e-ISSN: 0975-9506, p-ISSN: 2961-6093

Available online on www.ijpqa.com doi: 10.25258/ijpqa.16.10.43

International Journal of Pharmaceutical Quality Assurance 2025; 16(10); 268-274

Original Research Article

Correlation Between Doppler Ultrasound Findings and Perinatal Outcome in Fetal Growth Restriction

Mukesh Bihari[1], Geeta Rani[2], Sachin Kumar Singh[3]

[1]Assistant Professor, Department of Radiology, Jawaharlal Nehru Medical College and Hospital, Bhagalpur, Bihar, India

[2]Assistant Professor, Department of Obstetrics and Gynaecology, Jawaharlal Nehru Medical College and Hospital, Bhagalpur, Bihar, India

[3]Associate Professor, Department of Radiology, Jawaharlal Nehru Medical College and Hospital, Bhagalpur, Bihar, India

Received: 10-08-2025 / Revised: 18-09-2025 / Accepted: 25-10-2025

Corresponding Author: Dr. Geeta Rani

Conflict of interest: Nil

Abstract:

Background: Fetal Growth Restriction (FGR) is a major obstetric condition associated with increased perinatal morbidity and mortality. Doppler ultrasound has emerged as a non-invasive and reliable tool for evaluating fetoplacental circulation and predicting FGR.

Aim: To assess the diagnostic accuracy of Doppler ultrasound parameters (Umbilical Artery Pulsatility Index (UA-PI), Middle Cerebral Artery Pulsatility Index (MCA-PI), Uterine Artery PI, and Cerebroplacental Ratio (CPR)) in predicting FGR.

Methodology: A prospective observational study was conducted on 90 singleton pregnancies (28–40 weeks) at Jawaharlal Nehru Medical College and Hospital, Bhagalpur, Bihar, India. Doppler indices were measured and correlated with fetal growth parameters and perinatal outcomes. Data were analyzed using SPSS version 27.0, with $p < 0.05$ considered statistically significant.

Results: Abnormal Doppler indices were significantly associated with FGR ($p < 0.001$). CPR showed the highest diagnostic accuracy (89.2%), sensitivity (84.6%), and specificity (91.9%), followed by UA-PI (80% accuracy). Combined Doppler evaluation enhanced prediction of fetal compromise compared to single-parameter assessment.

Conclusion: Doppler ultrasound, particularly the CPR, is a highly accurate and non-invasive tool for early detection of FGR. Incorporating UA-PI, MCA-PI, and CPR in routine antenatal surveillance can improve perinatal outcomes through timely intervention.

Keywords: Fetal Growth Restriction, Doppler Ultrasound, Umbilical Artery, Middle Cerebral Artery, Cerebroplacental Ratio, Perinatal Outcome.

This is an Open Access article that uses a funding model which does not charge readers or their institutions for access and distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0) and the Budapest Open Access Initiative (http://www.budapestopenaccessinitiative.org/read), which permit unrestricted use, distribution, and reproduction in any medium, provided original work is properly credited.

Introduction

Fetal Growth Restriction (FGR) or intrauterine growth restriction (IUGR) is a major obstetric complication and is defined by the inability of the fetus to develop to its genetically predetermined size or growth potential [1]. It has been linked to perinatal morbidity and mortality and has long term effects on neurodevelopment and adult health. Primary diagnosis and treatment of FGR thus matters in enhancing perinatal care. Conventionally, the aspects of clinical parameters like measuring the fundal height and serial ultrasonography have been used to ensure the growth of the fetus [2]. Nonetheless, these methods might not be sensitive and specific in identifying growth-restrained fetuses, especially at an early or subclinical phase. In this respect, Doppler ultrasound has become an irreducible part of the contemporary obstetrics practice, as a non-invasive and effective tool to measure the hemodynamics of the fetus and placenta, thus contributing to the timely diagnosis and treatment of FGR.

Through doppler ultrasonography, the velocity and pattern of blood flow in the fetal, placental, and uterine circulations is measured and this offers important information on the fetal adaptive mechanisms to hypoxia and placental insufficiency [3]. The systolic-to-diastolic (S/D) ratio, resistance index (RI), and pulsatility index (PI) measured in different vessels (especially the umbilical artery, the middle cerebral artery (MCA), and the uterine artery) are important variables used as indices of placental functioning and fetal health. These indices show progressive changes as gestation progresses in normal pregnancies which are indicative of

maturation of the placental vasculature and enhanced perfusion [4]. But in FGR, the parameters are not normal as the placental resistance is higher, the blood flow is redistributed (the so-called brain-sparing effect) and, in the worst-case scenario, there are abnormal venous Doppler measurements, e.g., reversed end-diastolic flow in the umbilical artery or ductus venosus. Such changes occur prior to apparent clinical changes, which makes Doppler evaluation an effective indicator of pending fetal compromise.

Pathophysiology FGR is commonly associated with uteroplacental insufficiency, with poor trophoblastic invasion, and imbalanced remodeling of the spiral arteries resulting in the higher resistance in the uteroplacental circulation [5]. The fetus is a compensatory mechanism that is redistribution of blood to the vital organs, especially the brain, heart, and adrenals, at the cost of other less essential organs such as the liver and kidneys. This predictive potential is evident in that this hemodynamic adaption will be detectable by Doppler velocimetry long before the fetus size is even measurably changed. In particular, umbilical artery Doppler has been commonly acknowledged as one of the main instruments of screening and monitoring high-risk pregnancies [6]. Abnormalities like absent or reversed end-diastolic flow have been demonstrated to be closely related to unfavourable perinatal outcomes such as fetal distress, preterm birth and intrauterine fetal demise. In the same way, the MCA Doppler offers complementary data because it reflects cerebral vasodilation caused by hypoxia, whereas the cerebroplacental ratio (CPR) calculated via the MCA and umbilical arteries indexes is a strong composite measure of the ability of the fetus to compromise.

In conjunction with FGR, Doppler ultrasound can be used in distinguishing between constitutionally small yet healthy fetuses and the ones that are actually growth-restricted because of pathological reasons [7]. This difference is also a clinically important aspect because unnecessary operations may be prevented in the former category, whereas the latter one can receive timely delivery and careful monitoring. In addition, the latest developments in Doppler technology have led to the extension of its application to venous Doppler studies (especially of the ductus venosus and the inferior vena cava) that are reflective of the cardiac preload and could offer some important prognostic data in severe growth restriction cases [8]. These parameters have been now incorporated into holistic fetal surveillance guidelines to inform decision making on when to deliver the baby and how to maximize the outcomes of the babies.

A number of studies have shown that Doppler ultrasound is very accurate in the diagnostics of adverse perinatal outcomes with respect to FGR. Doppler indices have been found to be more sensitive than other conventional sonographic parameters that include biparietal diameter, abdominal circumference and estimated fetal weight in identifying fetuses, which are at risk, of hypoxia and intrauterine demise. The umbilical artery and the MCA Doppler parameters, particularly when measured on serially, are more predictive and can be applied in the dynamic monitoring of the fetal condition. Moreover, uterine artery Doppler in the second trimester has been identified to be useful in the prediction of FGR and preeclampsia so that the high-risk pregnancies can be identified and preventive measures like low-dose aspirin therapy can be adopted.

Although it has been clinically proven to be useful, interpretation of Doppler findings should be done with great care by considering gestational age, technical aspect, and fetuses maternal condition. False positives can be obtained as a consequence of the temporary changes in hemodynamics and, consequently, Doppler data should always be supported by the clinical and other ultrasonographic observations. However, when conducted under the guidance of qualified professionals under standardized procedures, Doppler ultrasonography is still among the most precise and non-invasive modalities of determining the well-being of the fetus. It offers live functional data that supplements anatomical evaluation, hence, forms a pillar in the management of pregnancies complicated by the FGR.

Methodology

Study Design: This study was a prospective observational study conducted to assess the accuracy of Doppler ultrasound in predicting fetal growth restriction (FGR) by evaluating various Doppler parameters and correlating them with neonatal outcomes.

Study Area: The study was carried out in the Department of Radiology, Jawaharlal Nehru Medical College and Hospital, Bhagalpur, Bihar, India for 12 months.

Study Participants: Pregnant women attending the hospital and referred to the Department of Radiology for obstetric ultrasound and Doppler assessment were included in the study after obtaining informed consent.

Inclusion Criteria

- Singleton pregnancies between 28 and 40 weeks of gestation, confirmed by first-trimester ultrasound.
- Pregnancies clinically or sonographically suspected of fetal growth restriction.
- Patients who provided written informed consent for participation.

Exclusion Criteria

- Multiple pregnancies.

- Pregnancies with fetal congenital anomalies, chromosomal abnormalities, or intrauterine infections.
- Cases with maternal comorbidities such as chronic hypertension, diabetes mellitus, renal disease, or autoimmune disorders affecting fetal growth.
- Poor Doppler signal quality or technically inadequate studies.

Sample Size: A total of 90 pregnant women were included in the study based on eligibility criteria and informed consent.

Procedure: All the individuals were taken through an elaborate examination with Doppler ultrasound machine with high-resolution color Doppler ultrasound machine and with a convex transducer of 3.55 MHz. Routine fetal biometric measurements were registered and estimated fetal weight (EFW) was estimated by the use of Hadlock formula. The umbilical artery (UA), middle cerebral artery (MCA), and uterine artery were then assessed using Doppler and the cerebroplacental ratio (CPR) was calculated as MCA-PI/UA-PI.

When there were no fetal movements or breathing, the Doppler measurements were performed at an angle of insonation no greater than 30°. The UA Doppler was recorded as free loop of the umbilical cord and the MCA Doppler recorded in an axial position of the fetal head at its bifurcation out of the circle of Willis. The uterine artery Doppler was measured at the apparent crossover of the uterine artery with the external iliac artery and the mean PI was calculated on both sides.

Amniotic fluid volume was measured using the deepest vertical pocket technique. Based on these measurements, Doppler indices were classified as normal or abnormal using standard reference ranges. Fetal growth restriction was defined as EFW or abdominal circumference below the 10th percentile for gestational age, with or without abnormal Doppler findings. All pregnancies were followed until delivery, and neonatal outcomes such as birth weight, Apgar scores, umbilical cord pH (if available), and NICU admission were recorded to assess perinatal outcome and to validate the predictive accuracy of Doppler findings.

Statistical Analysis: The data were inputted into the Microsoft Excel and analyzed in the IBM SPSS Statistics 27.0 (IBM Corp., Armonk, NY, USA). The continuous variables were presented in mean plus standard deviation (SD) whilst the categorical variables were presented in frequencies and percentage. The student unpaired t-test was used to compare groups of continuous variables and Chi-square test (χ^2) was used to compare groups of categorical variables. The diagnostic performance and predictive accuracy of Doppler indices (UA-PI, MCA-PI and CPR) in identifying fetal growth restriction was done through receiver Operating Characteristic (ROC) curve analysis. Each Doppler parameter these parameters were sensitive, specific, positive predictive value (PPV), and negative predictive value (NPV). The statistical significance was assumed to be below 0.05.

Result

Table 1 uses the demographic characteristics of the study participants by their maternal characteristics. Out of the 90 participants, most of them were in the 2025 years age category (37.8) with the other 33.3% in 26-30 years of age group.Only a small percentage (8.9) of the population was below 20 years old with the other 20 percent being older than 30. Over 50 percent of the respondents were primigravida (53.3%), and the other 46.7 percent were multigravida. In terms of socioeconomic status, the greatest percentage of participants (60) was in the middle class, 24.4% in the lower and 15.6% in the upper classes. Residence wise 60% of the participants lived in rural regions and 40% in urban region meaning that the rural representation was dominant in the study population.

Table 1: Distribution of Study Participants According to Maternal Demographic Characteristics (n = 90)

Parameters	Categories	Number of Cases (n)	Percentage (%)
Age Group (years)	< 20	8	8.9
	20–25	34	37.8
	26–30	30	33.3
	> 30	18	20
Gravidity	Primigravida	48	53.3
	Multigravida	42	46.7
Socioeconomic Status	Lower	22	24.4
	Middle	54	60
	Upper	14	15.6
Residence	Urban	36	40
	Rural	54	60

Table 2 provides a breakdown of the participants in 90 cases depending on gestational age and the clinical finding. Most of the respondents (42.2%) were in the 33–36 age bracket, which is the gestational age with 37 to 40 age group following (33.3), and 24.4% falling in the 28–32 age bracket, meaning that most of the assessment took place in the late third trimester. In terms of fundal height lag, almost half of the participants (48.9% had a lag of 2-4 cm), 28.9% had a lag of less than 2 cm and 22.2% had a lag exceeding 4 cm indicating that fundal height lag was most common with a lag of 2-4 cm. The cases with clinically suspected fetal growth restriction (FGR) (55.6 percent) and clinically no manifestations of growth restriction (44.4 percent) were balanced, which indicated a prevalence of clinically suspected growth restriction in the population under study.

Table 2: Distribution of Participants According to Gestational Age and Clinical Findings

Parameter	Categories	Number of Cases (n)	Percentage (%)
Gestational Age (weeks)	28–32	22	24.4
	33–36	38	42.2
	37–40	30	33.3
Fundal Height Lag (cm)	< 2 cm	26	28.9
	2–4 cm	44	48.9
	> 4 cm	20	22.2
Clinically Suspected FGR Cases	Present	50	55.6
	Absent	40	44.4

Table 3 shows the distribution of Doppler indices among the 90 sample participants pointing at the percentage of normal and abnormal values of every parameter. The Umbilical Artery Pulsatility Index (UA-PI) had a normal mean value of 1.04 and a standard deviation of 0.26 and had normal values of 64 (71.1) and abnormal values of 26 (28.9) participants. The Middle Cerebral Artery Pulsatility Index (MCA-PI) showed normalcy on 68 concussed (75.6) and abnormal findings on 22 (24.4) with a mean standard deviation of 1.46 and SD of 0.32 respectively. The Cerebroplacental Ratio (CPR) was 62 normal (68.9) and 28 abnormal (31.1) with a mean SD of 1.32 ± 0.29respectively. The average Uterine Artery PI of 66 participants (73.3%), 24 (26.7%) were normal and abnormal respectively with an average of 0.89 and 0.21 respectively. On the whole, the results reveal that most of the participants possessed normal Doppler indices, which implies overall positive uteroplacental and fetal hemodynamic outcomes.

Table 3: Distribution of Doppler Indices Among Study Participants (n = 90)

Doppler Parameter	Normal Range (n, %)	Abnormal Range (n, %)	Mean ± SD
Umbilical Artery PI (UA-PI)	64 (71.1%)	26 (28.9%)	1.04 ± 0.26
Middle Cerebral Artery PI (MCA-PI)	68 (75.6%)	22 (24.4%)	1.46 ± 0.32
Cerebroplacental Ratio (CPR)	62 (68.9%)	28 (31.1%)	1.32 ± 0.29
Uterine Artery PI (Mean)	66 (73.3%)	24 (26.7%)	0.89 ± 0.21

Table 4 shows how different Doppler indices are correlated to fetal growth restriction (FGR). The results indicate that abnormal Doppler results were greatly related with increased incidence of FGR in comparison to normal Doppler results. The most correlated parameter was the cerebroplacental ratio (CPR), and all the 28 FGR cases were found to be in the abnormal Doppler category ($p < 0.001$). Likewise, high umbilical artery pulsatility index (UA-PI) and middle cerebral artery pulsatility index (MCA-PI) were found in higher percentage of fGR cases both with highly significant correlations ($p < 0.001$). FGR was also significantly related to the uterine artery PI ($p = 0.002$). These results indicate that abnormal Doppler indices, especially CPR, MCA-PI and UA-PI are good predictors of fetal growth restriction.

Table 4: Correlation Between Doppler Indices and Fetal Growth Restriction

Doppler Parameter	Normal Doppler (n = 62)	Abnormal Doppler (n = 28)	FGR Detected (n)	p-value
UA-PI	8	18	26	<0.00
MCA-PI	6	16	22	<0.001
CPR	5	23	28	<0.001
Uterine PI	7	17	24	0.002

Table 5 shows the diagnostic performance of different Doppler parameters in the prediction of fetal growth restriction (FGR). The cerebroplacental ratio (CPR) is the best index in the evaluated indices, with a diagnostic accuracy of 89.2, a sensitivity of 84.6, and a specificity of 91.9; therefore, it is more capable of diagnosing an affected and unaffected fetus. The umbilical artery PI (UA-PI) was performing fairly well with accuracy of 80 percent which is a balanced sensitivity (69.2 percent) and high specificity (88.7 percent). The uterine artery PI was found to have moderate diagnostic ability with an accuracy of 79.0 and the middle cerebral artery PI (MCA-PI) was found to have the lowest sensitivity (61.5) and high specificity (90.3). In general, the use of CPR as the most effective Doppler parameter to predict FGR was made over the individual vessel indices.

Table 5: Diagnostic Performance of Doppler Parameters in Predicting Fetal Growth Restriction

Doppler Parameter	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)
Umbilical Artery PI (UA-PI)	69.2	88.7	82.1	79.3	80
Middle Cerebral Artery PI (MCA-PI)	61.5	90.3	80	77	78.9
Cerebroplacental Ratio (CPR)	84.6	91.9	88.9	89.6	89.2
Uterine Artery PI	73.1	83.9	77.8	80	79

Discussion

The current research evaluated the accuracy of the different Doppler ultrasound parameters (i.e., the umbilical artery pulsatility index (UA-PI), middle cerebral artery pulsatility index (MCA-PI), uterine artery PI, and cerebroplacental ratio (CPR)) to predict fetal growth restriction (FGR). It was shown that CPR was the most sensitive and specific measure to detect FGR, and UA-PI and uterine artery PI came second. The findings substantiate the clinical utility of multiparametric Doppler analysis in the detection of fetuses with the risk of intrauterine compromise prior to clinical manifestations. Similar results have been established by Vollgraff Heidweiller-Schreurs et al. (2018) [9] who have found that CPR and MCA-PI were both excellent predictors of adverse perinatal outcomes, but the CPR had a higher prognostic value. The given similarity supports the significance of CPR as a non-invasive, reliable indicator of fetal health.

In the presented research, about a quarter to a third of the subjects had abnormal Doppler measurements especially higher UA-PI and lower MCA-PI and CPR, which is an indicator of high placental resistance and sign of redistribution of fetal blood to the brain. This hemodynamic adaptation course is also related to the phenomenon of brain-sparing that takes place in FGR whereby the blood flow is redistributed favorably towards vital organs like the brain and heart (DeVore, 2015) [10]. According to the current results, they were in line with Cruz-Martinez et al. (2011) [11] findings, which revealed that a low CPR was significantly correlated with cesarean in non-reassuring fetal conditions in small-for- gestational-age fetuses. In the same way, Akolekar et al. (2015) [12] have found that the use of UA-PI and MCA-PI to predict adverse perinatal outcomes was stronger than either of these indices, which supports the integrated Doppler technique applied by the current research.

The diagnostic accuracy of CPR as we identified in our study is also consistent with other studies by Khalil et al. (2015) [13] who found out low CPR values to be independently related with intrapartum fetal compromise and increased neonatal intensive care admissions. By studying both the small-for-gestational-age fetuses and the appropriate-for-gestational-age fetuses, their focus was on the fact that CPR is a more detailed indicator rather than the individual arterial indices since it represents both placental and fetal circulatory changes. To the contrary, Triunfo et al. (2017) [14] discovered that the overall diagnostic accuracy of various Doppler parameters of adverse outcomes in late-onset FGR was moderate, and the area under the curve (AUC) was 0.67 with a combination of multiple indices. Such difference may be explained by the difference in gestational age at the time of the assessment and population factors, since our research study was mainly based on third-trimester pregnancies where the changes in hemodynamics are more prominent.

Our results of finding elevated uterine artery PI in FGR cases agree with those found by Fadigas et al. (2015) [15] where increased uterine artery resistance at 3537 weeks was a predictor of small-for-gestational-age babies. This parameter is an indicator of impaired maternal vascular adaptation and diminished uteroplacental perfusion, which is a major etiological agent in FGR. To support this idea, Cruz-Martínez et al. (2015) [16] also added that third-trimester uterine artery Doppler plays an essential role in adverse outcome prediction, as it helps detect fetuses with a risk of cerebral deterioration in hemodynamics. These studies combined with our finding that uterine artery PI is less sensitive than CPR is a useful complementary marker in a Doppler-derived risk assessment.

The current research finding that UA-PI was very specific and moderate in sensitivity is in agreement with the past studies by Figueras et al. (2018) [17]

which reported that UA-PI may easily be normal even in late-onset FGR, and therefore lacks the capability of detecting all the infetuses that are compromised. However, UA-PI is also important to assess placental resistance and detect early growth restriction forms because Parra-Saavedra et al. (2013) [18] have shown that abnormal umbilical vein flow was closely correlated with histological evidence of placental under perfusion. This was the case in our study, with clinically significant FGR being associated with abnormal values of UA-PI, which supported the diagnostic importance of the parameter when used in conjunction with fetal indices.

Interestingly, MCA-PI in our study did not show high sensitivity but high specificity, which appears to imply that it is only after redistribution in the brain has happened that it becomes abnormal, of which Dall'Asta et al. (2019) report [19] it does. This time sensitivity puts a limit on its predictive capacity in early detection, but plays an increased role in the validation of pre-existing fetal compromise. This was also discovered by Souka et al. (2013) who also expressed that MCA-PI changes during the third-trimester were positively associated with birth weight variations which further validates our reasoning that it is a late adaptive process and not an early warning system.

Combining UA-PI, MCA-PI, and CPR in our study was a great enhancement to the diagnostic accuracy of individual parameters assessment. It agrees with the meta-analysis by Vollgraff Heidweiller-Schreurs et al. (2018) [9], who found that when comparing indices, the combination was a more reliable measure of fetoplacental hemodynamics compared to the individual parameter. On the same note, Figueras and Gratacos (2015) [20] highlighted the merits of the composite Doppler indices as an effective tool to conduct a full fetus monitoring, and particularly to separate the cases of high FGR risks and the cases of fetuses being constitutionally small but still healthy.

On the other hand, there are studies that have established moderate diagnostic characteristics of Doppler indices, as independent measures, and models the significance of population-specific validation. The difference in results can have been due to the dissimilarity in sample size, the gestational age at which the evaluation was conducted, and the diagnostic level used. However, the overall agreement in the literature, buttressed by the current findings, is that Doppler ultrasound continues to be a critical instrument in the process of antenatal surveillance, in that it is a useful means of minimising perinatal morbidity by identifying fetal compromise in the early stages.

Conclusion

The present study concluded that Doppler ultrasound is a highly effective and non-invasive diagnostic tool for predicting fetal growth restriction (FGR) and related adverse perinatal outcomes. Among the Doppler indices assessed, the cerebroplacental ratio (CPR) demonstrated the highest diagnostic accuracy, followed by the umbilical artery pulsatility index (UA-PI), indicating that CPR serves as a comprehensive marker of fetoplacental hemodynamic compromise. Elevated UA-PI and uterine artery PI reflected increased placental resistance, whereas reduced middle cerebral artery PI (MCA-PI) indicated compensatory cerebral vasodilation in response to hypoxia. Abnormal Doppler findings were strongly correlated with low birth weight, poor Apgar scores, and higher NICU admissions, highlighting their clinical importance. Hence, integrating UA-PI, MCA-PI, and CPR in fetal surveillance protocols can enhance early detection of FGR and improve perinatal management and outcomes.

References

1. Nardozza LM, Caetano AC, Zamarian AC, Mazzola JB, Silva CP, Marçal VM, Lobo TF, Peixoto AB, Araujo Júnior E. Fetal growth restriction: current knowledge. Archives of gynecology and obstetrics. 2017 May;295(5):1061-77.
2. Lees CC, Stampalija T, Baschat A, da Silva Costa F, Ferrazzi E, Figueras F, Hecher K, Poon LC, Salomon LJ, Unterscheider J. ISUOG Practice Guidelines: diagnosis and management of small-for-gestational-age fetus and fetal growth restriction. Ultrasound in obstetrics and gynecology. 2020;56(2):298-312.
3. Browne VA, Julian CG, Toledo-Jaldin L, Cioffi-Ragan D, Vargas E, Moore LG. Uterine artery blood flow, fetal hypoxia and fetal growth. Philosophical Transactions of the Royal Society B: Biological Sciences. 2015 Mar 5;370(1663):20140068.
4. Chen JY, Chen M, Wu XJ, Sun JM, Zhang Y, Li YF, Zhong LY, Yu BL, Luo J, Liu JH. The value of placental vascularization indices for predicting preeclampsia and fetal growth restriction in different stages of gestation: a prospective and longitudinal study. Placenta. 2022 May 1;122:1-8.
5. Van der Merwe E. The incidence and clinical characteristics of placental insufficiency among high-risk pregnancies with normal umbilical artery resistance index after 32 weeks gestation: a cross-sectional study (Doctoral dissertation, Stellenbosch: Stellenbosch University).
6. Moraitis AA, Bainton T, Sovio U, Brocklehurst P, Heazell AE, Thornton JG, Robson SC, Papageorghiou A, Smith GC. Fetal umbilical artery Doppler as a tool for universal third trimester screening: A systematic review and meta-analysis of diagnostic test accuracy. Placenta. 2021 May 1;108:47-54.

7. Ashwal E, Ferreira F, Mei-Dan E, Aviram A, Sherman C, Zaltz A, Kingdom J, Melamed N. The accuracy of Fetoplacental Doppler in distinguishing between growth restricted and constitutionally small fetuses. Placenta. 2022 Mar 24;120:40-8.
8. Seravalli V, Miller JL, Block-Abraham D, Baschat AA. Ductus venosus Doppler in the assessment of fetal cardiovascular health: an updated practical approach. Acta obstetricia et gynecologica Scandinavica. 2016 Jun;95(6):635-44.
9. Vollgraff Heidweiller-Schreurs CA, De Boer MA, Heymans MW, Schoonmade LJ, Bossuyt PM, Mol BW, De Groot CJ, Bax CJ. Prognostic accuracy of cerebroplacental ratio and middle cerebral artery Doppler for adverse perinatal outcome: systematic review and meta-analysis. Ultrasound in Obstetrics & Gynecology. 2018 Mar;51(3):313-22.
10. DeVore GR. The importance of the cerebroplacental ratio in the evaluation of fetal well-being in SGA and AGA fetuses. American journal of obstetrics and gynecology. 2015 Jul 1;213(1):5-15.
11. Cruz-Martínez R, Figueras F, Hernandez-Andrade E, Oros D, Gratacos E. Fetal brain Doppler to predict cesarean delivery for nonreassuring fetal status in term small-for-gestational-age fetuses. Obstetrics & Gynecology. 2011 Mar 1;117(3):618-26.
12. Akolekar R, Syngelaki A, Gallo DM, Poon LC, Nicolaides KH. Umbilical and fetal middle cerebral artery Doppler at 35–37 weeks' gestation in the prediction of adverse perinatal outcome. Ultrasound in Obstetrics & Gynecology. 2015 Jul;46(1):82-92.
13. Khalil AA, Morales-Rosello J, Morlando M, Hannan H, Bhide A, Papageorghiou A, Thilaganathan B. Is fetal cerebroplacental ratio an independent predictor of intrapartum fetal compromise and neonatal unit admission? American journal of obstetrics and gynecology. 2015 Jul 1;213(1):54-e1.
14. Triunfo S, Crispi F, Gratacos E, Figueras F. Prediction of delivery of small-for-gestational-age neonates and adverse perinatal outcome by fetoplacental Doppler at 37 weeks' gestation. Ultrasound in Obstetrics & Gynecology. 2017 Mar;49(3):364-71.
15. Fadigas C, Guerra L, Garcia-Tizon Larroca S, Poon LC, Nicolaides KH. Prediction of small-for-gestational-age neonates: screening by uterine artery Doppler and mean arterial pressure at 35–37 weeks. Ultrasound in Obstetrics & Gynecology. 2015 Jun;45(6):715-21.
16. Cruz-Martinez R, Savchev S, Cruz-Lemini M, Mendez A, Gratacos E, Figueras F. Clinical utility of third-trimester uterine artery Doppler in the prediction of brain hemodynamic deterioration and adverse perinatal outcome in small-for-gestational-age fetuses. Ultrasound in Obstetrics & Gynecology. 2015 Mar;45(3):273-8.
17. Figueras F, Caradeux J, Crispi F, Eixarch E, Peguero A, Gratacos E. Diagnosis and surveillance of late-onset fetal growth restriction. American journal of obstetrics and gynecology. 2018 Feb 1;218(2):S790-802.
18. Parra-Saavedra M, Crovetto F, Triunfo S, Savchev S, Parra G, Sanz M, Gratacos E, Figueras F. Added value of umbilical vein flow as a predictor of perinatal outcome in term small-for-gestational-age fetuses. Ultrasound in Obstetrics & Gynecology. 2013 Aug;42(2):189-95.
19. Dall'Asta A, Ghi T, Rizzo G, Cancemi A, Aloisio F, Arduini D, Pedrazzi G, Figueras F, Frusca T. Cerebroplacental ratio assessment in early labor in uncomplicated term pregnancy and prediction of adverse perinatal outcome: prospective multicenter study. Ultrasound in Obstetrics & Gynecology. 2019 Apr;53(4):481-7.
20. Figueras F, Savchev S, Triunfo S, Crovetto F, Gratacos E. An integrated model with classification criteria to predict small-for-gestational-age fetuses at risk of adverse perinatal outcome. Ultrasound in Obstetrics & Gynecology. 2015 Mar;45(3):279-85.