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Aortic Isthmus Doppler Flow Analysis In Fetal Growth Restriction: Imaging Biomarker For Hemodynalic Compromise And Outcomes

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Abstract

Background: Fetal growth restriction (FGR) is associated with altered fetal hemodynamics secondary to placental insufficiency and carries significant perinatal morbidity and mortality. The aortic isthmus, located between the cerebral and systemic circulations, reflects the balance between cardiac output and placental resistance. This study aimed to evaluate aortic isthmus Doppler flow velocity patterns in FGR fetuses and determine their association with disease severity and adverse perinatal outcomes.

Results: Most FGR pregnancies occurred in women aged 25–30 years, with a significantly higher mean maternal age compared to normal pregnancies. Preeclampsia/pregnancy-induced hypertension and reduced amniotic fluid index were more frequent in the FGR group. Fetal biometric parameters, including abdominal circumference and estimated fetal body weight, were significantly lower in FGR cases ($p<0.01$). Marked Doppler abnormalities were observed in FGR fetuses, including abnormal umbilical artery pulsatility index, middle cerebral artery Doppler, cerebroplacental ratio, and uterine artery Doppler findings. Aortic isthmus Doppler demonstrated increased peak systolic velocity, resistance index, pulsatility index, and abnormal end-diastolic velocity in 70% of FGR cases, whereas all normal pregnancies showed normal flow patterns ($p<0.01$). Abnormal ductus venosus flow was also significantly associated with FGR. Neonatal complications, including respiratory distress syndrome, sepsis, and mortality, occurred exclusively in the FGR group and correlated strongly with abnormal Doppler findings.

Conclusion: Aortic isthmus Doppler is a valuable adjunct in the evaluation of fetal growth restriction and demonstrates significant correlation with fetal compromise and adverse perinatal outcomes. Combined with conventional fetal Doppler indices, it may improve early detection, monitoring, prognostication, and timely intervention in high-risk pregnancies.

Keywords: Fetal Growth Restriction (FGR); Aortic Isthmus Doppler; Doppler Imaging; Pulsatility Index (PI); Cerebroplacental Ratio (CPR); Ductus Venosus; Placental Insufficiency; Fetal Hemodynamics

Introduction

Fetal growth restriction (FGR) is characterized by a fetal growth rate that is subnormal relative to the development potential of an individual newborn, taking into account the fetus's race and gender. It is characterized as a divergence from or a diminution of an anticipated prenatal development trajectory, often resulting from inherent diminished growth capacity or several detrimental influences on the baby. [1]

The prevalence of FGR varies among nations, demographics, and ethnicities, and escalates with diminishing gestational age. A significant proportion of FGR newborns are seen throughout Asia, including almost 75% of all afflicted infants. In Asian nations, the largest occurrences of low birth weight (LBW) and fetal growth restriction-related low birth weight (FGR-LBW) is seen in Bangladesh followed by India.[2,3]

Growth restriction in fetus often results from maternal, placental, fetal, or genetic causes.[4] Multiple indicators, inter-pregnancy interval, health status, behavioural habits, and infections, influence fetal development and contribute to the occurrence of growth restriction. A discrepancy between the nutritional supply from the placenta and the fetal demand results in intrauterine growth restriction. Fetal deformities, metabolic disorders, and genetic anomalies account as cause of FGR in some instances.[5,6]

Given the absence of a definite treatment for FGR, precise clinical monitoring and care are crucial for establishing the optimal delivery timing and mitigating fetal complications, including newborn mortality and perinatal morbidity. Various ways exist for accurately monitoring the current circumstances. Given that abnormal velocity in umbilical artery blood flow is significantly correlated with fetal growth restriction, employing Doppler measurement of umbilical artery blood flow and assessing the pulsatility index are effective methods for monitoring growth restriction. [7,8,9]

Among the several prognostic instruments identified for FGR evaluation, the Doppler examination of the MCA and the aortic isthmus (AoI) have shown superior efficacy in illustrating fetal adaptation to hypoxemia.[10]

The aortic isthmus (AoI) is a distinct fetal watershed characterized by a waveform that represents its intricate hemodynamic physiology. The systolic component signifies left and right ventricular ejection, whereas the diastolic component indicates the relative downstream vascular resistance between the brachiocephalic and subdiaphragmatic fetal circulations.[11]

Research to measure various aspects of the waveform, including the pulsatility index, resistance index, isthmic flow index, and the newly introduced isthmic systolic index. Research show promise in applying these indicators to both cardiac (congenital) and extracardiac disorders, such as intrauterine growth restriction and twin-twin transfusion syndrome. The multifaceted origin of the waveform has presented challenges, and the difficulties in isolating its many components may account for the lack of evident clinical relevance in AoI examination.[12,13]

The greater the impairment of the AoI flow, the higher the likelihood of compromised Doppler velocimetry in other arteries; variations in AoI Doppler seem to precede other signs of severe hypoxemia.[14] While a connection seems to exist between retrograde flow in the AoI and the probability of long-term neurologic impairment, its predictive value regarding prenatal morbidity-mortality remains ambiguous. The AoI Doppler seems to be a promising instrument for managing fetuses with growth restrictions, further research is required to explore its use in clinical practice.[15,16]

Alterations in the characteristics of AoI blood flow leads to hemodynamic disturbances throughout the cardiac system. Consequently, it is probable that the AoI Doppler indices correlate with fetal growth restrictions.[14]

A study done to ascertain the significance of longitudinal assessments of AoI via Doppler ultrasonography in forecasting perinatal morbidity and mortality, indicating that aortic isthmus Doppler measurements are effective in detecting fetal growth restriction prior to the decline in ductus venosus blood flow and the onset of fetal acidosis.[17] This study is aimed to address the paucity of research on this issue, particularly in the specified study region.

Objectives:

1. To assess the flow velocity pattern of Aortic isthmus by Doppler imaging in fetuses with fetal growth restriction.
2. To evaluate the association of Aortic isthmus Doppler parameters with fetal growth restriction.

Materials And Methods:

1. **Study design:** Analytical cross-sectional Study
2. **Study period:** 18 months (March 2024 to September 2025)
3. **Study area:** Department of Radiodiagnosis, JJM Medical College Davangere (Bapuji Hospital), Chigateri District Hospital Davangere and Women and Children Hospital Davangere.

4. **Sample source:** 40 Pregnant females of 19-40 weeks gestation who present to OPD of J.J.M. Medical College (Bapuji Hospital), Chigateri District Hospital and WCH in Davangere with clinical signs of FGR and referred to the Department of Radiodiagnosis for Ultrasound and Doppler study. The study also includes 40 healthy controls which are selected randomly.
5. **Sample size: 80** (Normal Pregnancy: 40; FGR Pregnancy group: 40)

Inclusion Criteria*:* Selection of 40 cases based on combination of clinical and sonographic parameters i.e., h/o pre-eclampsia/previous FGR, oligohydramnios, fetal weight <10th percentile for gestational age and doppler & biometry values, willingness to participate in the study and pregnant females of 19 weeks to term.

For early onset FGR (less than or equal to 32 weeks of gestational age): (as per Barcelona criteria)

1) AC or EFW < 3rd percentile or Absent End Diastolic Flow in Umbilical Artery **or**
2) AC or EFW < 10th percentile **with**
    i) Uterine Artery PI > 95th percentile **and/or**
    ii) Umbilical Artery PI > 95th percentile

For late onset FGR (more than 32 weeks of gestational age): (as per Barcelona criteria):

a) AC or EFW < 3rd percentile **or**
b) At least two of the following:
    i) AC or EFW < 10th percentile
    ii) AC or EFW crossing centiles > 2 quartiles
    iii) Cerebroplacental ratio < 5th percentile or Umbilical Artery PI > 95th percentile

In addition, 40 healthy subjects with no h/o pre-eclampsia/FGR & normal fetal biometry are examined as control group.

Exclusion Criteria*:* Not willing to participate, Twin/multiple gestations**,** Chromosomal abnormalities**,** Intra Uterine Fetal Demise (IUFD)

Methodology:

All examinations are performed in the ultrasound machines available in the department-Volusion E8 Expert (General Electric System) / GE Healthcare LOGIQ P9 / GE Healthcare LOGIQ P10 / Mindray DC-40 Crystal, using convex 3-5 MHz array transducer. Ultrasound examination including fetal biometry and Doppler study is done on fetuses with FGR who met the inclusion criteria.

Doppler Study*:* Image directed colour and pulsed Doppler study of Umbilical artery, Uterine artery and Aortic Isthmus is performed using transabdominal transducer. The scanning plane is adjusted and the angle between the ultrasound beam and direction of flow is kept as close to zero degree as possible. The sample volume is adjusted to include as much as the lumen as possible without including vessel wall. All the measurements are taken in the absence of fetal movements.

Assessment of Umbilical Artery Doppler waveform is performed by focusing a free-floating segment of umbilical cord and placing the Doppler ultrasound gate in the segment, keeping insonation angle close to zero degree.

Assessment of Uterine Artery Doppler waveform is performed by focusing near the cross-over of uterine artery and internal iliac artery and placing the Doppler ultrasound gate in the segment, keeping insonation angle close to zero degree.

Fetal Aortic isthmus is assessed in longitudinal aortic arch view and the ultrasound gate is placed just beyond origin of left subclavian artery.

The following parameters are assessed: PSV, EDV, S/D, RI, PI, Isthmic flow index (IFI = {PSV+EDV}/PSV)

The IFI for aortic isthmus blood flow can be divided in five different types as follows:

Type I: IFI > 1, when the flow is antegrade throughout the cardiac cycle;

Type II: IFI = 1, when diastolic flow is absent;

Type III: IFI = 0–1, when the diastolic flow is reversed but the net flow is still antegrade;

Type IV: IFI = 0, when the antegrade and retrograde flows are equal; and Type V: IFI < 0, when the net flow is retrograde.

Results

The analysis showed that most FGR cases were in the 25–30 years group (55%) with a higher mean age

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(35.2±2.48) compared to normal pregnancies (24.15±2.72), where 52.5% were 18–25 years. Primigravida constituted 50% in FGR and 42.5% in normal pregnancies. Majority of cases were between 32–36 weeks (FGR 60%, normal 30%; mean 31.18±3.08 vs 29.98±6.42). NT ≥1 mm was seen in 70% of FGR and 67.5% of normal cases. Preeclampsia/PIH was present in 20% of FGR and 0% in normal pregnancies. Inadequate AFI was higher in FGR (55% vs 35%). Fetal parameters such as AC (20.69±1.98 vs 25.26±5.34) and EFBW (1086.54±342.9 vs 1915±840.1) were significantly lower ($p<0.01$). Doppler abnormalities were marked in FGR with 85% abnormal umbilical artery PI, 100% abnormal MCA, CPR, and uterine artery PI ($p<0.01$). Aortic isthmus Doppler showed increased PSV, RI, PI and abnormal EDV in 70% of FGR, while 100% of normal cases were normal ($p<0.01$). Abnormal ductus venosus flow was seen in 70% of FGR vs 0% in normal pregnancies. Postnatal complications like RDS (70%), sepsis (55%), and death (15%) occurred only in FGR cases ($p<0.01$), indicating a strong association between abnormal Doppler findings and adverse outcomes.

In normal pregnancies, the mean values of Doppler parameters (PSV, EDV, RI, and PI) across different gestational age groups from 19 to 40 weeks. The results indicate a gradual increase in PSV and PI values with increase in gestational age. In contrast, RI and EDV shows a decreasing trend with increase in gestational age.

Discussion:

In this study, All FGR pregnancies demonstrated pathological Doppler indices in umbilical artery, MCA, CPR, and uterine artery, whereas normal pregnancies predominantly showed normal Doppler values. These differences were highly statistically significant ($p<0.01$). Doppler abnormalities were strongly associated with FGR. Further, A significant proportion of FGR pregnancies showed abnormal PSV, EDV, RI, PI, and IFI values, while all normal pregnancies had normal parameters. These differences were highly statistically significant.

In a comparative study conducted by Verma VK et al., 66% of instances, the aortic isthmus PI value exceeded the 95th percentile. 14% of patients had retrograde AoI flow, but the umbilical artery Doppler indices remained within normal limits, indicating a correlation between reversed diastolic flow via the aortic isthmus and intrauterine growth limitation. This indicates that Doppler indices of the AoI may identify hemodynamic alterations in intrauterine growth restriction before the decline of umbilical artery Doppler waveforms.[18] This determined the potential use of AoI Doppler imaging in the early diagnosis of fetal growth restriction.

Abdelsalam HA et al. conducted a study to evaluate the role of aortic isthmus Doppler assessment in improving the detection of fetal growth restriction. It demonstrated that Doppler measurements of the AoI are a valuable tool for identifying fetuses affected by FGR.[19]

In this study, Aortic isthmus Doppler abnormalities were mostly associated with FGR. Abnormal ductus venosus flow was observed in 70% of FGR pregnancies. All normal pregnancies showed normal ductus venosus flow. This difference was highly statistically significant. Postnatal complications such as respiratory distress syndrome, sepsis, and neonatal death were observed exclusively in the FGR group. All neonates in the normal pregnancy group had no complications, which was highly statistically significant.

A similar study conducted by Cruz-Martínez et al. reported that a subset of small-for-gestational-age (SGA) fetuses exhibited aortic isthmus Doppler abnormalities, which were associated with poorer fetal prognosis. It shows AoI impairment may help identify fetuses at increased risk of adverse outcomes, possibly related to late-onset intrauterine growth restriction.[7]

Fardiazar Z et al., findings stated that no difference among IUGR and control groups for the color Doppler indicators of the aortic isthmus. No difference was seen between the IUGR and control groups for the comparison of color Doppler indicators of the aortic isthmus with normal and abnormal umbilical artery Doppler results. Thus, indicated that the color Doppler sonography of AoI did not exhibit significant differences between IUGR fetuses and healthy counterparts.[20] Another similar study by Kennelly MM et al., which compared 72 appropriate-for-gestational-age, 48 SGA, and 10 IUGR fetuses, found no significant differences in aortic isthmus pulsatility index among the three groups.[21]

The controversy about the value of the aortic isthmus index may be attributed to the isthmus being the

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narrowest segment of the aortic arch, its relatively short length, and the presence of adjacent tiny arteries, which hampers the acquisition of high-quality Doppler data. The technological challenges explain why the qualitative technique, which involves just detecting antegrade or reversed flow, is the predominant way used in clinical practice, despite the fact that these challenges may be significantly mitigated by the utilization of high-quality equipment operated by skilled professionals, as shown in our work. Consequently, to achieve a more objective assessment of the flow, quantitative approaches (PI, systolic volume) and semi-qualitative isthmic flow index have been proposed; nonetheless, a consensus remains elusive.[12,13]

Findings from this and other studies suggest that Doppler imaging can help guide the timing of delivery and management of fetal growth restriction. Based on the available evidence, assessment of aortic isthmus Doppler waveforms may be an important part of evaluating fetuses with IUGR.[21] However, before aortic isthmus Doppler indices are routinely used in clinical practice to guide decisions and prevent preterm birth, more prospective studies are needed to confirm their relationship with perinatal outcomes.

Table 1: Doppler Study (PI)

Doppler study (PI)	FGR pregnancy	Normal pregnancy	P-value
Umbilical artery PI			
• Normal	6(15)	40(100)	<0.01**
• Pathological	34(85)	0(0)	
MCA PI			
• Normal	0(0)	40(100)	<0.01**
• Pathological	40(100)	0(0)	
CPR PI			
• Normal	0(0)	40(100)	<0.01**
• Pathological	40(100)	0(0)	
Mean uterine artery PI			
• Normal	0(0)	33(82.5)	<0.01**
• Pathological	40(100)	7(17.5)	

Table 2: Aortic Isthmus Doppler Parameters

Aortic isthmus Doppler parameters	FGR pregnancy	Normal pregnancy	P-value
PSV			
• Normal	12(30)	40(100)	<0.01**
• Increased	28(70)	0(0)	
EDV			
• Normal	12(30)	40(100)	<0.01**
	18(45)	0(0)	

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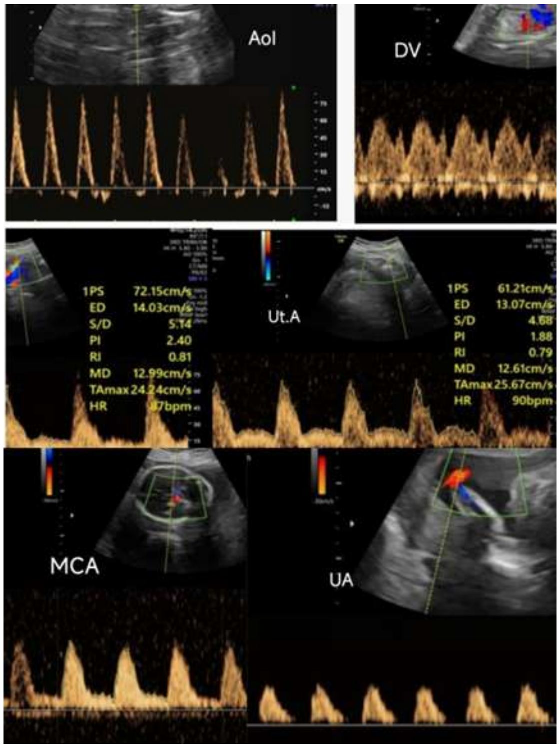
• Abnormal • Absent	10(25)	0(0)	
RI • Normal • Increased	12(30) 28(70)	40(100) 0(0)	<0.01**
PI • Normal • Increased	12(30) 28(70)	40(100) 0(0)	<0.01**
IFI • <1 • >1	12(30) 28(70)	0(0) 40(100)	<0.01**

Table 3: Postnatal Complications

Postnatal complications	FGR pregnancy	Normal pregnancy	p-value
NIL	12(30)	40(100)	<0.01**
RDS	28(70)	0(0)	<0.01**
Sepsis	22(55)	0(0)	<0.01**
Death	6(15)	0(0)	<0.01**

FIGURE 1:



(23 years pt) G2P1L1 (previous LSCS) came for growth scan. LMP: 29/08/2024 LMP-EDD: 05/06/2025 – 27wks 2 days. Dating Scan (done at 9 weeks) EDD: 04/06/2025 – 27wks 3days. GA assigned as per LMP – 27 weeks 2 days (on 08/03/2025) with EDD: 05/06/2025. Anomaly scan – BP 140/90 mm Hg. BP – 170/110 mm Hg on the day of USG examination.

NT SCAN: Mean uterine artery PI □2.08 (93rd percentile) □higher limits of normal range. No aneuploidy markers noted. ANOMALY SCAN: Mean uterine artery PI □1.63 (99th percentile) □Pathological □Screen Positive for pre-eclampsia.

Current scan at 27 weeks 2 days POG shows AC& EFBW<3RD percentile. MCA PI – 25th percentile, Umbilical artery – Absent end diastolic flow, Mean uterine artery PI - > 99th percentile (pathological), Aortic isthmus – Reversal of end diastolic flow, Ductus Venosus – Normal waveforms, no reversal of “a” waves.

Diagnosis: Early onset FGR – Stage II (Severe placental insufficiency)

(Suggested biweekly / 3 days follow up for doppler evaluation)

Follow up: 3 days follow up till 28 weeks. Daily monitoring from 28 weeks till 29 weeks due to reversal of end diastolic flow in umbilical artery. DV reversal of flow at 29 weeks 3 days. S/L/EPT/NVD/6:30 pm on next day ELBW (760 grams)/RDS. Weak cry at birth / reduced activity / reduced tone. Positive pressure ventilation with surfactant therapy for 10 days. NICU admission till 34 weeks of gestational age. Discharged to mother side.

Conclusion:

In this study, All FGR pregnancies demonstrated pathological Doppler indices in umbilical artery, MCA, CPR, and uterine artery, whereas normal pregnancies predominantly showed normal Doppler values. These differences were highly statistically significant ($p<0.01$). Doppler abnormalities were strongly associated with FGR. Further, A significant proportion of FGR pregnancies showed abnormal PSV, EDV, RI, PI, and IFI values, while all normal pregnancies had normal parameters. These differences were highly statistically significant.

This research emphasizes the clinical significance of Doppler evaluation of the aortic isthmus in pregnancies affected by fetal growth restriction. Changes in flow velocity patterns and Doppler indices of the aortic isthmus were correlated with FGR,

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indicating the hemodynamic adaptations resulting from placental insufficiency. These data show the use of AoI Doppler as a significant complement in assessing fetuses with suspected growth limitation, possibly facilitating the identification of those at elevated risk for severe perinatal outcomes.

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