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Uterine and umbilical artery Doppler are comparable in predicting perinatal outcome of growth-restricted fetuses

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Objective To compare umbilical and uterine artery Doppler in predicting outcome of pregnancies suspected of fetal growth restriction (FGR).

Design A prospective study included 353 singleton pregnancies complicated by an FGR fetus.

Setting University Hospital setting.

Sample Pregnancies suspected of FGR diagnosed by ultrasound fetal biometry during a 5-year period.

Main outcome measure Perinatal outcome in relation to uterine and umbilical artery Doppler.

Methods The women underwent Doppler examination of the umbilical and uterine arteries. Results from the uterine, but not the umbilical artery, were blind to the woman and managing obstetrician. The Doppler results were related to perinatal outcomes including small for gestational age newborns, caesarean delivery, premature delivery (<37 weeks of gestation) and admission of the newborn to a neonatal intensive care unit.

Results Abnormal uterine artery Doppler velocimetry was seen in 120 (33.4%) pregnancies and abnormal umbilical artery Doppler in 102 (28.4%). There was a statistically significant correlation between abnormal Doppler of both the umbilical and uterine arteries and adverse outcome of pregnancy. The two vessels were comparable in predicting adverse outcome. Women with normal umbilical artery Doppler (251) were analysed separately. Abnormal uterine artery Doppler, seen in 61 (24.3%) of those women, showed a statistically significant correlation for adverse outcome of pregnancy.

Conclusions Doppler examinations of the uterine and/or the umbilical arteries seem to be comparable as predictors of outcome in pregnancies complicated by FGR. Including uterine artery Doppler in the surveillance of growth-restricted fetuses might detect a group of pregnancies at high risk, even though the umbilical artery Doppler was normal.

Keywords Doppler, perinatal outcome, small for gestational age, ultrasound, umbilical artery, uterine artery.

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Introduction

Pregnancies suspected of fetal growth restriction (FGR) are a heterogeneous group. Some are constitutionally small and healthy, but others fail to reach their predestined growth potential due to lack of nourishment, chromosomal aberrations or external factors that influence growth like drugs or infections. Prenatal identification of the FGR fetuses is one of the most important factors improving perinatal outcome among those women.[1] Doppler examination of the placental circulation has improved the diagnosis of placental cause of FGR.

The first recordings of umbilical artery Doppler were reported in 1977.[2] In growth-restricted pregnancies, Doppler examinations of the umbilical artery can identify pregnancies with increased vascular impedance on the fetal side of the placenta and thus select a group of women in need of increased surveillance.[3,4] Doppler velocimetry of the uterine arteries reflects vascular impedance on the maternal side of the placental circulation. Increasing impedance, due to anomalous invasion of cytotrophoblastic cells into the decidual tissue of the placental bed, and defect remodelling of the spiral arteries, is reflected in decreasing diastolic blood flow velocities and/or persistent early diastolic notch in the uterine artery blood flow waveform. An increased pulsatility index (PI) and/or notch of the uterine arteries in the second trimester are correlated with FGR and pre-eclampsia later in

pregnancy.[5] In pregnancies complicated by pre-eclampsia, increased uterine artery vascular impedance in the third trimester has been correlated with adverse perinatal outcomes such as small-for-gestational-age (SGA) newborns, delivery by caesarean section, premature delivery and admission to a neonatal intensive care unit (NICU).[6] Despite these encouraging reports, uterine artery Doppler is not routinely used in the evaluation of pregnancies suspected for FGR.

The aim of the present study was to evaluate if uterine artery Doppler could identify a group of FGR fetuses at increased risk for adverse perinatal outcome, even though the umbilical artery Doppler was normal. The aim was also to compare uterine and umbilical artery Doppler as predictors of adverse outcome of pregnancy.

Methods

In a prospective double-blind study, 359 pregnancies suspected of FGR were included. Exclusions criteria were multiple pregnancies, congenital malformations and chromosomal abnormalities known before labour and delivery. All pregnancies were dated by ultrasound examination performed at 18–21 weeks of gestation. Six women with intrauterine fetal death were excluded from the analysis due to the impact on some of the outcome variables (mode of delivery and admission to NICU). These are listed in Table 1. The study was approved by the local ethical committee.

Suspected FGR fetuses were diagnosed with ultrasound fetal biometry performed either as routine examination at 32–34 weeks of gestation or on clinical indication during a 5-year period (1994–99), at Malmö University Hospital. Suspected FGR was defined as an estimated fetal weight of more than 2 SD below the mean gestational-age-related Scandinavian reference growth curve[7] or a decline of more than 1 SD between two ultrasound examinations performed at least 2 weeks apart.

Umbilical artery Doppler was performed as a clinical routine using an Acuson Sequoia 512 ultrasound machine (Siemens/Acuson, Mountain View, CA, USA). Recordings were performed in the absence of fetal breathing or movements. PI was calculated from three even subsequent blood flow velocity waveforms according to Gosling *et al.*,[8] and the blood flow waveform was classified as blood flow class (BFC) 0–3[9] defined as BFC 0: normal umbilical artery blood flow velocity waveforms (PI ≤ 2 SD above the mean); BFC 1: PI between 2 and 3 SD; BFC 2: PI > 3 SD and forward diastolic blood flow and BFC 3: absent or reversed diastolic blood flow. Abnormal umbilical artery Doppler was defined as BFC of 1–3 (Table 2).

Doppler examination of the uterine arteries was performed at the same time. Colour Doppler was used to identify the apparent crossing of the uterine and iliac vessels. Uterine artery velocimetry was recorded just cranial of the vessel 'crossing'. Three even subsequent blood flow velocity waveforms were used to calculate PI and to analyse the presence or absence of an early diastolic notch.[10,11] PI > 2 SD (PI > 1.20) was considered abnormal[12] as was the finding of an early diastolic notch in the blood flow waveform. The blood flow waveform of the uterine artery was classified as uterine artery score (UAS) defined as UAS 0: normal blood velocity waveform (PI ≤ 2 SD and no notch present in either uterine arteries); UAS 1: PI > 2 SD or presence of notch in one uterine artery; UAS 2: two abnormal parameters (notch or PI > 2 SD); UAS 3: three abnormal parameters and UAS 4: PI > 2 SD and presence of notch in both uterine arteries, as described by Gudmundsson *et al.*[13] (Table 2). Abnormal uterine artery Doppler was defined as UAS of 1–4. Only the results of umbilical and uterine artery Doppler at diagnosis of an FGR fetus were used for analysis. The results of the umbilical, but not the uterine arteries, were disclosed to the obstetrician in charge of the patient's clinical care. The women were hospitalised or followed by close polyclinic check-ups following the local protocol for management of pregnancies suspected of an

Table 1. Women excluded due to intrauterine fetal death

Case	UAS	BFC	SGA	Weight dev. (%)	Gestational age (weeks + days)	Comment
1	1	1	Yes	−24	33 + 5	Placental infarctions and haematoma
2	2	2	No	−21	29 + 5	Complete ablation of the placenta
3	0	1	Yes	−38	35 + 4	Constricted true knot of the umbilical cord
4	0	0	Yes	−23	36 + 3	Trisomy 18, hypoplastic left heart syndrome, hydrocephalus, club foot, confirmed at autopsy
5	3	3	Yes	−32	23 + 5	Pre-eclampsia in early pregnancy. Infarctions and fibrosis of the placenta
6	3	2	Yes	−31	33 + 5	Trisomy 18, polyhydramnios, diaphragm hernia, suspicion of heart malformation

Weight dev., deviation in birthweight from the normal gestational age mean.

Table 2. Definition of umbilical artery BFC and UAS

Umbilical artery BFC
BFC 0: PI ≤ 2 SD
BFC 1: PI 2–3 SD
BFC 2: PI > 3 SD and forward diastolic blood flow
BFC 3: ARED
UAS
UAS 0: PI ≤ 2 SD and absence of notch in both uterine arteries
UAS 1: one abnormal parameter (PI > 2 SD or early diastolic notch)
UAS 2: two abnormal parameters
UAS 3: three abnormal parameters
UAS 4: four abnormal parameters (PI > 2 SD and early diastolic notch in both uterine arteries)

FGR fetus. The intention of the protocol was to minimise the risk for fetal damage caused by growth restriction without causing unnecessary prematurity. Fetal surveillance included Doppler examinations of the umbilical artery, estimation of amniotic fluid index (AFI) and nonstress test (NST) every second week if umbilical artery Doppler was normal. In case of BFC 1: the same control twice weekly; BFC 2: three times weekly and in case of absent or reversed end-diastolic blood flow (ARED) (BFC 3), admission with NST twice daily and Doppler evaluations daily. Fetal growth was estimated by ultrasound every second week in all women. If estimated fetal growth was more than 3 SD below the mean gestation age reference fetal weight, the woman was hospitalised for further evaluations such as karyotyping, screening for viral infection and congenital malformations. The decision for time and mode of delivery was made by a senior obstetrician based on gestational age, ultrasound estimation of fetal growth and AFI, umbilical artery Doppler, NST and/or maternal signs for severe pre-eclampsia. ARED flow in the umbilical artery was regarded as indication for delivery except for cases of extreme prematurity where individual assessment was based on Doppler, NST, AFI and fetal growth with time.

SGA newborns (>2 SD below mean gestational age birthweight), delivery by caesarean section, premature delivery (<37 weeks of gestation) and admission of the newborn to NICU were chosen as perinatal outcome variables. The outcome data were extracted from the local perinatal database. The outcome variables were compared with the results from the Doppler examinations of both the uterine and umbilical arteries.

Mild/moderate pre-eclampsia was defined as blood pressure ≥140/90 mmHg in the presence of ≥0.3 g albumin/24 h in the urine. Severe pre-eclampsia was defined as diastolic blood pressure of ≥110 mmHg and ≥0.3 g albumin/24 h in the urine. Pregnancy-induced hypertension was defined as blood pressure >140/90 mmHg.

The data were analysed using chi-square test for trends within the blood flow scores (MedCalc statistical software, Mariakerke, Belgium). P value of <0.05 was considered statistically significant. Receiver operating characteristic (ROC) curves were constructed for both UAS and BFC in relation to the four perinatal outcome variables. The area under the curve was used to compare the two Doppler examinations.

Results

The study included 359 women. Six fetuses died before birth. Those cases were excluded from analysis. One baby died within 7 days of delivery. The perinatal mortality was 1.9%. Description of the six excluded cases is given in Table 1. There were two unexpected cases of Down syndrome. None of the newborns had major congenital malformation or signs of congenital infections.

Mean gestational age at inclusion was 34.6 ± 3.2 weeks. Mean time between inclusion and delivery was 19.6 ± 18 days. Twenty-six women had also mild/moderate pre-eclampsia, 27 had severe pre-eclampsia and 13 had pregnancy-induced hypertension. Three pregnancies were complicated by autoimmune disease, two had coagulopathy, one insulin-treated diabetes mellitus and one developed deep vein thrombosis. In all women with severe pre-eclampsia ($n = 27$), the decision for delivery was made on maternal indication.

Of the remaining 353 women, abnormal uterine artery Doppler was seen in 120 (34.0%) fetuses and abnormal umbilical artery Doppler in 102 (28.9%). Abnormal Doppler was seen in both the uterine and umbilical arteries in 59 fetuses (16.7%). Of the 251 fetuses with normal umbilical artery Doppler (BFC 0), 61 (24.3%) had abnormal uterine artery Doppler. Furthermore, of the 233 (66.2%) fetuses with normal uterine artery Doppler (UAS 0), 43 (18.4%) had abnormal umbilical artery Doppler. Table 3 gives the distribution of cases based on umbilical and uterine artery vascular impedance.

The total number of SGA newborns was 197 (55.8%). A total of 188 (53.3%) women were delivered by caesarean section, 116 (32.9%) women were prematurely delivered, and of those, only 12 had a spontaneous vaginally delivery. The number of newborns admitted to NICU was 149 (42.2%). In the 27 women with severe pre-eclampsia, the decision for delivery was made on maternal indication. However, the results were not affected if these women were excluded from the analyses.

Of the 120 women with abnormal uterine artery Doppler, 93 (77.5%) newborns were SGA, 96 (80.0%) were delivered by caesarean section, 72 (60.0%) were delivered prematurely and 88 (73.3%) were admitted to NICU. The corresponding numbers for the 102 women with abnormal Doppler of the umbilical artery were 80 (78.4%), 90 (88.2%), 60 (58.8%) and 73 (71.6%), respectively. A statistically significant correlation was seen between the Doppler examinations of both the uterine and umbilical arteries and all the four outcome

Table 3. Distribution of UAS and BFC

BFC \ UAS	0	1	2	3	4	Total, *n* (%)
0	190	33	18	7	3	251 (71.1)
1	27	13	14	6	4	64 (18.1)
2	15	3	6	4	4	32 (9.1)
3	1	1	3	0	1	6 (1.7)
Total, *n* (%)	233 (66.0)	50 (14.2)	41 (11.6)	17 (4.8)	12 (3.4)	353 (100)

parameters (Table 4). The degree of increasing vascular impedance was significantly related to increasing frequency of adverse outcome ($P < 0.0001$).

The group of fetuses with normal Doppler of the umbilical artery ($n = 251$) was analysed separately. Abnormal Doppler of the uterine artery in this group showed a statistically significant correlation with SGA newborns, delivery by caesarean section, premature delivery and admission to NICU, even though the Doppler velocimetry of the umbilical artery was normal (Table 5). Similarly, the group with normal Doppler of the uterine arteries ($n = 233$) was analysed. In this group, abnormal Doppler of the umbilical artery showed a statistically significant correlation with SGA newborns, delivery by caesarean section, premature delivery and admission to NICU (Table 5).

ROC curves were used to compare UAS and BFC, in relation to SGA newborns, delivery by caesarean section, premature delivery and admission to NICU. The area under the curve showed no statistically significant differences between Doppler examinations of the two vessels in relation to these four outcome variables (Table 6). Furthermore, the women were divided into four groups according to normal or abnormal Doppler result of the two vessels, group 1: normal uterine and umbilical artery ($n = 190$); group 2: abnormal uterine (UAS > 0) but normal umbilical artery ($n = 61$); group 3: normal uterine artery but abnormal umbilical artery (PI > +2 SD) ($n = 42$); and group 4: abnormal uterine and umbilical artery Doppler ($n = 59$). Perinatal outcome in each group was analysed. The results show that the risk for adverse perinatal outcome was lowest when both uterine and umbilical artery Doppler were normal and highest when Doppler examination of both vessels was abnormal (Figure 1). Interestingly, the group with abnormal uterine, but normal umbilical artery Doppler, showed a higher risk for all outcome parameters (except for delivery by caesarean) than the group with abnormal umbilical but normal uterine artery Doppler (Figure 1).

Discussion

The results of the present study on pregnancies complicated by suspected FGR fetuses suggest that Doppler examination of the uterine arteries can identify fetuses at increased risk, even though the umbilical artery Doppler was normal. Abnormal Doppler velocimetry of both the uterine and umbilical arteries was strongly correlated with SGA newborns, delivery by caesarean section, premature delivery and admission of the newborn to NICU. The two vessels seem to be comparable in its ability to identify fetuses at increased risk.

Umbilical artery Doppler examination identifies a large part of the fetuses, which are growth restricted based on feto-placental vascular insufficiency. Of the 353 women in the present study, 251 (71.1%) had normal umbilical artery Doppler, and of those, 61 (24.3%) had abnormal uterine artery Doppler. Even though Doppler was reassuring in the umbilical artery, a strong correlation was seen between

Table 4. Perinatal outcome in relationship to UAS and BFC

	Number	SGA, *n* (%)	Caesarean section, *n* (%)	<37 weeks, *n* (%)	NICU, *n* (%)
UAS					
0	233	104 (44.6)	92 (39.5)	44 (18.9)	61 (26.2)
1	50	35 (70.0)	33 (66.0)	23 (46.0)	28 (56.0)
2	41	29 (70.7)	36 (87.8)	29 (70.7)	32 (78.0)
3	17	17 (100)	15 (88.2)	9 (52.9)	16 (94.1)
4	12	12 (100)	12 (100)	11 (91.7)	12 (100)
P value		<0.0001	<0.0001	<0.0001	<0.0001
BFC					
0	251	117 (46.6)	98 (39.0)	56 (22.3)	76 (30.3)
1	64	48 (75.0)	52 (81.2)	32 (50.0)	40 (62.5)
2	32	26 (81.2)	32 (100)	22 (68.8)	27 (84.4)
3	6	6 (100)	6 (100)	6 (100)	6 (100)
P value		<0.0001	<0.0001	<0.0001	<0.0001

P values are given for trend within a blood flow score.

Table 5. Perinatal outcome in women with normal Doppler velocimetry in either the umbilical or the uterine arteries

	Number	SGA, *n* (%)	Caesarean section, *n* (%)	<37 weeks, *n* (%)	NICU, *n* (%)
Normal Doppler of the umbilical artery (*n* = 251)					
UAS 0	190	78 (41.1)	59 (31.1)	27 (14.2)	41 (21.6)
UAS 1	33	19 (57.6)	18 (54.5)	11 (33.3)	15 (45.4)
UAS 2	18	10 (55.6)	13 (72.2)	11 (61.1)	11 (61.1)
UAS 3	7	7 (100)	5 (71.4)	3 (42.9)	6 (85.7)
UAS 4	3	3 (100)	3 (100)	3 (100)	3 (100)
P value		<0.003	<0.0001	<0.0001	<0.0001
Normal Doppler of the uterine arteries (*n* = 233)					
BFC 0	190	78 (41.1)	59 (31.1)	27 (14.2)	41 (21.6)
BFC 1	27	15 (55.6)	17 (63.0)	9 (33.3)	9 (33.3)
BFC 2	15	11 (73.3)	15 (100)	8 (53.3)	10 (66.7)
BFC 3	1	1 (100)	1 (100)	1 (100)	1 (100)
P value		<0.04	<0.0001	<0.0001	<0.0003

P values are given for trend within a blood flow score.

abnormal uterine artery Doppler and adverse perinatal outcomes. The results from the present study indicate that uterine artery Doppler seems to offer a possibility to identify an additional group of fetuses, namely those with impaired circulation on the maternal side of the placenta. Intensified surveillance and optimal timing of delivery might or may not improve perinatal outcome for those fetuses. Furthermore, the knowledge of abnormal uterine artery Doppler may be used to prepare the parents for the possibility of premature birth and caesarean section as well as for optimising neonatal resources. Our present recommendations for follow up of FGR fetuses with normal umbilical artery Doppler are UAS of 0–2: surveillance every other week by fetal biometry, umbilical and uterine artery Doppler, NST and AFI evaluation; UAS 3: umbilical and uterine artery Doppler, NST and AFI evaluation weekly and fetal biometry every other week and UAS 4: umbilical and uterine artery Doppler, NST and AFI evaluation twice weekly and fetal biometry every other week. Benefit or detriment of this testing is unknown and should be evaluated by randomised trials.

Table 6. ROC curves of UAS and BFC in correlation to perinatal outcome

	UAS	BFC	*P* value
SGA	0.66 (0.61–0.69)	0.64 (0.59–0.69)	NS
Caesarean section	0.69 (0.64–0.74)	0.71 (0.66–0.76)	NS
<37 weeks of gestation	0.72 (0.67–0.77)	0.69 (0.64–0.74)	NS
NICU	0.73 (0.68–0.78)	0.68 (0.63–0.73)	NS

NS, non-significant.
Values are expressed as area under the curve (95% CI).

The division of the women into four groups according to normal/abnormal Doppler profile of placental vessels (group 1: normal uterine and umbilical artery; group 2: abnormal uterine but normal umbilical artery; group 3: normal uterine but abnormal umbilical artery and group 4: abnormal uterine and umbilical artery Doppler) showed an increasing risk for adverse outcome when both vessels were affected. Interestingly, the group with abnormal uterine, but normal umbilical artery Doppler, showed higher risk for adverse outcome

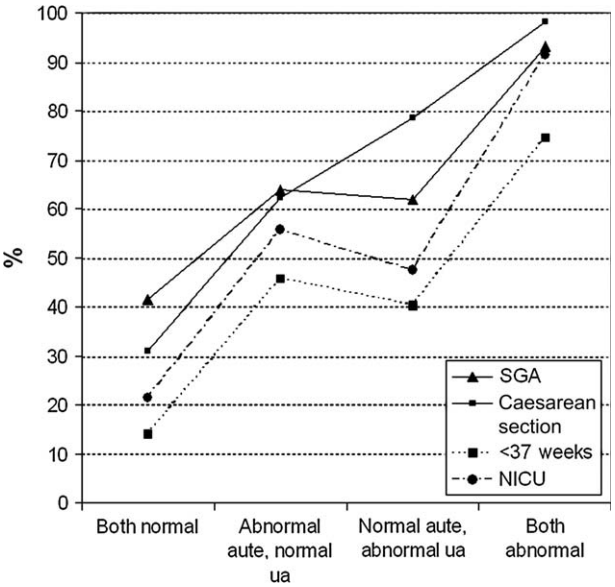

Figure 1. Perinatal outcome in relationship to four groups according to normal or abnormal Doppler profile of placental vessels. Group 1: normal uterine and umbilical artery; group 2: abnormal uterine but normal umbilical artery; group 3: normal uterine but abnormal umbilical artery and group 4: abnormal uterine and umbilical artery Doppler. Aute, uterine artery; ua, umbilical artery.

(except for caesarean delivery) compared with the group with normal uterine but abnormal umbilical artery Doppler (Figure 1). The fact that the abnormal results of the uterine artery Doppler were blinded to the physician, but the reassuring umbilical artery Doppler were available, confirms the importance of uterine artery Doppler as a tool for detecting high-risk pregnancies.

The results from the Doppler examination of the umbilical artery were revealed to the physician. This knowledge could have affected the results of the analysis. Although abnormal umbilical artery Doppler is associated with poor outcome, intervention (e.g. premature delivery) due to the knowledge of a very bad umbilical artery Doppler result could have improved outcome in this group. Furthermore, we are aware that more than one of the outcome parameters could be present in a woman, and the results should be interpreted with that in mind. However, we chose to include all the parameters as they are important and have different implications.

The vascular bed of the placenta starts to develop early in pregnancy. Invasion of cytotrophoblastic cells into the decidual tissue transforms the subplacental vasculature into a low resistance circulation. In pregnancies complicated by pre-eclampsia and/or FGR, the transformation of the vessels is incomplete.[14] Immunological factors are thought to be responsible for this development.[15] Furthermore, morphological evaluation of the placental bed has shown lack of vessel transformation in association with increased vascular impedance of the uterine artery in these pregnancies.[16]

Uterine artery Doppler can be performed in early pregnancy, and increased PI and/or persistent notches in the blood flow waveform can be detected in the second trimester. Screening for abnormality in the uterine arteries has been performed in an attempt to predict complications such as pre-eclampsia and FGR later in pregnancy. Screening an unselected population seems to be of limited value, and the result suggests that the effort should be concentrated on a high-risk population.[17,18] In combination with placental growth factor or maternal characteristics, uterine artery Doppler has proven to identify women at risk for early onset and/or severe pre-eclampsia.[19,20] Uterine artery Doppler has, however, not been used in the routine evaluation of the FGR fetus, but the results of the present study confirm its value in that aspect. Our results are in accordance with the results of Vergani *et al.*[21] who showed a correlation between abnormal uterine artery Doppler and increased risk for caesarean section, low birthweight and admission to NICU in growth-restricted pregnancies. Severi *et al.*[22] showed an increased risk for emergency caesarean sections in FGR fetuses with abnormal uterine artery Doppler but normal umbilical artery Doppler. The present study, however, present result from Doppler examinations of both the umbilical and uterine arteries, and even though a large part of the women had abnormal Doppler results from both vessels, there seems to be a group of women with isolated abnormal Doppler on either the fetal or the maternal side of the placental circulation. The results indicate that both the maternal and the fetal side of the placental perfusion seem to be important in the evaluation of the FGR fetus.

The growth-restricted fetus is at high risk for perinatal complications. No scientifically proven treatment exists to enhance perfusion of the placenta, and further research is needed in this area. Another focus must be directed at surveillance and optimal timing for delivery of the growth-restricted fetus. Doppler examination of the umbilical artery is today an important part of that surveillance. Reversed diastolic blood flow velocity of the umbilical artery is in most cases, especially after 32 weeks, an indicator for delivery. Uterine artery Doppler is, however, not commonly used in surveillance of the growth-restricted fetus.

The uterine artery Doppler waveform has so far not provided us with information on the optimal time for delivery of the growth-restricted fetus. Presently, the decision is based on information on fetal growth, NST, amniotic fluid volume and Doppler examination of the umbilical artery, the umbilical vein and ductus venosus. However, preliminary results (Prof. K. Marsal, pers. comm.) show that reversed diastolic blood flow in the uterine artery is an ominous sign for the fetus. This has also been reported by Ekici *et al.*[23] who described a case with reversed end-diastolic blood flow velocities in the uterine arteries, preceding intrauterine fetal death, and Lau *et al.*[24] who describe a case with reversed end-diastolic blood flow in the uterine arteries preceding the emergency caesarean delivery of a severely growth-restricted baby. However, in both cases, ARED blood flow was found in the umbilical artery simultaneously with the pathological findings in the uterine arteries. These results are based on case reports and should therefore be interpreted with utmost caution. Today, there is no scientifical evidence that abnormal uterine artery Doppler alone constitutes an indication for delivery.

In conclusion, the results of the present study suggest that uterine artery Doppler velocimetry can be used to identify fetuses with increased risk for adverse perinatal outcome, that is those with restricted fetal growth associated with impaired blood flow on the maternal side of the placenta. Even though the uterine and umbilical artery Doppler velocimetry were comparable as predictors of adverse perinatal outcome, uterine artery Doppler seems to be able to identify a group, not detected by umbilical artery Doppler alone. Randomised studies evaluating management protocols including uterine artery Doppler should be performed before an evaluation of this vessel, in addition to umbilical artery, is included in the surveillance of the growth-restricted fetus.

Disclosure of interest

There were no conflicts of interest involved.

Contribution to authorship

S.G. designed and funded the study. G.S.G analysed and wrote the main part of the text. The recordings were performed by trained ultrasonographers that were not involved in patient care.

Details of ethics approval

The local ethics committee approved the study, and all the women who participated gave their written consent.

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