e-ISSN: 0976-822X, p-ISSN:2961-6042

Available online on http://www.ijcpr.com/

International Journal of Current Pharmaceutical Review and Research 2025; 17(12); 2215-2222

Original Research Article

Functional–Structural Dual Assessment of the Fetoplacental Unit: Umbilical Artery Doppler versus Placental Histomorphology in SGA Outcomes

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Received: 01-09-2025 / Revised: 15-10-2025 / Accepted: 21-11-2025

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Conflict of interest: Nil

Abstract

Background: Small for Gestational Age (SGA) fetuses represent a heterogeneous group, with a significant proportion affected by placental insufficiency leading to adverse perinatal outcomes. Umbilical artery Doppler provides functional assessment of fetoplacental circulation, while placental histomorphology reflects underlying structural pathology. Correlating these parameters may improve prediction of perinatal risk in SGA pregnancies.

Aims and Objectives: To evaluate the relationship between umbilical artery Doppler findings and placental histomorphological changes in SGA pregnancies, and to assess their combined predictive value for perinatal outcomes.

Materials and Methods: This prospective observational study was conducted at a tertiary care center over one year and included 86 antenatal women diagnosed with SGA after 24 weeks of gestation. All participants underwent third-trimester umbilical artery Doppler assessment, recording systolic/diastolic ratio, resistance index, pulsatility index, and end-diastolic flow patterns. Placentas were examined post-delivery for gross and histopathological changes using hematoxylin and eosin staining. Perinatal outcomes, including birth weight, Apgar scores, NICU admission, neonatal complications, and perinatal mortality, were recorded. Statistical analysis was performed using SPSS version 25.0, with $p < 0.05$ considered significant.

Results: Abnormal umbilical artery Doppler findings were observed in 38 cases (44.2%), including decreased, absent, or reversed end-diastolic flow. The most frequent placental histomorphological lesions were syncytial knot proliferation (79.1%), fibrinoid necrosis (68.6%), and perivillous fibrin deposition (64.0%). Abnormal Doppler findings showed strong positive correlation with placental infarction ($r = 0.69$), syncytial knot proliferation ($r = 0.67$), and fibrinoid necrosis ($r = 0.65$) (all $p < 0.001$). Adverse perinatal outcomes, including low Apgar scores, increased NICU admissions, and perinatal deaths, were significantly higher in the abnormal Doppler group.

Conclusion: Umbilical artery Doppler abnormalities strongly correlate with placental histomorphological evidence of maternal vascular malperfusion and are associated with adverse perinatal outcomes in SGA pregnancies. A combined functional–structural assessment of the fetoplacental unit enhances risk stratification and may guide timely obstetric intervention to improve neonatal outcomes.

Keywords: Small for Gestational Age; Umbilical Artery Doppler; Placental Histomorphology; Fetal Growth Restriction; Perinatal Outcome.

Introduction

Small for Gestational Age (SGA) neonates, defined as infants with a birth weight below the 10th percentile for gestational age, constitute a clinically heterogeneous population that includes

constitutionally small but healthy fetuses as well as those affected by true intrauterine growth restriction (IUGR) secondary to placental insufficiency [1]. Differentiating between these two entities is of paramount importance, as growth-restricted fetuses are associated with significantly higher risks of perinatal morbidity, mortality, and long-term neurodevelopmental impairment compared with their constitutionally small counterparts [2].

The burden of SGA remains disproportionately high in low- and middle-income countries, particularly in South Asia, where maternal malnutrition, anemia, hypertensive disorders, and inadequate antenatal surveillance are prevalent [3]. In such settings, timely identification of fetoplacental compromise is critical to optimize obstetric decision-making and improve neonatal outcomes.

The placenta plays a central role in fetal growth by facilitating efficient maternal–fetal exchange of oxygen, nutrients, and metabolic waste. Structural or vascular abnormalities within the placental villous tree can impair uteroplacental perfusion, resulting in chronic fetal hypoxia and restricted growth [4]. Functional assessment of the fetoplacental circulation is routinely performed using umbilical artery Doppler velocimetry, a non-invasive technique that reflects downstream placental vascular resistance. Commonly evaluated Doppler indices include the systolic-to-diastolic (S/D) ratio, resistance index (RI), and pulsatility index (PI), which serve as indirect markers of placental impedance [5].

Abnormal umbilical artery Doppler findings—such as increased resistance indices, reduced diastolic flow, or absent/reversed end-diastolic flow—have been consistently associated with adverse perinatal outcomes, including fetal distress, preterm delivery, low Apgar scores, NICU admission, and intrauterine fetal demise [6]. Despite its established clinical utility, Doppler assessment alone does not fully explain all cases of SGA, as a subset of growth-restricted neonates may exhibit normal antenatal Doppler parameters yet experience poor neonatal adaptation.

This limitation underscores the importance of structural evaluation of the placenta. Histomorphological examination provides direct insight into the pathological substrate of placental insufficiency, revealing characteristic features of maternal vascular malperfusion such as villous infarction, syncytial knot proliferation, fibrinoid necrosis, perivillous fibrin deposition, and calcification [7,8]. These lesions represent the anatomical correlates of impaired placental perfusion and are believed to underlie many of the functional abnormalities detected on Doppler velocimetry.

Therefore, a combined functional–structural assessment of the fetoplacental unit—integrating antenatal umbilical artery Doppler findings with post-delivery placental histopathology—offers a more comprehensive understanding of the pathophysiology of SGA. Such an approach may enhance risk stratification, guide timing and mode of delivery, and improve prediction of perinatal outcomes. The present study aims to correlate umbilical artery Doppler indices with placental histomorphological changes and evaluate their combined diagnostic and prognostic value in pregnancies complicated by SGA fetuses in a tertiary care setting.

Materials and Methods

Study Design and Setting: This prospective observational study was conducted in the Department of Obstetrics and Gynaecology, in collaboration with the Department of Pathology, at Venkateshwara Institute of Medical Sciences (VIMS), Gajraula, Uttar Pradesh, India. The study was carried out over a period of one year after obtaining approval from the Institutional Ethics Committee. Written informed consent was obtained from all participants prior to enrolment.

Study Population and Sample Size: The study included antenatal women diagnosed with Small for Gestational Age (SGA) pregnancies attending the antenatal outpatient and inpatient services of the institution. A total of 86 participants were enrolled based on the sample size calculation using the formula:

$$n = \frac{Z^2 \times p \times q}{r^2}$$

Where p was taken as 34% prevalence of SGA, q = 1 − p, r as 10% allowable error, and Z corresponding to a 95% confidence interval. Eligible participants were recruited consecutively during the study period.

Inclusion Criteria

- Booked antenatal women after 24 weeks of gestation
- Singleton pregnancies with cephalic presentation
- Fetuses diagnosed clinically and/or ultrasonographically as SGA
- Pregnancies with or without pregnancy-induced hypertension
- Willingness to participate with written informed consent

Exclusion Criteria

- Multiple gestations
- Fetuses with congenital anomalies

- Maternal infections including malaria, TORCH infections, and HIV
- Maternal systemic disorders such as diabetes mellitus, systemic lupus erythematosus, antiphospholipid antibody syndrome, cardiovascular disease, and severe preeclampsia
- Non-consenting participants

Doppler Ultrasound Assessment: All enrolled participants underwent third-trimester ultrasonographic evaluation with umbilical artery Doppler using a high-resolution ultrasound machine operated by experienced radiologists. Doppler measurements were obtained from a free-floating loop of the umbilical cord during fetal quiescence. The following Doppler indices were recorded:

- Systolic/Diastolic (S/D) ratio
- Resistance Index (RI)
- Pulsatility Index (PI)

Umbilical artery Doppler flow patterns were categorized as normal end-diastolic flow, decreased end-diastolic flow, absent end-diastolic flow, or reversed end-diastolic flow based on standard reference values.

Placental Collection and Gross Examination: Immediately after delivery, placentas were collected, washed under running water to remove blood clots, and fixed in 10% neutral buffered formalin. Gross examination included documentation of placental weight, surface area, and thickness, and umbilical cord insertion, presence of infarcts, calcification, and retroplacental hematoma.

Histopathological Examination: Representative tissue sections were taken from standardized placental sites, including central and peripheral regions. Sections were processed routinely and stained with hematoxylin and eosin (H&E). Microscopic examination was performed by pathologists blinded to Doppler findings. The following histomorphological features were assessed:

- Syncytial knot proliferation
- Fibrinoid necrosis
- Perivillous fibrin deposition
- Villous edema
- Villous vascularity
- Calcification

Findings were recorded systematically for correlation with Doppler parameters.

Perinatal Outcome Assessment: Perinatal outcomes were recorded for all neonates and included gestational age at delivery, birth weight, Apgar scores at 1 and 5 minutes, mode of delivery, need for neonatal intensive care unit (NICU) admission, and duration of NICU stay. Neonatal complications such as respiratory distress, neonatal jaundice, meconium aspiration syndrome, hypoxia, and perinatal mortality were documented.

Statistical Analysis: Data were entered into Microsoft Excel and analyzed using IBM SPSS version 25.0. Continuous variables were expressed as mean ± standard deviation, while categorical variables were presented as frequencies and percentages. The Student's t-test was used for comparison of continuous variables, and the Chi-square test or Fisher's exact test was applied for categorical variables as appropriate. Correlation between umbilical artery Doppler abnormalities and placental histopathological findings was assessed using Pearson's correlation coefficient (r). A p-value of less than 0.05 was considered statistically significant.

Results

A total of 86 antenatal women with clinically and ultrasonographically diagnosed Small for Gestational Age (SGA) fetuses were included in the final analysis.

Maternal and Obstetric Profile: The mean maternal age was 26.8 ± 4.1 years, with 58% of women being multigravidas. The mean gestational age at delivery was 36.4 ± 1.8 weeks. Preterm delivery (<37 weeks) occurred in 34 cases (39.5%), while 52 cases (60.5%) delivered at term.

Umbilical Artery Doppler Findings: Umbilical artery Doppler evaluation revealed normal end-diastolic flow in 48 cases (55.8%), while 38 cases (44.2%) demonstrated abnormal flow patterns. Among abnormal Doppler findings, decreased end-diastolic flow was observed in 26 cases (30.2%), absent end-diastolic flow in 8 cases (9.3%), and reversed end-diastolic flow in 4 cases (4.7%).

The mean Doppler indices were:

- S/D ratio: 3.1 ± 0.6
- Resistance Index (RI): 0.74 ± 0.08
- Pulsatility Index (PI): 1.25 ± 0.12

Table 1: Umbilical Artery Doppler Flow Patterns (n = 86)

Doppler Flow Pattern	Cases	Percentage (%)
Normal EDF	48	55.8
Decreased EDF	26	30.2
Absent EDF	8	9.3
Reversed EDF	4	4.7
Total	86	100

Gross Placental Findings: Gross placental examination revealed a reduced mean placental weight of 382.6 ± 54.7 g. Placental infarction was the most common gross abnormality, identified in 60.5% of cases. Calcification was noted in 45.3%, and retroplacental hematoma in 11.6%, suggesting compromised uteroplacental perfusion.

Table 2: Gross Placental Findings (n = 86)

Parameter	Mean ± SD / n	Percentage (%)
Placental weight (g)	382.6 ± 54.7	—
Infarction present	52	60.5
Calcification present	39	45.3
Retroplacental hematoma	10	11.6

Histomorphological Findings of Placenta: Microscopic examination revealed features consistent with maternal vascular malperfusion. Syncytial knot proliferation was the most frequent lesion (79.1%), followed by fibrinoid necrosis (68.6%) and perivillous fibrin deposition (64.0%). Villous edema and decreased villous vascularity were observed in 52.3% and 47.7% of cases, respectively.

Table 3: Histomorphological Findings of Placenta (H&E) (n = 86)

Histological Feature	Cases	Percentage (%)
Syncytial knot proliferation	68	79.1
Fibrinoid necrosis	59	68.6
Perivillous fibrin deposition	55	64.0
Villous edema	45	52.3
Decreased villous vascularity	41	47.7
Calcification	39	45.3

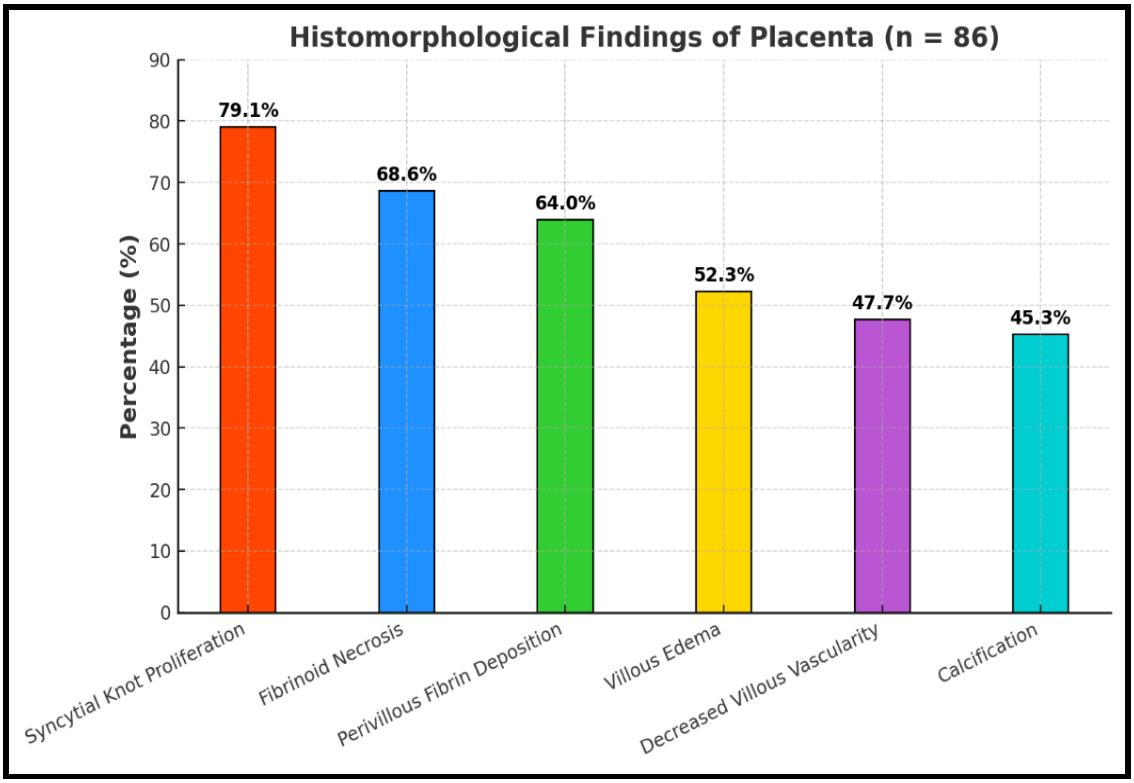

Figure 1: Histomorphological findings of placenta showing syncytial knots, fibrinoid necrosis, perivillous fibrin deposition, and villous edema (H&E stain)

Perinatal Outcomes: The mean neonatal birth weight was 2.25 ± 0.38 kg. Apgar score <7 at one minute was observed in 27.9% of neonates. NICU admission was required in 40.7% of cases. Nearly half (47.7%) of neonates developed at least one complication, with respiratory distress being the most common.

Table 4: Perinatal Outcomes (n = 86)

Outcome	Mean ± SD / n	Percentage (%)
Birth weight (kg)	2.25 ± 0.38	—
Term delivery (≥37 weeks)	52	60.5
Preterm delivery (<37 weeks)	34	39.5
Apgar <7 at 1 min	24	27.9
NICU admission	35	40.7
Neonatal complications (any)	41	47.7
Respiratory distress	18	20.9
Neonatal jaundice	14	16.3
Meconium aspiration	9	10.5
Perinatal deaths	3	3.5

Correlation between Doppler Abnormalities and Placental Lesions: A statistically significant positive correlation was observed between abnormal umbilical artery Doppler findings and placental pathology, particularly placental infarction, syncytial knot proliferation, and fibrinoid necrosis.

Table 5: Correlation of Doppler Abnormality with Placental Lesions

Placental Lesion	Correlation Coefficient (r)	p-value	Interpretation
Infarction	0.69	<0.001	Strong positive
Syncytial knots	0.67	<0.001	Strong positive
Fibrinoid necrosis	0.65	<0.001	Strong positive
Villous edema	0.53	0.002	Moderate
Calcification	0.48	0.004	Moderate

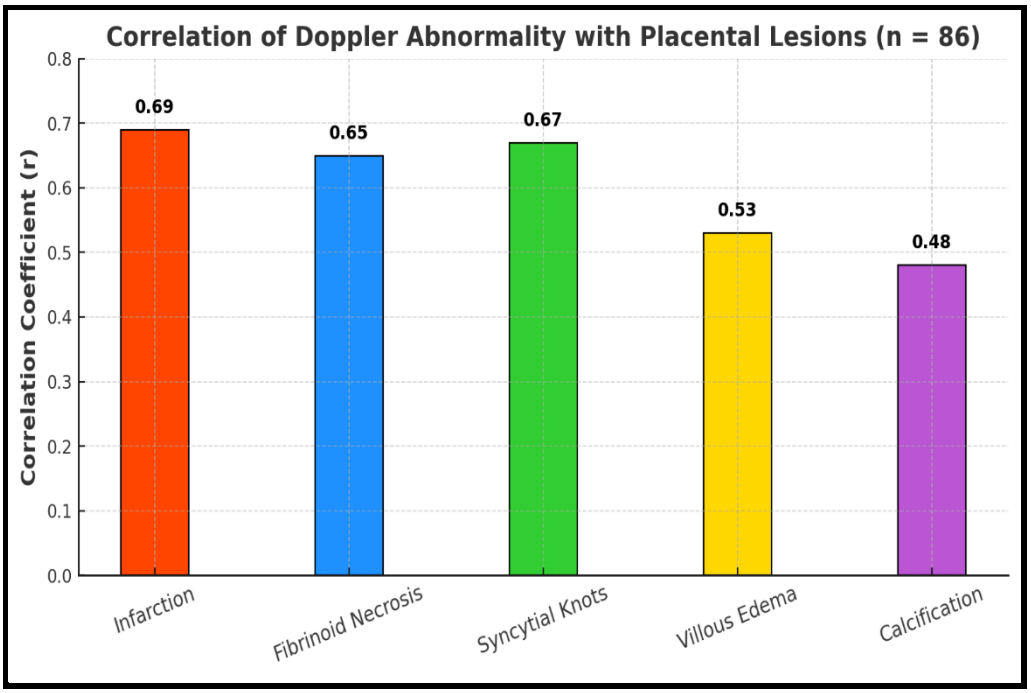

Figure 2: Correlation between umbilical artery Doppler abnormality and placental histopathological lesions.

Association between Umbilical Artery Doppler Findings and Perinatal Outcomes: Adverse perinatal outcomes were significantly more frequent among pregnancies with abnormal Doppler findings. Apgar score <7 and NICU admission were markedly higher in the abnormal Doppler group. All perinatal deaths occurred exclusively in this group.

Table 6: Association between Umbilical Artery Doppler Findings and Perinatal Outcomes

Outcome	Normal Doppler (n=48)	Abnormal Doppler (n=38)	χ^2	p-value
Apgar <7 at 1 min	6 (12.5%)	18 (47.4%)	11.82	0.001
NICU admission	9 (18.8%)	26 (68.4%)	21.75	<0.001
Perinatal death	0 (0%)	3 (7.9%)	4.01	0.045

Discussion

The present study was undertaken to evaluate the relationship between umbilical artery Doppler findings and placental histomorphological changes in pregnancies complicated by Small for Gestational Age (SGA) fetuses and to assess their impact on perinatal outcomes. By integrating functional assessment of placental circulation with structural placental pathology, this study provides a comprehensive evaluation of fetoplacental insufficiency in SGA pregnancies.

In the current study, the mean maternal age was 26.8 ± 4.1 years, with a predominance of multigravidas (58%). A substantial proportion of pregnancies (39.5%) resulted in preterm delivery, reflecting the clinical tendency toward early termination in SGA pregnancies complicated by placental compromise. Similar demographic and obstetric profiles have been reported in Indian and other low- and middle-income country studies, where nutritional factors and placental dysfunction contribute significantly to fetal growth restriction [9,11].

Umbilical Artery Doppler and Fetoplacental Compromise: Umbilical artery Doppler evaluation revealed abnormal flow patterns in 44.2% of cases, including decreased, absent, and reversed end-diastolic flow. These findings indicate increased placental vascular resistance and impaired fetoplacental circulation. Comparable proportions of abnormal Doppler findings have been reported by Yadav et al. and Malik et al., who observed abnormal umbilical artery waveforms in approximately 40–45% of IUGR/SGA pregnancies [9,12]. Elevated Doppler indices in the present study further support the presence of placental insufficiency as a major etiological factor in SGA.

Abnormal umbilical artery Doppler has been shown to reflect placental bed arteriopathy and progressive vascular compromise, leading to chronic fetal hypoxia [6,10]. The presence of absent or reversed end-diastolic flow in 14% of cases in the present study represents advanced placental pathology and is widely recognized as a poor prognostic marker.

Placental Gross and Histomorphological Changes: Gross placental examination in this study demonstrated reduced placental weight along with a high prevalence of infarction and calcification. These findings indicate diminished uteroplacental perfusion and premature placental aging. Similar gross abnormalities have been consistently reported in placentas from SGA pregnancies by Sajid et al. and Malik et al., reinforcing the role of placental structural compromise in fetal growth restriction [11,12].

Histomorphological evaluation revealed predominant features of maternal vascular malperfusion, including syncytial knot proliferation, fibrinoid necrosis, perivillous fibrin deposition, villous edema, and reduced villous vascularity.

These lesions are characteristic of chronic hypoxic injury and defective maternal–fetal exchange. Mardi and Sharma also reported syncytial knot proliferation and fibrinoid necrosis as the most frequent histological findings in IUGR placentas [13]. Similar observations were noted by Visan et al. and Induja et al., who emphasized the association between placental villous pathology and adverse neonatal outcomes [8,7].

Correlation between Doppler Findings and Placental Pathology: A major strength of the present study is the demonstration of a strong positive correlation between abnormal umbilical artery Doppler findings and placental histopathological lesions. Placental infarction, syncytial knot proliferation, and fibrinoid necrosis showed strong correlations with Doppler abnormalities ($p < 0.001$), indicating that functional Doppler changes reliably reflect underlying placental structural damage.

These findings are consistent with the observations of Spinillo et al. and Herman et al., who reported that abnormal umbilical artery Doppler is strongly associated with histological evidence of maternal vascular malperfusion and poor neonatal outcomes [5,14]. Thus, umbilical artery Doppler serves as a valuable antenatal surrogate marker for placental pathology.

Perinatal Outcomes and Clinical Implications: Adverse perinatal outcomes were common in the present study, with nearly half of the neonates experiencing at least one complication. NICU admission was required in 40.7% of cases, and perinatal mortality was 3.5%. Importantly, all perinatal deaths occurred in the abnormal Doppler group, highlighting the prognostic significance of umbilical artery Doppler abnormalities.

The significantly higher incidence of low Apgar scores and NICU admissions among fetuses with abnormal Doppler findings aligns with previous studies by Gidi et al. and Berkley et al., which demonstrated increased neonatal morbidity and mortality in SGA fetuses with abnormal umbilical artery Doppler waveforms [6,15]. Recent studies by Marijnen et al. and Martins et al. further support the role of progressive Doppler deterioration in predicting severe placental pathology and adverse neonatal outcomes [16,17].

Clinical Relevance: The findings of this study underscore the importance of integrating umbilical artery Doppler assessment with placental histopathology to better understand the pathophysiology of SGA. While Doppler serves as

an effective antenatal screening and monitoring tool, placental histomorphology provides confirmatory evidence of placental insufficiency and explains adverse neonatal outcomes. A combined functional–structural approach enhances risk stratification, aids in timing of delivery, and supports improved perinatal decision-making, particularly in resource-limited settings.

Conclusion

This study demonstrates a strong association between umbilical artery Doppler abnormalities and placental histomorphological changes in pregnancies complicated by Small for Gestational Age (SGA) fetuses. Abnormal Doppler indices, particularly reduced, absent, or reversed end-diastolic flow, were closely correlated with features of maternal vascular malperfusion such as placental infarction, syncytial knot proliferation, and fibrinoid necrosis. These functional and structural abnormalities were significantly associated with adverse perinatal outcomes, including low Apgar scores, increased NICU admissions, and perinatal mortality. The findings highlight the value of umbilical artery Doppler as a reliable, non-invasive antenatal tool for identifying fetuses at risk due to placental insufficiency. When complemented by placental histopathological evaluation, a more comprehensive understanding of fetoplacental compromise is achieved. Adoption of a combined functional–structural assessment approach may facilitate timely obstetric intervention, optimize delivery planning, and improve neonatal outcomes, particularly in resource-limited settings where the burden of SGA remains high.

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