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Association of Ductus Venosus and Aortic Isthmus Doppler in 22-32 Weeks in Early Fetal Growth Restriction: A Prospective Observational Study

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Abstract

Introduction: Early-onset fetal growth restriction (FGR) is associated with significant perinatal morbidity and mortality [1,2]. Advanced Doppler parameters such as ductus venosus (DV) and aortic isthmus (AoI) Doppler may provide important insight into fetal cardiovascular adaptation and impending compromise [3,4].

Objective: To evaluate the association between ductus venosus and aortic isthmus Doppler parameters in fetuses with early-onset fetal growth restriction during the late second trimester and to analyze the pattern of Doppler changes in fetal circulation.

Materials and Methods: A prospective observational study was conducted on 56 singleton pregnancies diagnosed with early-onset fetal growth restriction between 22 and 32 weeks of gestation. Comprehensive Doppler assessment including umbilical artery (UA), middle cerebral artery (MCA), aortic isthmus (AoI), and ductus venosus (DV) Doppler was performed using high-resolution ultrasound systems.

Results: A statistically significant positive correlation was observed between AoI PI and DV PI ($r = 0.602$, $p < 0.001$). AoI PI also demonstrated positive correlation with UA PI and negative correlation with MCA PI. DV PI showed strong negative correlation with MCA PI.

Conclusion: Aortic isthmus Doppler abnormalities demonstrate significant association with ductus venosus hemodynamic changes in early-onset fetal growth restriction. Combined assessment of AoI and DV Doppler provides a comprehensive evaluation of fetal circulatory adaptation and may help identify fetuses at risk of progressive compromise.

Keywords: Fetal Growth Restriction, Ductus Venosus, Aortic Isthmus, Doppler Ultrasound, Placental Insufficiency, Fetal Hemodynamics.

Introduction

Fetal growth restriction (FGR) is a pathological condition in which the fetus fails to achieve its genetically predetermined growth potential due to placental insufficiency and chronic intrauterine hypoxia [1,2]. Early-onset FGR diagnosed before 32 weeks of gestation is associated with significantly increased perinatal morbidity, neurodevelopmental impairment, and perinatal mortality [2,3].

Doppler ultrasound has emerged as an indispensable non-invasive modality for fetal surveillance and assessment of placental circulation3. Umbilical artery Doppler reflects placental resistance, while middle cerebral artery Doppler evaluates fetal redistribution and the brain-sparing effect[4]. However, arterial Doppler indices alone may not accurately identify the transition from fetal compensation to cardiovascular decompensation [5].

The ductus venosus is a specialized venous shunt that reflects myocardial compliance and central venous pressure [6]. Increased ductus venosus pulsatility index and absent or reversed A-wave patterns are considered indicators of advanced fetal compromise and acidemia [6,7]. The aortic isthmus represents the hemodynamic junction between cerebral and placental circulations[8]. Alterations in AoI Doppler may occur during intermediate stages of redistribution before venous compromise develops [8,9]. Simultaneous assessment of DV and AoI Doppler may therefore provide a more comprehensive understanding of fetal hemodynamic progression in early-onset FGR [5,8].

The present study was undertaken to evaluate the association between ductus venosus and aortic isthmus Doppler findings in fetuses diagnosed with early-onset fetal growth restriction during the late second trimester.

Materials and Methods

This prospective observational study was conducted in the Department of Radiodiagnosis in collaboration with the Department of Obstetrics and Gynaecology, GSVM Medical College, Kanpur, over a period of 18 months from July 2024 to December 2025.

A total of 56 singleton pregnancies diagnosed with early-onset fetal growth restriction between 22 and 32 weeks of gestation were included. Fetuses with structural anomalies, multiple gestation, chronic maternal hypertension, autoimmune disorders, chronic kidney disease, and pre-existing diabetes mellitus were excluded.

Detailed obstetric ultrasonography and Doppler examination were performed using Samsung RS80A and GE Versana Balance ultrasound systems. Fetal biometric parameters including biparietal diameter, head circumference, abdominal circumference, and femur length were recorded.

Comprehensive Doppler evaluation included the umbilical artery, middle cerebral artery, ductus venosus, and aortic isthmus. DV pulsatility index and A-wave pattern were recorded. AoI pulsatility index and direction of blood flow were also evaluated [6,8].

Statistical analysis was performed using SPSS version 26. Continuous variables were expressed as mean ± standard deviation. Pearson correlation analysis was used to evaluate relationships among Doppler indices. A p-value <0.05 was considered statistically significant.



Figure 1: USG scan shows Aortic isthmus Doppler

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Figure 2: USG scan shows Ductus Venosus Doppler



Figure 3: USG scan shows MCA Doppler



Figure 4: USG scan shows Umbilical artery Doppler

Results and Discussion

A total of 56 singleton pregnancies diagnosed with early-onset fetal growth restriction between 22 and 32 weeks of gestation were prospectively evaluated. All cases underwent detailed Doppler evaluation including assessment of the umbilical artery (UA), middle cerebral artery (MCA), aortic isthmus (AoI), and ductus venosus (DV). The Doppler indices were analyzed to evaluate the pattern of fetal circulatory adaptation associated with placental insufficiency and chronic fetal hypoxia.

The demographic characteristics and Doppler parameters of the study population were systematically evaluated to determine the relationship between arterial redistribution, transitional circulation, and venous hemodynamic compromise in early-onset fetal growth restriction.

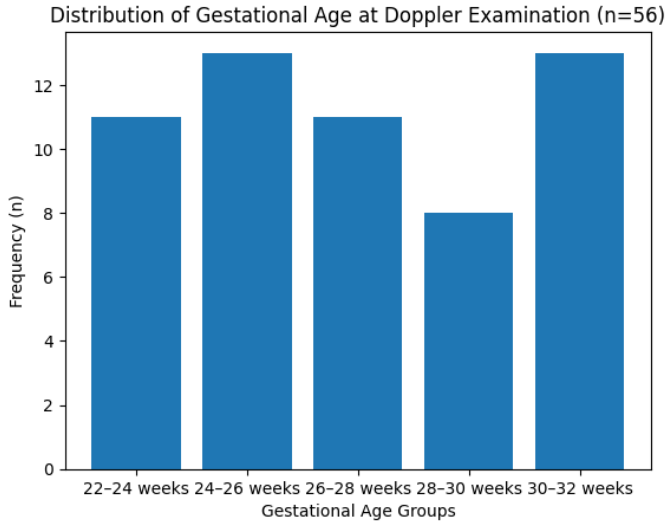


Figure 5: Distribution of Gestational Age at the Time of Doppler Examination

Descriptive Statistics of Doppler Parameters

The Doppler assessment demonstrated significant alterations in fetal circulation consistent with placental insufficiency and progressive fetal hemodynamic adaptation.

The umbilical artery pulsatility index (UA PI) showed elevated values with a mean of 2.20 ± 0.75, reflecting increased placental vascular resistance. The middle cerebral artery pulsatility index (MCA PI) demonstrated comparatively lower values with a mean of 1.24 ± 0.17,

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indicating cerebral vasodilatation and redistribution of blood flow toward the fetal brain.

The aortic isthmus pulsatility index (AoI PI) demonstrated increased values with a mean of 2.65 ± 0.40, suggesting circulatory imbalance between cerebral and placental circulations. The ductus venosus pulsatility index (DV PI) demonstrated a mean value of 1.01 ± 0.25, reflecting alterations in fetal venous hemodynamics and increasing cardiac workload.

These findings collectively demonstrate the multilevel hemodynamic adaptation occurring in pregnancies complicated by early-onset fetal growth restriction.

Table 1: Descriptive Statistics of Doppler Parameters in Early-Onset FGR (Mean ± SD)

Doppler Parameter	Mean	Standard Deviation
Umbilical Artery PI	2.2095	0.7500
Middle Cerebral Artery PI	1.2436	0.1671
Aortic Isthmus PI	2.6573	0.4004
Ductus Venosus PI	1.0129	0.2504

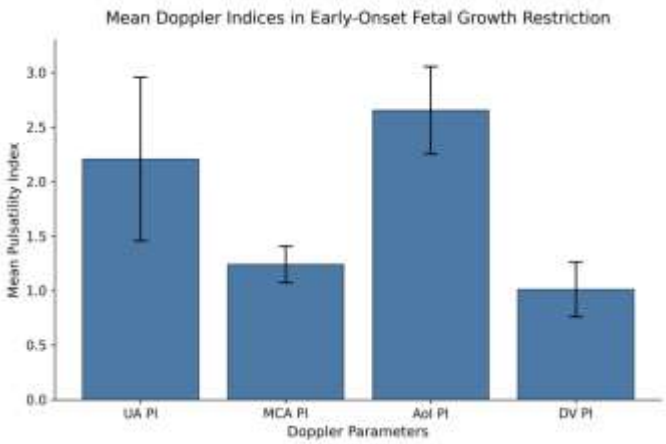


Figure 6: Bar diagram demonstrating mean pulsatility indices of Doppler parameters in pregnancies complicated by early-onset fetal growth restriction

Correlation Between Doppler Parameters

Pearson correlation analysis demonstrated statistically significant relationships among the studied Doppler parameters.

A moderate positive correlation was observed between AoI PI and DV PI ($r = 0.602$, $p < 0.001$), indicating that increasing abnormalities in aortic isthmus Doppler are associated with worsening ductus venosus hemodynamics and progressive fetal cardiovascular compromise.

Similarly, AoI PI showed a significant positive correlation with UA PI ($r = 0.523$, $p < 0.001$), whereas a significant negative correlation was observed with MCA PI ($r = -0.488$, $p < 0.001$), reflecting cerebral vasodilatation associated with fetal hypoxia and redistribution.

Additionally, UA PI demonstrated a significant positive correlation with DV PI ($r = 0.650$, $p < 0.001$). Both UA PI and DV PI showed negative correlations with MCA PI, with the strongest negative correlation observed between DV PI and MCA PI ($r = -0.765$, $p < 0.001$).

Overall, these findings support the concept that progressive placental insufficiency leads to arterial redistribution followed by venous compromise in early-onset fetal growth restriction.

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Table 2: Pearson Correlation Between Doppler Parameters in Early-Onset FGR (n = 56)

Variables	Pearson Correlation (r)	p value
AoI PI vs DV PI	0.602	<0.001
AoI PI vs UA PI	0.523	<0.001
AoI PI vs MCA PI	-0.488	<0.001
UA PI vs DV PI	0.650	<0.001
UA PI vs MCA PI	-0.525	<0.001
DV PI vs MCA PI	-0.765	<0.001

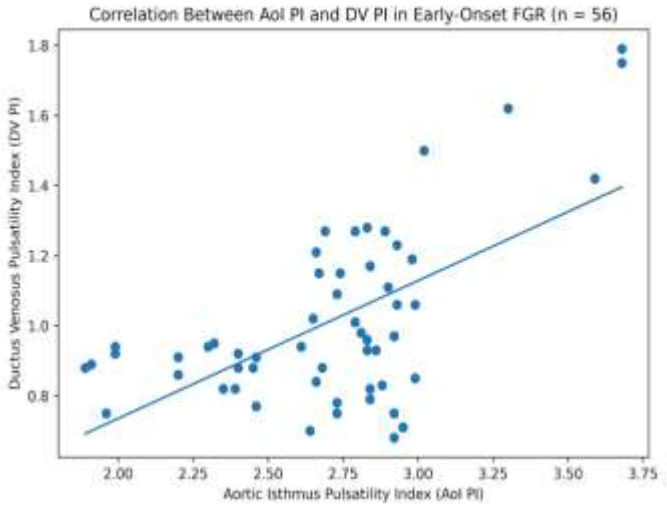


Figure 7: Scatter Plot Demonstrating Correlation Between Aortic Isthmus PI and Ductus Venosus PI in Early-Onset FGR

Distribution of Ductus Venosus A-wave and Aortic Isthmus Flow Patterns

The distribution of ductus venosus A-wave and aortic isthmus flow patterns is summarized in Table 3.

Most fetuses demonstrated forward ductus venosus A-wave flow (91.1%), while absent A-wave and reversed A-wave were observed in 3.6% and 5.3% of cases, respectively.

Similarly, antegrade aortic isthmus flow was present in 91.1% of fetuses, whereas retrograde flow was identified in 8.9%.

Absent or reversed ductus venosus A-wave patterns indicate advanced fetal cardiac compromise and increased central venous pressure, while retrograde aortic isthmus flow represents severe placental insufficiency and advanced fetal circulatory redistribution. Together, these findings reflect progressive deterioration of fetal hemodynamics in advanced stages of early-onset fetal growth restriction.

Table 3: Distribution of Ductus Venosus A-wave and Aortic Isthmus Flow Patterns in Early-Onset FGR (n = 56)

Parameter	Pattern	Frequency (n)	Percentage (%)
Ductus Venosus A-wave	Forward	51	91.1
	Absent	2	3.6
	Reversed	3	5.3
Aortic Isthmus Flow	Antegrade	51	91.1
	Retrograde	5	8.9

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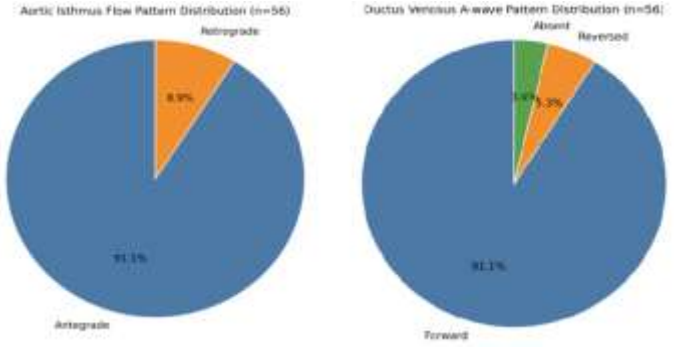


Figure 8: Distribution of Ductus Venosus A-wave Patterns and Aortic Isthmus Flow Patterns in Early-Onset FGR

Doppler Hemodynamic Progression in Early-Onset Fetal Growth Restriction

The Doppler findings observed in the present study demonstrate the sequential hemodynamic progression associated with fetal growth restriction.

The progression begins with increased placental vascular resistance manifested by elevated umbilical artery pulsatility index. This is followed by cerebral vasodilatation leading to reduction in middle cerebral artery pulsatility index and redistribution of blood flow toward vital organs.

Subsequently, alterations occur in the aortic isthmus, indicating imbalance between cerebral and placental circulations. In advanced stages, changes develop in the ductus venosus, reflecting increased cardiac workload, impaired myocardial compliance, and altered fetal venous return.

Overall, these findings demonstrate the progressive transition from placental insufficiency to fetal cardiovascular compromise in early-onset fetal growth restriction.

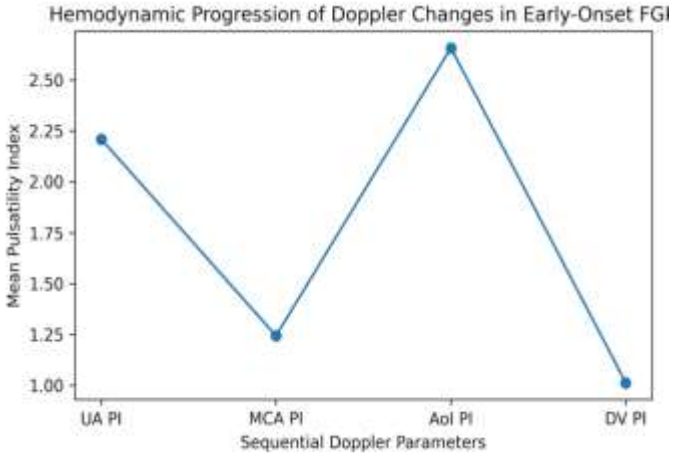


Figure 9: Illustration of Doppler Hemodynamic Progression in Early-Onset Fetal Growth Restriction

Discussion

The Doppler parameters evaluated in the present study demonstrated significant alterations in fetal circulation associated with early-onset fetal growth restriction (FGR). The observed Doppler changes reflected progressive fetal hemodynamic adaptation secondary to placental insufficiency and chronic intrauterine hypoxia. The overall distribution of Doppler indices in the present study was consistent with the sequential hemodynamic changes described in previous fetal surveillance studies by Baschat et al. [6], Hecher et al. [3], and Bilardo et al. [5]. These findings further support the utility of combined arterial and venous Doppler assessment in pregnancies complicated by severe placental insufficiency.

One of the principal observations of the present study was the statistically significant positive correlation between aortic isthmus pulsatility index (AoI PI) and ductus venosus pulsatility index (DV PI) ($r = 0.602$, $p < 0.001$). This finding suggests that worsening abnormalities in the aortic isthmus are associated with progressive deterioration in fetal venous hemodynamics and myocardial function. Similar observations were reported by Cruz-Martinez et al.[9], who demonstrated that abnormalities in the aortic isthmus precede ductus

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venosus deterioration and may represent an intermediate stage of fetal cardiovascular compromise in early-onset FGR. Likewise, Fouron et al.[8] emphasized the physiological significance of the aortic isthmus as a transitional vascular segment reflecting the balance between cerebral and placental circulations.

The elevated umbilical artery pulsatility index observed in the present study reflected increased placental vascular resistance and impaired placental perfusion. Concurrently, reduced middle cerebral artery pulsatility index values demonstrated cerebral vasodilatation and redistribution of blood flow toward vital organs, representing the classical "brain-sparing effect." Similar Doppler alterations have been consistently reported in severe fetal growth restriction by Hecher et al. [3] and Baschat and Gembruch [7]. The significant negative correlation observed between MCA PI and DV PI ($r = -0.765$, $p < 0.001$) in the present study indicates that worsening cerebral redistribution is associated with progressive fetal cardiac compromise and altered venous return.

The sequential pattern of Doppler deterioration observed in the present study further supports the hemodynamic progression model described in the TRUFFLE study and related fetal surveillance literature [2]. Initially, placental insufficiency results in elevated umbilical artery resistance, followed by redistribution of blood flow to the fetal brain, subsequently affecting the aortic isthmus circulation and ultimately leading to venous compromise involving the ductus venosus. The presence of retrograde aortic isthmus flow in 8.9% of cases and abnormal ductus venosus A-wave patterns in advanced cases reflected severe fetal compromise and advanced placental insufficiency. Similar findings have been associated with fetal acidemia, adverse perinatal outcomes, and increased risk of intrauterine fetal demise in previous studies [6,9].

Another important finding of the present study was that most fetuses demonstrated preserved forward ductus venosus A-wave flow (91.1%), while absent or reversed A-wave patterns were identified only in a smaller subset of severe cases. This observation supports the concept that venous Doppler abnormalities occur relatively late in the progression of fetal compromise and are often indicative of advanced myocardial dysfunction. Baschat et al. [6] similarly demonstrated that ductus venosus abnormalities represent late manifestations of fetal cardiovascular deterioration and correlate strongly with fetal acid-base imbalance.

The findings of the present study further highlight the importance of incorporating advanced Doppler parameters such as aortic isthmus and ductus venosus assessment into routine surveillance protocols for early-onset fetal growth restriction. While umbilical artery and middle cerebral artery Doppler remain standard surveillance tools, isolated arterial Doppler assessment may not adequately identify the transition from compensatory redistribution to impending fetal decompensation. Combined evaluation of arterial, transitional, and venous circulations therefore provides a more comprehensive assessment of fetal cardiovascular adaptation and may improve risk stratification in compromised fetuses [5,8].

The present study also demonstrated that Doppler assessment of the aortic isthmus can be reliably performed in routine clinical settings using standard ultrasound equipment. Despite being technically more challenging than conventional arterial Doppler evaluation, adequate visualization and measurement of the aortic isthmus were successfully achieved in all included cases following standardized imaging protocols. This supports the practical applicability of aortic isthmus

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Doppler assessment even in resource-constrained tertiary care institutions.

Despite its strengths, the present study had certain limitations. The sample size was relatively moderate and the study was conducted at a single tertiary care center, which may limit the generalizability of the findings. Additionally, the study primarily focused on Doppler correlations and did not include extensive longitudinal neonatal follow-up or detailed assessment of long-term neurodevelopmental outcomes. Correlation of Doppler abnormalities with neonatal morbidity, NICU admission, perinatal mortality, and long-term developmental outcomes would further strengthen the clinical significance of these observations.

Furthermore, although Doppler evaluation was performed using standardized protocols, interobserver and intraobserver variability were not formally assessed in the present study. Future multicentric studies with larger sample sizes, serial Doppler follow-up, and comprehensive neonatal outcome analysis may further validate the prognostic significance of combined aortic isthmus and ductus venosus Doppler assessment in early-onset fetal growth restriction.

Conclusion

The present study concluded that combined assessment of ductus venosus and aortic isthmus Doppler provides valuable insight into fetal hemodynamic adaptation in pregnancies complicated by early-onset fetal growth restriction. Significant positive correlation between aortic isthmus pulsatility index and ductus venosus pulsatility index demonstrated that progressive circulatory redistribution is associated with worsening fetal venous hemodynamics and myocardial compromise.

The study further demonstrated that increasing placental vascular resistance is associated with sequential Doppler deterioration involving the umbilical artery, middle cerebral artery, aortic isthmus, and ductus venosus circulations. Retrograde aortic isthmus flow and abnormal ductus venosus A-wave patterns represented advanced stages of fetal cardiovascular compromise and severe placental insufficiency.

Importantly, the findings support the role of aortic isthmus Doppler as an intermediate marker between arterial redistribution and venous deterioration, thereby improving understanding of the hemodynamic progression in early-onset fetal growth restriction. Integration of advanced Doppler parameters such as aortic isthmus and ductus venosus into fetal surveillance protocols may therefore improve identification of fetuses at risk of deterioration and assist in optimizing timing of intervention and delivery.

The present study also established that comprehensive Doppler evaluation including aortic isthmus and ductus venosus assessment can be effectively performed using standardized ultrasonographic techniques in routine clinical practice. Further large-scale prospective studies with long-term neonatal follow-up are recommended to validate the prognostic and clinical utility of these Doppler parameters in fetal growth restriction.

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