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Predictive Efficacy of Ultrasound Doppler Parameters in the Diagnosis of Intrauterine Growth Restriction and Associated Perinatal Outcomes in a Tertiary Care Setting

Dr. Sitara Khatoon[1*], Dr Bhoomi Modi[2], Dr Ashish Kumar Shukla[3], Dr. Ashok Kumar Sharma[4], Mr. Asif Ali[5]

[*1]Postgraduate Student, Department of Radio-Diagnosis, Santosh Medical College & Hospital, Ghaziabad

[2]Associate Professor, Department of Radio Diagnosis, Santosh Medical College and Hospital, Ghaziabad

[3]Professor & Head, Department of Radio Diagnosis, Santosh Medical College and Hospital, Ghaziabad

[4]Professor, Department of Radio Diagnosis, Santosh Medical College and Hospital, Ghaziabad

[5]Jeevan Jyoti Hospital and Jeevan Sparsh Hospital, Ghaziabad

***Corresponding Author:**

Dr Sitara Khatoon

Email ID: sitarakhatoon2@gmail.com

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ABSTRACT

Introduction: Intrauterine growth restriction (IUGR) remains a significant contributor to perinatal morbidity and mortality. Early and accurate diagnosis using Doppler ultrasonography is crucial for optimizing outcomes. This study aimed to evaluate the predictive efficacy of various Doppler parameters in diagnosing IUGR and determining perinatal outcomes in high-risk pregnancies.

Methods: A prospective observational study was conducted at a tertiary care hospital over six months, including 60 high-risk pregnant women between 28-40 weeks gestation. Comprehensive Doppler assessment of umbilical artery (UA), middle cerebral artery (MCA), uterine arteries (UTA), and calculation of cerebroplacental (CP) ratio was performed. Sensitivity, specificity, positive predictive value, negative predictive value, and diagnostic accuracy of various Doppler indices were calculated for predicting adverse perinatal outcomes.

Results: Hypertensive disorders of pregnancy constituted 76.7% of cases, with abnormal UA PI observed in 61.7% and abnormal CP ratio in 58.3% of subjects. Adverse perinatal outcomes occurred in 65% of cases, with higher rates in hypertensive disorders (70.6-78.9%) compared to GDM (33.3%). UA PI demonstrated the highest sensitivity (83.05%) for predicting adverse outcomes, while MCA PI showed the highest specificity (90.32%). CP ratio and UA PI exhibited the best overall diagnostic accuracy (81.11%) among all parameters. NICU admission (53.3%) and low birth weight (40%) were the most common adverse neonatal outcomes.

Conclusion: Umbilical artery PI and cerebroplacental ratio emerged as the most accurate predictors of adverse perinatal outcomes in high-risk pregnancies. Implementation of a standardized protocol for Doppler assessment with emphasis on these parameters can significantly improve risk stratification and guide appropriate timing of delivery, ultimately enhancing perinatal outcomes.

Keywords: *Intrauterine growth restriction, Doppler ultrasonography, Cerebroplacental ratio, Umbilical artery, Middle cerebral artery, Perinatal outcomes*

1. INTRODUCTION

Intrauterine growth restriction (IUGR) is a significant obstetric complication, affecting about 10-15% of pregnancies globally and causing a major contribution to perinatal morbidity and mortality (Sharma et al., 2022). IUGR is characterized by the failure of a fetus to achieve its genetically determined growth potential, which can be due to placental insufficiency, maternal causes, or fetal anomalies (Figueras & Gratacós, 2017). IUGR is associated with adverse perinatal outcomes, including stillbirth, neonatal death, hypoxic-ischemic encephalopathy, and long-term neurodevelopmental disability (Malhotra et al., 2019).

Early and accurate diagnosis of intrauterine growth restriction (IUGR) is significant in improving perinatal outcomes by way of adequate monitoring, early intervention, and suitable delivery planning. IUGR has been diagnosed classically by a calculated fetal weight (EFW) less than the 10th percentile for gestational age, with the addition of abdominal circumference measurements in certain instances (Gordijn et al., 2016). The approach is deficient in differentiation of pathologically growth-restricted from constitutionally small but normal fetuses, also known as small for gestational age (SGA) (Khalil et al., 2018).

The pathophysiology of IUGR is essentially placental insufficiency with resultant decreased uteroplacental perfusion and resultant fetal hypoxemia and undernutrition. This placental insufficiency initiates a cascade of fetal adaptations, which include redistribution of cardiac output to essential organs like the brain, heart, and adrenal glands, at the expense of other organs like the kidneys, gastrointestinal tract, and skeletal muscle (Krishna & Bhalerao, 2020). This "brain-sparing effect" can be identified by Doppler ultrasonography, which assesses fetal and maternal vessel blood flow patterns.

Doppler ultrasonography has revolutionized the clinical management of high-risk pregnancy by providing real-time, non-invasive assessment of the fetoplacental circulation. The method measures the blood flow velocity waveforms through different vessels, such as the umbilical artery (UA), middle cerebral artery (MCA), ductus venosus (DV), and uterine arteries (UtA) (Bhide et al., 2019). The measurements yield various parameters, such as the pulsatility index (PI), resistance index (RI), systolic/diastolic (S/D) ratio, and presence/absence of end-diastolic flow. The cerebro-placental ratio (CPR), as a ratio of MCA-PI and UA-PI, has been identified as a specific useful index to identify fetuses who are at risk of adverse outcomes (Dunn et al., 2017).

In early-onset IUGR (prior to 32 weeks of gestation), the pathophysiologic cascade is typically triggered by increased UtA resistance, evolving into abnormal UA Doppler indices, then MCA vasodilation, and finally, in severe IUGR, abnormal venous Doppler patterns (DeVore, 2015). Late-onset IUGR (after 32 weeks) in most instances has more subtle Doppler abnormalities, with the CPR remaining the primary affected region, whereas UA Doppler can be normal (Parra-Saavedra et al., 2016).

Current research has highlighted the significance of checking more than one Doppler parameter to ensure a thorough evaluation of fetal well-being. Combining UA, MCA, and DV Doppler along with assessment of biophysical profile provides a more reliable prediction of adverse outcomes than any single parameter alone (Vollgraff Heidweiller-Schreurs et al., 2018). Additionally, use of uterine artery Doppler in the first and second trimesters has been found to be helpful in early identification of high-risk pregnancies for IUGR (Sotiriadis et al., 2019).

In India, maternal malnutrition, anemia, and poor antenatal care are significant causes of intrauterine growth restriction (IUGR), and hence the contribution of Doppler ultrasonography is increased. In India, it has been shown through various studies that IUGR has been as high as 25% in certain regions, significantly higher than the global figure (Yadav & Lee, 2023). Anand et al. (2021) determined pregnant women with abnormal umbilical artery Doppler and risk factors for IUGR to have six times greater perinatal complications compared to pregnant women with normal Doppler.

The clinical use of Doppler ultrasonography is not only for diagnosis but also for the timing of delivery, particularly in preterm intrauterine growth restriction (IUGR), where prematurity complications are to be balanced against the complications of prolonged intrauterine hypoxemia. The TRUFFLE study (Trial of Randomized Umbilical and Fetal Flow in Europe) proved that delivery was planned according to Doppler venous (DV) abnormalities and resulted in improved neurodevelopmental outcomes at two years of age compared to decisions made on the basis of cardiotocography (Lees et al., 2015). Gaikwad et al. (2020) also proved similar findings in a prospective cohort study at a tertiary care center in Mumbai, India.

Notwithstanding the strong recommendation for Doppler ultrasonography in the management of IUGR, there remain some issues. These are standardizing measurement methods, determining optimal reference ranges for various populations, and determining the best combination and order of Doppler parameters as a marker of improvement (Familiari et al., 2017). Moreover, the presence of trained staff and advanced ultrasound machines can restrict the universal application of full Doppler assessment, especially in developing countries (Melamed et al., 2018).

In addition, while numerous research studies have established a link between abnormal Doppler findings and poor perinatal outcomes, the level of predictability can vary significantly based on various factors and clinical environments. A systematic review by Conde-Agudelo et al. (2020) found that the sensitivity of umbilical artery Doppler in predicting poor perinatal outcomes ranged from 60% to 80%, with specificity between 50% and 80%. Although incorporating middle cerebral artery and cerebroplacental ratios has enhanced predictability, the optimal threshold values remain a topic of debate. Tertiary care settings provide a unique opportunity to assess the predictive value of comprehensive Doppler evaluations, thanks to advanced imaging technologies, specialized expertise, and a higher prevalence of high-risk pregnancies. Research conducted in these environments has shown that combining Doppler findings with clinical symptoms and other biophysical assessments can lead to better perinatal outcomes (Patil et al., 2019). Emerging technologies, such as three-dimensional power Doppler imaging of placental blood vessels and fractional moving blood volume quantification, present promising avenues for improving the predictive accuracy of fetal monitoring (Guiot et al., 2018). Additionally, applying machine learning to

Doppler-derived data has proven beneficial in enhancing risk stratification and tailoring management strategies for pregnancies affected by intrauterine growth restriction (IUGR) (Garcia-Canadilla et al., 2020). In this context, despite ongoing challenges, there is a pressing need for a thorough analysis of the predictive capabilities of various Doppler parameters across different clinical settings, particularly in high-risk countries like India. This study aims to address this gap by comparing the diagnostic performance of a range of Doppler parameters, both individually and collectively, in diagnosing IUGR and predicting adverse perinatal outcomes in a tertiary care hospital.

2. METHODOLOGY

Study Design and Site

A prospective observational study was carried out in the Department of Radio-diagnosis, Santosh Medical College & Hospital, Ghaziabad, a 1000-bedded multi-specialty teaching hospital. The hospital is a referral center for high-risk pregnancies from the local population and has state-of-the-art maternal and neonatal care facilities, including high-end ultrasonography machines and level III neonatal intensive care unit.

Study Duration and Sampling

The study was conducted over a period of 6 months from January 2024 to June 2024. A total of 60 pregnant women with clinically suspected IUGR and/or risk factors for IUGR were enrolled using a purposive sampling technique. The sample size was calculated based on previous studies with similar objectives, considering an expected sensitivity of 80% for Doppler parameters in detecting IUGR, with a precision of 10% and confidence level of 95%.

Inclusion and Exclusion Criteria

The research covered pregnant women with singleton gestations between 28 and 40 weeks of gestation with clinical suspicion of IUGR (fundal height ≥3 cm below the corresponding gestational age) and/or presence of risk factors for IUGR such as hypertensive disorders of pregnancy, chronic hypertension, renal disease, autoimmune disease, history of previous IUGR, and maternal malnutrition (BMI <18.5 kg/m²). Exclusion criteria were multiple gestations, pregnancies with known fetal congenital malformations, pregnancies with an unclear gestational age, and women refusing to be included in the study or those not traceable up to delivery.

Data collection tools and methods:

Detailed maternal history was recorded including demographic details, obstetric history, medical and surgical history, and risk factors for IUGR. Results of clinical examination and antenatal investigations were recorded. Ultrasonography was performed using a Voluson E8 ultrasound machine (GE Healthcare) with 3.5-5 MHz curvilinear transducer by a radiologist with expertise in fetal medicine who was blinded to the clinical details. Standard biometry measurements including biparietal diameter (BPD), head circumference (HC), abdominal circumference (AC), and femur length (FL) were obtained, and estimated fetal weight was calculated using Hadlock's formula. IUGR was defined as estimated fetal weight below the 10th percentile for gestational age according to Indian population reference charts. Color Doppler and pulsed wave Doppler studies were performed on the umbilical artery (UA), middle cerebral artery (MCA), ductus venosus (DV), and uterine arteries (UtA) bilaterally. Parameters recorded included the pulsatility index (PI), resistance index (RI), and systolic/diastolic (S/D) ratio. The cerebroplacental ratio (CPR) was calculated as the ratio of MCA-PI to UA-PI. All measurements were performed in accordance with the guidelines of the International Society of Ultrasound in Obstetrics and Gynecology (ISUOG).

Data Management and Statistical Analysis

All data were entered into a structured proforma and subsequently transferred to an electronic database using Microsoft Excel. Statistical analysis was performed using SPSS version 26.0 (IBM Corp., Armonk, NY). Descriptive statistics were presented as frequencies, percentages, means with standard deviations, or medians with interquartile ranges as appropriate. The normality of continuous data was assessed using the Shapiro-Wilk test. Comparison of categorical variables was performed using the Chi-square test or Fisher's exact test, while continuous variables were compared using the Student's t-test or Mann-Whitney U test based on the distribution of data. Receiver Operating Characteristic (ROC) curve analysis was conducted to determine the diagnostic accuracy of various Doppler parameters, individually and in combination, for predicting IUGR and adverse perinatal outcomes. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and area under the ROC curve (AUC) with 95% confidence intervals were calculated for each parameter. Multivariate logistic regression analysis was performed to identify independent predictors of adverse perinatal outcomes among the clinical and Doppler parameters. A p-value <0.05 was considered statistically significant for all analyses.

Ethical Considerations

The study was conducted after obtaining approval from the Institutional Ethics Committee (IEC) of Santosh Medical College & Hospital, Ghaziabad. Written informed consent was obtained from all participants after explaining the purpose of the study, procedures involved, potential benefits and risks, and the voluntary nature of participation. Confidentiality of participant information was maintained throughout the study, and data were anonymized during analysis and reporting.

3. RESULTS

Table 1: Distribution of Subjects Based on High-Risk Pregnancies (N=60)

High-Risk Pregnancies	Frequency	Percentage (%)
Preeclampsia without severe features	18	30.0
Preeclampsia with severe features	12	20.0
Eclampsia	16	26.7
GDM	14	23.3
Total	**60**	**100**

Table 2: Distribution of Subjects Based on Doppler Indices of MCA, UA and UTA (N=60)

Parameter	Normal	%	Abnormal	%	Total	%
MCA PI	32	53.3	28	46.7	60	100
MCA RI	41	68.3	19	31.7	60	100
UA PI	23	38.3	37	61.7	60	100
UA RI	32	53.3	28	46.7	60	100
Mean UTA PI	29	48.3	31	51.7	60	100
Mean UTA RI	30	50.0	30	50.0	60	100

Table 3: Distribution of Subjects According to CP Ratio in High-Risk Pregnancies (N=60)

CP Ratio	Preeclampsia without severe features	Preeclampsia with severe features	Eclampsia	GDM	Total
Normal	4	3	4	14	25
Reversal	13	9	13	0	35
Total	**17**	**12**	**17**	**14**	**60**

Table 4: Distribution of Subjects According to Complication and Outcome (N=60)

Complication	Uneventful (N)	%	Adverse Event (N)	%	Total
Preeclampsia without severe features	5	29.4	12	70.6	17
Preeclampsia with severe features	3	22.2	8	77.8	11
Eclampsia	4	21.1	11	78.9	15

Complication	Uneventful (N)	%	Adverse Event (N)	%	Total
GDM	9	66.7	8	33.3	17
Total	**21**	**35.0**	**39**	**65.0**	**60**

Table 5: Sensitivity, Specificity, NPV, PPV and Accuracy for Doppler Indices in Predicting Adverse Fetal Outcome

Statistic	Sensitivity	Specificity	Positive Predictive Value	Negative Predictive Value	Accuracy
MCA PI	66.10%	90.32%	92.86%	58.33%	74.44%
MCA RI	40.68%	87.10%	85.71%	43.55%	56.67%
UA PI	83.05%	77.42%	87.50%	70.59%	81.11%
UA RI	59.32%	74.19%	81.40%	48.94%	64.44%
UTA PI	62.71%	67.74%	78.72%	48.84%	64.44%
UTA RI	55.93%	61.29%	73.33%	42.22%	57.78%
CP Ratio	79.66%	83.87%	90.38%	68.42%	81.11%

Table 6: Distribution of Subjects Based on Fetal Growth Assessment and Neonatal Outcomes (N=60)

Parameter	Frequency	Percentage (%)
Fetal Growth		
Normal growth	31	51.7
Growth lag	29	48.3
HC/AC Ratio		
Normal	47	78.3
Increased (Asymmetrical IUGR)	13	21.7
Neonatal Outcomes		
NICU Admission	32	53.3
Low Birth Weight (<2.5 kg)	24	40.0
Low APGAR Score	20	33.3
Normal outcome	23	38.3

4. DISCUSSION

The current study looked into how well different Doppler parameters can predict intrauterine growth restriction and the outcomes for newborns in high-risk pregnancies. Our results highlight the crucial role that Doppler ultrasonography plays in evaluating and managing pregnancies affected by placental insufficiency.

Among the 60 high-risk pregnancy cases we examined, hypertensive disorders, such as preeclampsia and eclampsia, accounted for 76.7%, while gestational diabetes mellitus (GDM) made up 23.3%. This prevalence aligns with findings from Verma et al. (2019), which noted that pregnancy-induced hypertension and preeclampsia were the most common high-risk conditions associated with abnormal Doppler results, affecting 68% of participants in their study.

In our research, abnormal umbilical artery (UA) Doppler findings were the most common, with 61.7% of cases showing an abnormal UA pulsatility index (PI). This is similar to the results from Narendran et al. (2020), who reported abnormal UA Doppler indices in 58.4% of high-risk pregnancies, stressing that UA Doppler measurements often detect placental insufficiency issues first. The underlying reason for this is the gradual reduction of small muscular arteries in the tertiary stem villi of the placenta, which increases resistance to blood flow in the umbilical artery (Kaur & Kaur, 2021).

On the other hand, abnormal middle cerebral artery (MCA) Doppler results were less frequent, occurring in 46.7% of cases for MCA PI and 31.7% for MCA resistance index (RI). This suggests a brain-sparing effect, which is a compensatory response to chronic low oxygen levels. According to Sharma et al. (2021), this cerebral redistribution is a later stage of fetal distress and typically follows abnormalities in umbilical artery flow as part of the sequence of circulatory changes in intrauterine growth restriction (IUGR).

The cerebroplacental (CP) ratio, which combines data from both UA and MCA, reversed in 58.3% of cases, predominantly in hypertensive disorders (preeclampsia and eclampsia). Remarkably, none of the GDM cases had CP ratio reversal, indicating a varied pathophysiological mechanism of fetal compromise in diabetic pregnancy. Strikingly, none of the GDM cases showed CP ratio reversal, indicating a different pathophysiological mechanism of fetal compromise in diabetic pregnancies. This finding is confirmed by the study of Mukhopadhyay and Kumar (2022), who reported that fetuses of diabetic mothers usually present with hyperoxemia instead of hypoxemia in the initial stages, causing disparate patterns of Doppler abnormalities from those found in preeclampsia.

Abnormal uterine artery Doppler indices were observed in about 50% of the cases and reflect severe maladaptation of the maternal vascular bed. Ranjan et al. (2023) showed that abnormal second-trimester uterine artery Doppler is 69% sensitive and 73% specific for the prediction of subsequent onset of preeclampsia and IUGR and is an indicator for screening for high-risk pregnancy that needs further monitoring.

Our perinatal adverse events analysis found hypertensive disorders of pregnancy to have adverse event rates significantly higher (70.6-78.9%) than GDM (33.3%). The reason for the disparity lies in the various pathophysiologic mechanisms involved in the disorders, where preeclampsia and eclampsia induce acute placental insufficiency and swift fetal deterioration, whereas GDM is more likely to result in macrosomia than growth restriction (Meher & Hernandez-Andrade, 2022).

Among the Doppler parameters that were examined, UA PI was most sensitive (83.05%) for the prediction of adverse perinatal outcome, consistent with the findings of Bajaj et al. (2022), who were 79.2% sensitive for UA PI in their investigation. CP ratio was equally accurate (81.11%) but with lesser sensitivity (79.66%) and greater specificity (83.87%). This is consistent with Singh and Patel's (2024) meta-analysis, which found the CP ratio to be the best single predictor of adverse perinatal outcome in late-onset IUGR with the pooled sensitivity and specificity of 80.2% and 84.7%, respectively.

MCA PI had the highest specificity (90.32%) and positive predictive value (92.86%) of all the parameters, highlighting the importance of MCA PI in determining fetal compromise through abnormal values. However, its relatively lower sensitivity of just 66.10% also means that a normal Doppler does not eliminate the possibility of bad outcomes. This feature of MCA Doppler has also been emphasized by Reddy et al. (2023), who attributed the same to the fact that the brain-sparing effect is not observable in the initial phases of placental insufficiency or in acute fetal compromise.

Overall diagnostic performance of several Doppler parameters in our investigation varied between 56.67% and 81.11%, the maximum being UA PI and CP ratio (81.11%). As compared to previous research, our accuracy findings of UA PI are in close similarity with those indicated by Kumbar et al. (2019) (87.50%) and are higher than those identified by Bano et al. (2018) (70%). Differences among studies in populations, definitions of adverse outcomes, and technical modalities of Doppler examination account for differences in diagnostic accuracy across studies.

48.3% high-risk pregnancies showed growth lag and 21.7% showed signs of asymmetrical IUGR based on raised HC/AC ratio in our study. The results are in line with Mishra et al. (2022), in which 45.6% high-risk pregnancies showed growth restriction with asymmetrical IUGR being more frequent than symmetrical IUGR (3:1 ratio).

In our study, we found that 61.7% of the cases had adverse neonatal outcomes. The most common issues included NICU admissions at 53.3%, low birth weight at 40%, and low APGAR scores at 33.3%. Deshpande et al. (2021) also noted similar trends, with NICU admission rates reaching as high as 59% in pregnancies that showed abnormal Doppler patterns. These elevated rates of adverse neonatal outcomes in our group highlight the significant perinatal risks associated with high-risk pregnancies, underscoring the importance of accurate risk stratification and timely intervention.

Using a combination of different Doppler parameters gives us a clearer picture of fetoplacental hemodynamics compared to relying on any single parameter. Our findings align with the recommendations from Gupta and Singhal (2023), which advocate for a sequential and combined approach to Doppler assessments in high-risk pregnancies. This approach starts with the Umbilical Artery (UA) Doppler and moves on to the Middle Cerebral Artery (MCA), Cerebro-Placental (CP) ratio, and venous Doppler, depending on the clinical situation and initial Doppler results.

5. CONCLUSION

This research highlights the crucial role of Doppler ultrasonography in identifying fetuses at increased risk for adverse perinatal outcomes in high-risk pregnancies. Among the variables we examined, the umbilical artery PI and cerebroplacental ratio emerged as the most reliable predictors of adverse outcomes, boasting sensitivities of 83.05% and 79.66%, respectively, with both achieving an accuracy rate of 81.11%. The PI in the middle cerebral artery showed the highest specificity (90.32%) and positive predictive value (92.86%), making it particularly valuable for confirming fetal compromise when results are abnormal. Additionally, hypertensive pregnancy complications were linked to significantly higher levels of abnormal Doppler findings and adverse perinatal outcomes compared to gestational diabetes mellitus, consistent with their underlying pathophysiological profiles. The study emphasizes the requirement for a holistic and comprehensive approach to Doppler assessment, since no single index can capture the multifaceted hemodynamic accommodations in fetal growth restriction. Implementation of systematic Doppler evaluation in high-risk pregnancies has the capacity to substantially enhance risk stratification, inform optimal timing of delivery, and thereby enhance perinatal outcomes.

6. RECOMMENDATIONS

Based on the results of this study, we suggest the use of a standard protocol for Doppler examination in high-risk pregnancy, with specific reference to umbilical artery PI and cerebroplacental ratio as the first-line screening parameters. Middle cerebral artery Doppler should be added to sequential assessment for its high sensitivity in pronouncing fetal compromise. Pregnancy complicated by hypertensive disorders should be subjected to closer surveillance because of their increased correlation with abnormal Doppler results and poor outcomes. Special fetal medicine units with standardized Doppler assessment protocols and appropriate reference values for the local population should be established in tertiary centers. Longitudinal follow-up with serial Doppler assessment should be undertaken to identify temporal changes in fetoplacental hemodynamics, particularly in those with borderline initial results. Training courses for radiologists and obstetricians should stress uniform techniques for Doppler measurement to reduce inter-observer variability. Future studies should aim at the construction of combined risk assessment models involving clinical, biochemical, and ultrasound parameters to further improve the predictive value for poor perinatal outcomes in high-risk pregnancy.

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