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A Comparative Analysis Of Placental Vasculature And Placental Volume In Normal And IUGR Pregnancies With The Use Of 3D Power Doppler

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Abstract

Introduction:

Adequate placental vascularization is essential for normal fetal growth, and its impairment leads to placental insufficiency and intrauterine growth restriction (IUGR). This study hypothesized that placental vascular indices and placental volume are significantly reduced in IUGR pregnancies compared to normal pregnancies.

Materials and Methods:

An analytical cross-sectional study was conducted from March 2024 to September 2025 in a Department of Radio-Diagnosis at the teaching hospitals of Bapuji Education Association, JJM Medical college, Davangere including Bapuji hospital, Chigateri hospital, Women & Children Hospital. 60 pregnant women with singleton gestations beyond 22 weeks (30 normal and 30 IUGR) were included after informed consent and ethical approval. Ultrasound evaluation included fetal biometry and Doppler assessment of the umbilical artery, middle cerebral artery, and uterine artery. Pulsatility indices and cerebroplacental ratio (CPR) were calculated. 3D placental volume and vascular indices—vascularization index (VI), flow index (FI), and vascularization flow index (VFI)—were assessed using three-dimensional power Doppler with the VOCAL technique. Statistical analysis was performed, with $p < 0.05$ considered significant.

Results:

IUGR pregnancies demonstrated significantly altered Doppler parameters, including reduced CPR and significant differences in pulsatility indices ($p < 0.05$). Placental vascular indices (VI, FI, VFI) and placental volume were significantly lower in the IUGR group ($p < 0.01$). Higher placental grades were more frequent in IUGR cases. Neonatal outcomes were poorer, with increased incidence of low birth weight (<2500 g), NICU admission, and preterm delivery.

Conclusion:

IUGR is associated with impaired placental vascularity and reduced placental volume. Three-dimensional power Doppler assessment, combined with Doppler parameters, provides a reliable tool for early detection and risk stratification of IUGR.

Keywords: Cerebroplacental ratio(CPR), Doppler ultrasound, Intrauterine Growth Restriction(IUGR), Placental vascular indices, Placental volume, 3D Power Doppler

Introduction

The human placenta functions as the primary interface for nutrient, gas, and waste exchange between mother and fetus. Abnormal feto-maternal circulation can result in increased resistance to blood flow through uterine circulation, causing placental insufficiency and decreased supply of oxygen to fetus. This leads to adverse obstetrical outcome of fetal growth restriction, preterm labor, preeclampsia, fetal hypoxia and death. Intra uterine growth restriction is important complication of pregnancy leading to perinatal mortality and morbidity.[1] Intrauterine growth restriction indicates a first point of stress that leads to negative developmental programming of fetus. This early onset defective programming increases susceptibility to diseases in later life which are triggered by secondary life events in offspring (infection, stress, and malnutrition).[3-6] According to epidemiological definitions, the important measurable feature of IUGR is Estimated fetal body weight (EFBW)/ Abdominal circumference(AC) < 3rd percentile for gestational age (GA) or Estimated fetal body weight (EFBW)/ Abdominal circumference(AC) < 10th percentile for gestational age (GA) with abnormal Doppler indices.[8,9,14] The impact of IUGR is severe that it occurs early during pregnancy.[10,11]

If IUGR is clinically suspected, ultrasonography should be performed to confirm the diagnosis. Accurate determination of the exact gestational age is essential and it is best established in the first trimester by fetus-crown to rump length.[11] Fetal Abdominal Circumference is most specific parameter for detecting IUGR with specificity of 89.8% and negative predictive value of 90.7%.[12-13]

Over the last few decades ultrasonogram and Doppler has provided a major breakthrough in the area of evaluation of fetal growth inside the uterus.

Intra-placental blood flow is assessed by the help of Doppler which forms as an effective tool for diagnosing and managing pregnancies complicated by fetal intrauterine growth restriction. Doppler identifies changes in the maternal uterine arteries and fetal umbilical arteries and which occur due to alterations in the placental vascular architecture.[14]

Two-dimensional (2D) ultrasound is used to measure placental diameter and thickness. But 2D ultrasound does not assess the placental vasculature.[15]

Due to great technological progress over the last few years, the intra placental circulation and placental volume can be evaluated by 3D Power Doppler and VOCAL technique.[14,16,17] The research studies related this topic are limited.

Thus this study was conducted to assess and compare placental vascular indices namely Vascularization Index (VI), Flow Index (FI), Vascularization Flow Index (VFI) and 3D Placental Volume (PV) between Normal and IUGR pregnancies.

Objectives:

To evaluate differences in placental vascular indices like Vascularization Index (VI), Flow Index (FI), Vascularization Flow Index (VFI) and 3D Placental Volume (PV) between Normal and IUGR pregnancies.

Materials And Methods:

2a. Source of data: The main source of data for the study is patients from the teaching hospitals attached to Bapuji Education Association J.J.M. Medical College, Davangere.

2b. Study design: Analytical cross-sectional study.

2c. Study period: 18 months (March 2024 to September 2025).

2d. Study area*:* Department of Radio-Diagnosis, JJM Medical College, Davangere (including Bapuji hospital, Chigateri General hospital, Women & Children Hospital, Davangere)

2e. Sample size: A total of 60 women were included- 30 women with normal pregnancy & 30 with intrauterine growth restriction.

2f. An informed consent in English and patient's native language was taken. Approval from the ethical committee of J.J.M Medical College, Davangere was taken before the commencement of the study.

2g. Inclusion criteria: Singleton pregnancies above 22 weeks of gestation and complete placental visualization. The normal pregnancy group consisted of women without systemic disease, with normal fetal morphology and appropriate fetal growth. The IUGR group included pregnancies with fetal weight or abdominal circumference below the 3rd percentile, or below the 10th percentile associated with abnormal Doppler indices, with postnatal confirmation of IUGR.

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2h. Exclusion criteria: Unwilling participants, multiple pregnancies, inability to visualize the placenta, fetal anomalies, abnormal growth patterns, systemic disease, substance abuse, and unconfirmed IUGR diagnosis after delivery.

Methodology:

Ultrasound was performed using Volusion E6 Expert (General Electric System) with a volumetric probe RAB 4-8D (4-8MHz).

2D ultrasonography was performed according to Hadlock formula to assess fetal biometry and morphology. Parameters including BPD, HC, AC, and FL were measured, and estimated fetal body weight was calculated to confirm fetal growth restriction below the 3rd or 10th percentile. Doppler evaluation of the umbilical artery, middle cerebral artery and uterine arteries was performed using standard ultrasound techniques (Figure-1 A,B,C&D). Pulsatility index (PI) measurements were obtained from adequate flow waveforms, and the cerebroplacental ratio (CPR) was calculated using MCA PI and UA PI values with the help of Barcilona Fetal calculater. Doppler findings were considered abnormal when UA PI was >95th percentile, MCA PI was <5th percentile for gestational age, absent/reversed end-diastolic flow was present in the umbilical artery, or CPR was <1. Amniotic fluid index was assessed.

Placental localization was done. 3D Power Doppler combined with VOCAL technique was used for detailed placental localization and assessment of placental volume (PV) along with placental vascular indices such as Vascularisation Index (VI), Flow Index (FI), and Vascularisation Flow Index (VFI).

After visualization of the placental vascular tree, a 3D static Power Doppler scan with a wide 85° scanning angle was obtained to ensure complete placental data acquisition. VOCAL imaging software with manual tracing and a 30° rotation angle was utilized to calculate placental volume and assess placental vascular indices using three-dimensional Power Doppler data. Additional analysis using 3D Power Doppler Volume Histogram software automatically calculated VI, FI, and VFI values for the entire placental volume(Figure-1E). All ultrasound examinations were performed by a single experienced operator to reduce interobserver variation and maintain uniformity in measurements. To standardize placental vacular evaluation, fixed pre-established Power Doppler settings were used for all patients, including pulse repetition frequency, wall motion filter, image quality, frequency, and smoothing parameters.

Figure 1 : Case Report - High-vascularity 3D Power Doppler histogram in a IUGR pregnancy.

Figure demonstrates multimodal Doppler and three-dimensional placental assessment in a 25-year-old G2P1L1 woman at 27 weeks 2 days gestation. The fetus demonstrated abdominal circumference(AC) and estimated fetal body weight(EFBW) below the 3rd percentile, consistent with Stage 1 FGR, despite preservation of normal fetal and maternal Doppler parameters including umbilical artery, middle cerebral artery, and uterine artery Doppler indices. Image A shows normal umbilical artery Doppler waveform with preserved forward end-diastolic flow, indicating maintained fetoplacental circulation. Image B depicts middle cerebral artery Doppler with normal indices and no evidence of fetal brain-sparing effect. Images C and D represent bilateral uterine artery Doppler studies demonstrating normal flow patterns without significant notching or increased vascular resistance. Image E demonstrates three-dimensional placental volumetry revealing reduced placental volume of 130.17 cm³ with decreased vascular indices (VI: 25.5, FI: 30.8, and VFI: 7.9), suggestive of impaired placental vascularization and placental insufficiency. The pregnancy subsequently resulted in delivery at 37 weeks 2 days with a birth weight of 2200 g, and the neonate required NICU admission for birth asphyxia.

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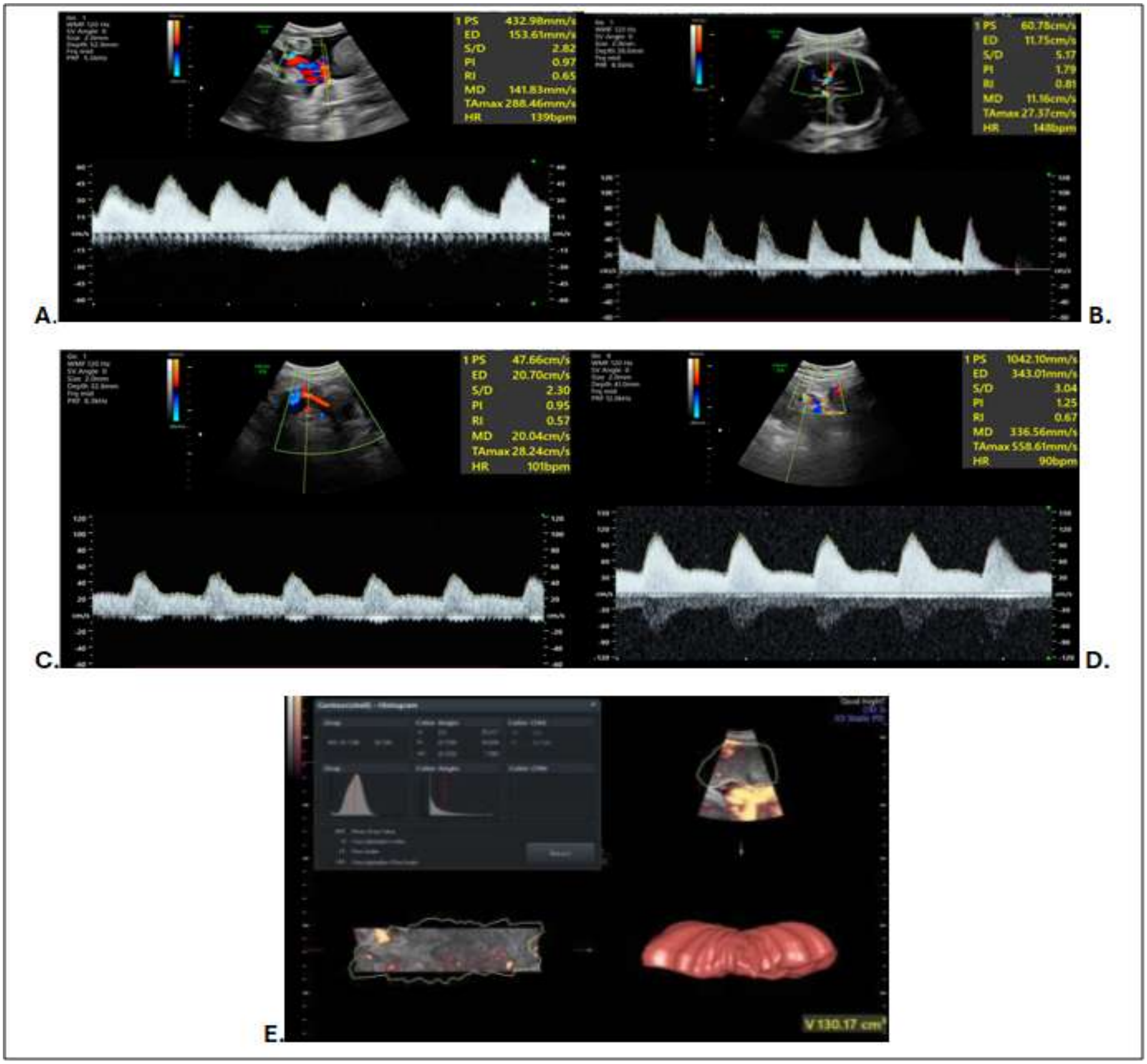

Results:

The study evaluated maternal characteristics, fetal biometry, Doppler indices, placental vascular indices, placental volume, and neonatal outcomes in IUGR and normal pregnancy groups. Most IUGR cases were observed in mothers aged 18–25 years (66.67%), whereas normal pregnancies were more evenly distributed across age groups. The majority of IUGR pregnancies were between 36–38 weeks of gestation (36.67%).

Fetal biometric parameters including BPD, HC, AC, FL, fetal heart rate, and estimated fetal body weight did not show statistically significant differences between the two groups (p>0.05), indicating that routine fetal biometry alone may not reliably differentiate IUGR pregnancies.

Table 1: Comparison of Doppler Indices

Doppler study(PI)	IUGR	Normal pregnancy	P-value
CPR	1.64±0.32	1.87±0.48	0.0330*
Umbilical artery	0.99±0.1	0.93±0.08	0.0267*
MCA	1.46±0.33	1.74±0.38	0.0035*
Mean uterine artery	0.77±0.06	0.73±0.05	0.0397*

*p-value<0.05-statistically significant

Abnormal Doppler indices in the IUGR group indicate increased placental resistance and fetal circulatory redistribution secondary to placental insufficiency.

Significant differences were observed in Doppler parameters(Table-1). The IUGR group showed lower CPR (1.64±0.32 vs 1.87±0.48), lower MCA PI (1.46±0.33 vs 1.74±0.38), and higher umbilical artery PI (0.99±0.10 vs 0.93±0.08) compared to normal pregnancies, all of which were statistically significant ($p<0.05$). These findings indicate altered fetoplacental circulation and placental insufficiency in IUGR pregnancies.

Placental assessment using 3D Power Doppler demonstrated markedly reduced placental vascularity in the IUGR group(Table-2). Vascularisation Index (VI) was significantly lower in IUGR pregnancies (8.46±1.69) compared to normal pregnancies (23.45±3.90).

Table 2: Placental Vascular Indices and Placental Volume

Parameters	IUGR	Normal pregnancy	p-value
VI	8.46±1.69	23.45±3.9	<0.01**
FI	41.45±1.72	44.31±2.96	<0.01**
VFI	4.57±1.47	9.26±1.89	<0.01**
3D Placental volume	347.67±34.84	603.2±107.06	<0.01**

**p-value<0.01-highly statistically significant

Marked reduction in placental vascular indices and placental volume suggests decreased placental vascularity and impaired perfusion in IUGR pregnancies.

Similarly, Flow Index (FI), Vascularisation Flow Index (VFI), and placental volume were significantly reduced in IUGR cases ($p<0.01$). Mean placental volume in IUGR pregnancies was 347.67±34.84 cm^3 compared to 603.2±107.06 cm^3 in normal pregnancies(Figure-2). These findings suggest impaired placental perfusion and reduced placental vascular development in IUGR.

Neonatal outcomes were significantly poorer in the IUGR group. Low birth weight (<2500 g) was observed in 76.67% of IUGR babies compared to only 6.67% in normal pregnancies. Mean birth weight was significantly lower in the IUGR group (2363.33±272.26 g) than in normal pregnancies (3010±223.4 g). NICU admissions were also markedly higher in IUGR pregnancies (60%), along with increased rates of preterm delivery and poor neonatal prognosis.

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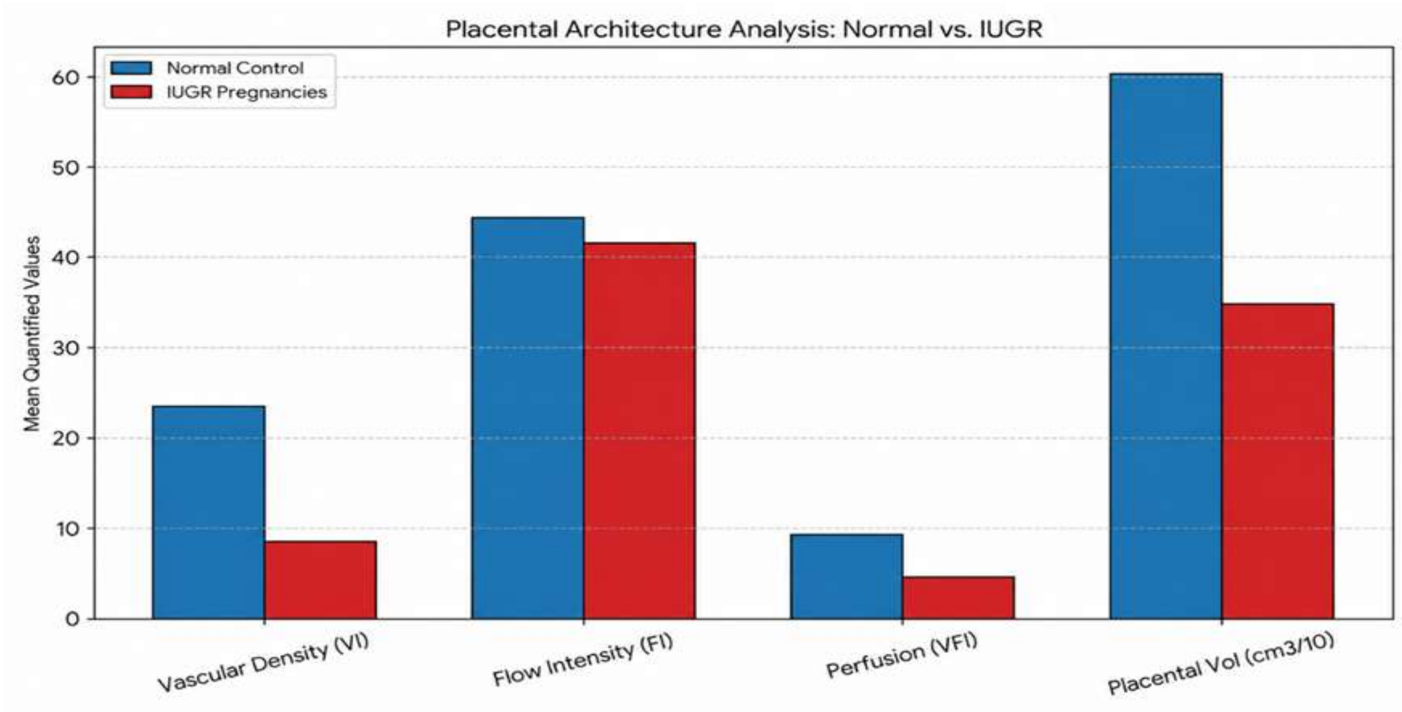
Figure 2 : Bar chart showing the profound depletion of placental indices in the IUGR cohort



Discussion:

The present study compared placental vascularity and placental volume between normal pregnancies and pregnancies complicated by intrauterine growth restriction (IUGR) using 3D Power Doppler. The study demonstrated significant reductions in placental vascular indices and placental volume in IUGR pregnancies, highlighting the important role of placental insufficiency in fetal growth restriction.

Most IUGR cases were observed in younger mothers aged 18–25 years, although maternal age and gestational age were overall comparable between groups. Multigravida women were slightly more common in the IUGR group. Higher placental grades (Grade II and III) and oligohydramnios were more frequently associated with IUGR, suggesting accelerated placental maturation and chronic uteroplacental insufficiency.

Routine fetal biometric parameters such as BPD, HC, AC, FL, FHR, and estimated fetal body weight did not show significant differences between groups, indicating that fetal biometry alone may not reliably detect early or compensated IUGR.

Doppler evaluation showed lower cerebroplacental ratio (CPR) and middle cerebral artery (MCA) pulsatility index in IUGR pregnancies, reflecting the fetal “brain-sparing effect” due to redistribution of blood flow to vital organs. The most significant finding of the study was the marked reduction in placental vascular indices including vascularization index (VI), flow index (FI), vascularization flow index (VFI), and 3D placental volume in the IUGR group ($p<0.01$). These findings suggest reduced placental vascularity and impaired placental perfusion, emphasizing the value of 3D Power Doppler in the assessment and early detection of placental insufficiency and fetal growth restriction.

5a. Overview of IUGR and Placental Pathophysiology: Intra-Uterine Growth restriction (IUGR) is defined as inability of fetus to achieve its genetic growth potential due to an adverse intrauterine environment, often resulting from placental insufficiency and impaired nutrient supply or oxygen supply. According to Armengaud et al., IUGR affects nearly 10–15% of pregnancies worldwide and may originate from maternal, placental, or fetal causes, with inadequate fetal nutrition being a major contributor.[2]

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5b. Maternal and Obstetric Characteristics: The index study demonstrated that majority of IUGR cases occurred in younger mothers aged 18–25 years, although the mean of maternal age was comparable between the two groups. While maternal demographic factors may influence pregnancy outcomes, Armengaud et al. emphasize that environmental conditions and placental factors play a more predominant role in determining fetal growth than maternal age alone.[2]

In the current study, majority of IUGR cases were in mothers aged 18–25 years, with comparable mean maternal age between IUGR and normal pregnancy groups. Similarly, Marhatta et al. reported that most patients belong to 19–25 years, with mean age of 25.7±3.46 years in the IUGR group and 26.34±4.26 years in the normal group, and found no association between maternal age and IUGR which was statistically significant.[18]

5c. Placental Characteristics and Amniotic Fluid: A higher proportion of advanced placental grades (Grade II and III) were noted in the IUGR group, indicating possible premature placental maturation. This observation is consistent with the pathophysiological explanation provided by Armengaud et al., who identify uteroplacental vascular abnormalities and metabolic alterations as key mechanisms leading to impaired fetal growth.[2] Oligohydramnios was present exclusively in IUGR pregnancies, further supporting the association between reduced placental function and chronic fetal compromise.

5d. Fetal Biometry versus Functional Assessment: No significant differences were found in fetal biometric parameters such as biparietal diameter, head circumference, abdominal circumference, femur length, and estimated fetal weight which were statistically significant. This suggests that structural measurements alone cannot be sufficient to differentiate growth-restricted fetuses from normal ones. IUGR represents an abnormal adaptive fetal response to a deleterious prenatal environment rather than merely reduced size. Therefore, functional assessment of placental circulation becomes essential for early identification.

5e. Doppler Findings and Fetal Adaptation: Significant difference in Cerebro-Placental Ratio (CPR) and middle cerebral artery pulsatility index indicate compensatory mechanism of fetal hemodynamic adaptation. Such redistribution of blood flow reflects the fetus's attempt to preserve oxygen delivery to vital organs under conditions of limited supply. Placental vascular impairment is widely recognized as a major contributor to these adaptive responses.

The current study showed difference in cerebroplacental ratio (CPR) and middle cerebral artery pulsatility index, indicating fetal hemodynamic adaptation to placenta insufficiency. Abulé et al. reported an inverse correlation between placental volume and uterine artery resistance, demonstrating that smaller placenta are associated with reduced blood flow.[23]

Choudhary et al. concluded that placental vascular indices remain relatively constant during pregnancy but show negative correlation with pulsatility and resistive indices, indicating that high vascular resistance was associated with reduced placental perfusion.[20] It aligns with the findings in the present study, highlighting placental insufficiency as a key factor in IUGR.

5f. Placental Vascular Indices and Volume: The most notable finding of current study was the markedly reduced vascularization index (VI), flow index (FI), vascularization flow index (VFI), and placental volume in IUGR pregnancies. These results strongly support the concept of placental insufficiency as a central mechanism in growth restriction.

A major finding of the current study was significantly reduced vascularization index, flow index, vascularization-flow index, and placental volume in IUGR pregnancies. Mercé et al. emphasized that three-dimensional power Doppler enables quantification of blood vessels through the vascularization index and assessment of blood flow using flow and vascularization-flow indices, allowing a more comprehensive evaluation of placental vascular tree.[23]

Placental volume was low in the IUGR group in index study. Pomorski et al. similarly found that placental volume in normal pregnancy was on average 92.42 cm^3 larger than in IUGR pregnancies, emphasizing role of impaired placental development in fetal growth restriction.[19]

5g. Birth Outcomes and Neonatal Prognosis: The current study found low birth weight among IUGR neonates, along with higher rates of NICU admission,

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poor prognosis and preterm delivery. These findings were supported by Armengaud et al., that impaired fetal growth was associated with both short- and long-term adverse health outcomes. IUGR new borns are more susceptible to cardiovascular, metabolic, and renal diseases later in life, underscoring the importance of timely diagnosis and intervention.[2]

The current study showed significantly low birth weights and higher NICU admissions among IUGR neonates. Abulé et al. also highlighted that fetal growth restriction was associated with high rate of perinatal morbidity and mortality, particularly in severe cases. This similarity underscores the clinical importance of early diagnosis and close monitoring to improve neonatal outcomes.[23]

Mahalinga G et al. reported that decreased placental vascular indices was directly associated with lower neonatal birth weight, establishing a clear relationship between placental perfusion and fetal growth outcomes. [21]

5g. Clinical Implications: The consistency between the present findings and those described by Armengaud et al. highlights importance of evaluating placental vasculature rather than relying solely on fetal size measurements alone.[2] Advanced imaging modalities 3D power Doppler provide quantitative insight into placental perfusion and may enhance early detection of compromised pregnancies. Improved screening could facilitate closer surveillance, optimize delivery timing, and ultimately reduce neonatal morbidity.

Abulé et al. concluded that pregnancy complicated by severe fetal growth restriction were characterized by reduced placental volume and vascularization, and that combining 3D placental assessment with Doppler studies can help in clinical decision-making.[23] The current study justifies these findings, suggesting that quantitative placental evaluation can serve as important tool for early detection and risk stratification of Intra uterine growth restriction.

Conclusion:

The current study highlights that intrauterine growth restriction was primarily associated with placental dysfunction rather than maternal demographic factors. Maternal age, gestational age and parity showed no significant differences between IUGR and normal pregnancy groups. Conventional fetal biometric parameters alone were insufficient to differentiate IUGR from normal pregnancies. In contrast, Doppler indices, particularly cerebroplacental ratio and middle cerebral, umbilical and uterine artery pulsatility index, demonstrated significant alterations in IUGR cases, reflecting fetal adaptive mechanisms to compromised placental perfusion.

Placental vascular indices and three-dimensional placental volume were markedly reduced in IUGR pregnancies, confirming impaired placental vascularity as a predominant underlying pathology. These findings were supported by higher placental grades and presence of oligohydramnios in IUGR cases.

Neonatal outcomes were significantly affected in the IUGR group, with increased incidence of low birth weight, NICU admission and adverse perinatal outcomes in the IUGR fetuses. Assessment of placental vascularity and Doppler parameters provided a reliable method for early identification and risk stratification of IUGR than routine fetal biometry alone. Incorporation of these modalities into routine antenatal evaluation may improve timely intervention and perinatal outcome in these cases

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