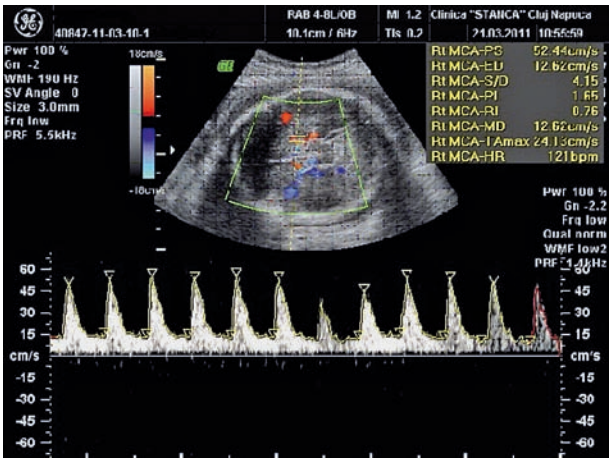

Fig 9. Abnormal pulsed and color Doppler of middle cerebral artery with vasodilation (38 WG)

flow by the compression of the fetal skull as a cause of decelerations occurring during labor [39,41].

Repeated decelerations trigger cerebral vasodilation, which is reflected by an increase in telediastolic velocity (fig 9).

Thus, the fetal brain will be protected from blood flow and blood pressure variations [42]. When these adaptive phenomena are overcome, a correlation between fetal heart rate and diastolic cerebral blood flow can be detected (the decrease in FHR results in a reduction of diastolic cerebral flow) [39-41].

Doppler ultrasound examination and peridural analgesia

The sympathetic denervation of the uterus with the decrease of vascular resistances can be evidenced by Doppler ultrasound [43,44]. In this sense, the S/D index in the umbilical arteries shows a variable and inconsistent decrease during peridural analgesia with chlorprocaine. Under these conditions, the values of the S/D index in dorsal decubitus are higher than in the left lateral decubitus [11,45].

Bupivacaine, which induces a negative inotropic effect, causes a constant and important decrease in the umbilical S/D index [46]. Fetal aortic blood flow may increase during labor, independently of peridural analgesia. In contrast, in the case of bethridine administration, fetal aortic blood flow is significantly reduced.

However, there are studies that do not show significant blood flow changes during the course of different peridural analgesia methods [43]. These apparently contradictory aspects emphasize the complexity of interlacing mechanisms: the secretion of vasoactive substances during labor on the one hand, and the different actions of the administered drugs on blood flow, on the other hand [11,45].

Conclusions

Doppler ultrasound examination during labor, unlike Doppler ultrasound during non-labor, can detect blood flow changes, which develop within seconds. Uterine muscle contraction leads to an increase in resistance in the uterine arteries, with a corresponding reduction in blood flow. The proportion of these changes depends on the intensity of UC, without significantly correlating with external tocography.

On the examination of umbilical and fetal vessels, the direct mechanical effects due to the compression exerted by UC should be differentiated from heart rate changes or hypoxic factors, which can alter the characteristics of the blood flow. In the case of normal FHR, UC do not alter the characteristics of umbilical artery blood flow. When the antepartum umbilical spectrum is changed, decelerations can induce a drastic and exponential decrease in umbilical blood flow. These decelerations during spontaneous or induced labor should be avoided under these circumstances.

The intrapartum Doppler examination of fetal vessels evidences and quantifies the blood flow redistribution mechanisms in the case of hypoxia – peripheral vasoconstriction in the mesenteric, renal, cutaneous territories and the preferential vasodilation of privileged territories, particularly the brain. The increased pressure on the fetal brain during UC may cause a decrease in diastolic flow velocity in cerebral vessels, as a result of increased intracranial pressure. Certain decisions regarding the extraction of the fetus can only be made by correlating Doppler ultrasound results with the other paraclinical methods for the monitoring of the intrapartum fetal status.

Conflict of interest: absence of conflict of interest

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