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The Predictive Value of Doppler Indices of the Superior Vena Cava in Early Diagnosis of Fetal Growth Restriction in Pregnancies

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Abstract

Objectives: This study aimed to evaluate the diagnostic and predictive value of superior vena cava (SVC) Doppler indices in the early detection of intrauterine growth restriction (IUGR) and to examine their incremental contribution beyond conventional arterial Doppler parameters of the umbilical and middle cerebral arteries.

Materials and Methods: This cross-sectional analytical study was conducted at a high-risk pregnancy clinic of Kowsar Medical Center between October 2025 and February 2026 on 85 singleton pregnancies at 24–36 weeks' gestation. Fetuses with structural or chromosomal anomalies and pregnancies requiring urgent termination were excluded. Standard fetal biometry and Doppler ultrasound of the umbilical artery (UA), middle cerebral artery (MCA), and SVC were performed. IUGR was defined according to ISUOG criteria and stratified into mild, moderate, and severe subgroups. Statistical analysis was performed using SPSS 26, with $P < 0.05$ considered significant.

Results: The mean maternal age and gestational age were 30 years and 33 weeks, respectively. Most IUGR cases were moderate to severe. Reduced SVC Doppler resistance indices were observed in 58% of IUGR fetuses and were significantly associated with growth restriction ($P<0.05$). In contrast, the SVC-to-Aorta diameter ratio did not differ significantly between IUGR and normally grown fetuses. Functional SVC Doppler parameters demonstrated stronger discriminatory value than static vessel size measurements.

Conclusions: SVC Doppler indices offer meaningful complementary information regarding fetal hemodynamic redistribution in IUGR. Decreased SVC resistance reflects central circulatory adaptation to placental insufficiency. Integration of venous Doppler assessment with established arterial indices may improve fetal surveillance, although larger prospective studies are needed to confirm clinical utility.

Keywords: Fetal growth retardation, Ultrasonography, Doppler, Color, IUGR

Introduction

Intrauterine growth restriction (IUGR) is a common, but poorly understood, problem in obstetrics. IUGR has been defined as fetuses whose estimated fetal weight (EFW) falls below the 10th percentile for gestational age (1). The incidence of IUGR in newborns is estimated to range from 3% to 7% of the total population (2,3). It affects approximately 10% of pregnancies in developed countries and up to 34% in developing countries (4,5). The imbalance between uterine blood flow and placental demand for nutrients and oxygen is the main cause of IUGR (6).

IUGR is a strong risk factor for stillbirth, neonatal mortality, and perinatal complications, and is also a risk factor for some chronic diseases in the future. Infants with IUGR are at increased risk for metabolic syndrome, diabetes mellitus, obesity, and cardiovascular disease (7,8). IUGR is the leading cause of perinatal mortality in anatomically healthy infants (9). Fetal health assessment in obstetrics is important for optimizing clinical management, and for this purpose, Doppler ultrasound is one of the most commonly used methods. This noninvasive method assesses the dynamics of blood flow in the major fetal vessels, including the umbilical artery (UA), the middle cerebral artery (MCA), and the ductus venosus (10). IUGR is divided into two general types: early and late, based on gestational age at diagnosis (before or after 32 weeks).

The incidence of early IUGR is lower than that of late (1% versus 5-10%), while early IUGR is generally easier to diagnose than late, and neonatal and maternal complications are typically more severe in early-onset cases. Early IUGR is diagnosed based on increased Doppler PI in the uterine or UA ultrasound, while late IUGR is diagnosed based on Doppler examination of cerebral blood flow redistribution, which is necessary to maintain brain growth and function (11-13). Diagnosis and follow-up of early IUGR and determination of the

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Key Messages

- SVC Doppler indices provide additional hemodynamic information and may improve early identification of fetal growth restriction alongside standard arterial Doppler parameters.
- Balanced diagnostic group design enabled more precise comparison of Doppler markers between IUGR and non-IUGR pregnancies.
- SVC Doppler assessment may serve as a complementary tool in high-risk pregnancy surveillance protocols.

time of delivery are performed by various methods, such as the biophysical profile scoring system and uterine artery Doppler. Absence or reversal of end-diastolic velocity indicates fetal distress. Since 2000, more attention has been directed towards the examination of the ductus venosus and short-term variability of the fetal heart rate to determine the time of delivery in fetuses with early IUGR (14). The fetal circulatory system redistributes blood to vital organs, namely the brain, heart, and adrenal glands, when the fetus is hypoxemic (15,16). On the arterial side, Doppler velocimetry of the umbilical cord and middle cerebral arteries is often used to detect this phenomenon (17).

On the venous side, the ductus venosus and umbilical vein are the most commonly used to assess fetal health (18). The flow patterns of the fetal inferior vena cava (IVC) have also been studied (19,20), but these veins represent venous return from the lower body and placenta. On the other hand, the superior vena cava (SVC) is the only vessel that returns blood from the head and upper body to the heart. Because approximately 80% of SVC blood flow originates from the brain, its assessment may provide useful clinical information. In premature infants, measurement of SVC blood flow has been shown to be a useful tool in hemodynamic assessment and prediction of complications, such as intraventricular hemorrhage (21). However, this part of the venous circulation has not been extensively studied in fetuses with IUGR. Therefore, the aim of the present study is to determine the predictive value of Doppler indices of the SVC in the early diagnosis of fetal growth restriction (FGR).

Materials and Methods

Study population

This cross-sectional analytical study was conducted at the high-risk pregnancy clinic of Kowsar Medical Center between October 2025 and February 2026. 85 singleton pregnancies at 24–36 weeks' gestation were included. Gestational age was established from first-trimester crown-rump length and confirmed during second-trimester ultrasound by measuring bi-parietal diameter.

Sample size was calculated based on the expected area under the ROC curve (AUC = 0.783) for QSVCW in diagnosing IUGR reported by Stefopoulou et al. With a type I error of 1% and a statistical power of 99%, the minimum required sample size was estimated at 85 subjects, assuming equal proportions in the IUGR and non-IUGR groups according to the reference standard (2). The calculation was performed using MedCalc software. Due to practical recruitment limitations, 70 eligible participants were finally included. Sampling was performed using a convenience approach among eligible pregnant women. Although the calculated minimum sample size was larger, recruitment constraints resulted in a smaller final sample, potentially reducing statistical power for some secondary and subgroup analyses. Equal group sizes were intentionally targeted at the design stage to improve statistical efficiency and the precision of diagnostic comparisons of Doppler indices.

Inclusion criteria were maternal age 18-45 years, singleton pregnancy at 24-36 weeks' gestation, and absence of chromosomal and structural abnormalities. Exclusion criteria for the study were the presence of factors requiring termination of pregnancy within the next 48 hours, such as PPROM, preeclampsia, eclampsia, and HELLP syndrome.

Ultrasonography

All examinations were performed using a GE ultrasound system equipped with a curved abdominal transducer operating within a 2–5 MHz frequency bandwidth. Fetal viability was confirmed at the beginning of each scan, followed by the acquisition of standard biometric parameters. EFW was derived from head circumference (HC), abdominal circumference (AC), and femur length (FL) using the Hadlock-3 regression model (22). All Doppler assessments were performed by an experienced, certified sonographer involved in the study. Blood flow velocity waveforms of the UA and the MCA were obtained according to standard protocols (18).

Pulsed-wave Doppler velocity waveforms were recorded from each vessel in the absence of fetal movements, keeping the insonation angle of the Doppler close to zero and always below 30 degrees. The pulsatility index (PI) was automatically calculated using the built-in software (PI = (S-D)/TAMxV). On the venous side, SVC Doppler velocities were recorded, and SVC diameters were measured. The pulsatility index for vein (PIV) was calculated using the formula (S-A)/TAMxV as previously described (17,23). SVC Doppler assessment was performed using the pulsatility index for veins (SVC PI), and the index was calculated using the standard venous pulsatility formula as described previously.

To ensure consistency, the term SVC PI is used uniformly throughout the manuscript. Based on prior reference data indicating that SVC PI remains relatively stable across gestation with an approximate value of 1.50 between 20 and 40 weeks, abnormal SVC Doppler was defined using a percentile-based approach. Values below the 5th percentile (less than 1.00) were considered abnormal and interpreted as indicating decreased venous resistance. Accordingly, the term "decreased resistance in the SVC" in this study refers specifically to SVC PI values below the 5th percentile cutoff. This cutoff definition was consistently applied across all analyses (17).

Definition of Subgroups of the Study

The initial diagnosis of IUGR is based on clinical examination and on measuring uterine height with a tape measure from the top of the symphysis pubis to the fundus of the uterus with an empty bladder. Then, for final confirmation, the fetal weight percentile will be calculated according to the ISUOG protocol criteria, and a weight percentile below the 10th percentile and an AC below the 10th percentile for gestational age are considered to indicate uterine growth restriction. IUGR is divided into mild, moderate, and severe types based on the deviation of the EFW from the normal value, and also the Doppler vascular evidence.

In the mild type, the EFW is between the 5th and 10th percentiles based on gestational age, and vascular Doppler and amniotic fluid volume are normal. In the moderate type, the EFW is between the 3rd and 5th percentiles, the AC is below the 5th percentile, and there is increased UA resistance. In the severe form of IUGR, the estimated weight is below the 3rd percentile, and the AC may also be below the 3rd percentile for gestational age. In the severe type, color Doppler of the umbilical and middle cerebral arteries is also impaired (24-26).

Statistical Analysis

Statistical analysis was performed using SPSS version 26 and MedCalc software. Continuous variables were tested for normality and reported as mean ± standard deviation, median, or percentages, depending on the variable. Descriptive characteristics of patients were presented in frequency tables. Between-group comparisons were conducted using an independent t-test or Mann–Whitney U test, and categorical variables were compared using the chi-square test. Effect size measures were calculated for principal between-group comparisons.

Diagnostic performance was evaluated using receiver operating characteristic (ROC) curve analysis, and area under the curve (AUC), sensitivity, and specificity were reported with 95% confidence intervals. To address multiplicity due to multiple Doppler indices and comparisons, adjusted significance thresholds (Bonferroni correction) were applied where appropriate. The predictive value of Doppler indices of the SVC compared to the middle cerebral artery and UA in IUGR, and the predictive value of the ratio of the diameter of the SVC to the aorta in the three-vessel view compared to the middle cerebral artery and UA in IUGR were evaluated using the Kruskal-Wallis test. For statistical comparisons between groups and for assessing the significance of the data, the chi-square test was used for qualitative variables, and the Kruskal-Wallis test was used for quantitative variables. The significance level for the tests was set at 0.05 or lower.

Results

A total of 85 women participated in this study, 15 of whom required early termination due to HELLP syndrome, preeclampsia, and preterm labor and were excluded from the study. Finally, 70 women remained at the end of the study: 35 (50%) had normal intrauterine growth and 35 (50%) had IUGR. Table 1 presents the baseline clinical characteristics of the study population. The average age of the participants in this study was 30 years, and the mean gestational age was 33 weeks. Among these women, 56 underwent first-trimester ultrasound screening, 8 underwent noninvasive prenatal testing, and 6 underwent both with normal results. All of them subsequently had a routine second-trimester ultrasound, which did not show any fetal anomalies. 2 (2.9%) of the participants had preexisting type 2 diabetes mellitus, and 7 (10%) had gestational diabetes. 25 (35.7%) of the participants had chronic hypertension, and 15 (21.4%) had preeclampsia.

Seven (10%) participants in this study had mild IUGR, 15 (21.4%) had moderate IUGR, and 21 (30%) had severe IUGR (Table 2).

58% of patients with IUGR had decreased resistance on Doppler ultrasound of the SVC, and this association was statistically significant ($P < 0.05$%) (Tables 3 and 4).

Analysis of the SVC/Ao ratio in IUGR patients and the normal population showed higher values in the IUGR group (mean ± SD: 0.74, range: 0.45–1.41) compared to the normal group (mean ± SD: 0.66, range: 0.43–0.90). The IUGR group also demonstrated greater variability. However, statistical comparison using the Mann-Whitney U test indicated that the difference between groups was not statistically significant (Table 5). These findings suggest that while the SVC/Ao ratio tends to be higher and more variable in IUGR patients, the observed differences do not reach statistical significance in this study. The relationship between the ratio of the SVC to the aorta diameter was

Table 1. Baseline Clinical Characteristics of the Study Population

Variable	Normal group, No. (%)	IUGR group, No. (%)	*P* value
Nulliparous	20 (57)	17 (48)	0.493
Multipara	15 (42)	18 (51)	0.289
Chronic ıypertension	4 (11)	21(60)	0.011
Preeclampsia	0 (0)	15 (42)	0.036
Overt diabetes mellitus	1 (2)	1 (2)	0.609
Gestational diabetes mellitus	1 (2)	6 (17)	0.508

Table 2. Fetal Biometry and Growth Classification in the IUGR Group

Parameter	IUGR & Normal (n=70)	No. (%)
	AC <3%	22 (31.4)
AC	AC 3-10%	13 (18.6)
	AC > 10%	35 (50)
	EFW < 3%	17 (24.3)
EFW	EFW 3-10%	21 (30)
	EFW > 10%	32 (45.7)
SGA	AC or EFW <10% with NL Doppler	7 (10)
	Moderate	15 (21.4)
IUGR	Severe	21 (30)
	Normal	27 (38.6)

Abbreviations: IUGR, Intrauterine growth restriction; AC, abdominal circumference; EFW, estimated fetal weight; SGA: small gestational age; NL: normal color Doppler.

not significant in IUGR patients or normal patients ($P >$ 0.05%).

Discussion

In the present study, most growth-restricted fetuses were classified as moderate to severe, and more than half (58%) demonstrated significantly decreased resistance in SVC Doppler indices. In contrast, the SVC-to-aorta diameter ratio did not differ significantly between IUGR and normally grown fetuses. From a hemodynamic perspective, this pattern suggests that venous Doppler changes at the SVC level primarily reflect functional circulatory redistribution and altered cerebral venous return rather than fixed structural differences in vessel size. Accordingly, functional flow and resistance parameters appear to be more sensitive markers of fetal adaptation to placental insufficiency than static diameter ratios alone.

Modern definitions of FGR extend beyond biometric thresholds such as EFW or AC below the 10th percentile and increasingly incorporate Doppler-based vascular assessment (27,28). Within this framework, Doppler evaluation has become a central component in the assessment of placental insufficiency and fetal compromise (29). The relationship between fetal brain blood flow and blood flow in other organs can be detected on prenatal ultrasound through fetal growth patterning and through proven spectral and color Doppler studies, with particular value in high-risk pregnancies. Cerebral redistribution (brain-sparing) represents a key adaptive mechanism in high-risk pregnancies and is typically characterized by preferential cerebral perfusion at the expense of peripheral circulation (30). However, with the available tools, accurately assessing actual fetal growth remains challenging.

Our findings expand this concept by showing that venous Doppler—specifically, reduced SVC resistance—is frequently present in IUGR and may serve as an additional marker of central hemodynamic adaptation. Reproducibility remains an important methodological issue in Doppler research. Sweid Zidan Raghda et al demonstrated significant inter-measurement variability across several Doppler indices, potentially contributing to discrepancies in IUGR diagnosis; however, UA PI and the umbilico-cerebral ratio showed the highest reproducibility and were recommended as more reliable parameters for clinical and research use (31). These observations highlight the importance of standardized acquisition techniques and repeated measurements when incorporating additional Doppler parameters, such as SVC indices, into clinical studies.

Our observations are conceptually consistent with recent venous Doppler investigations focusing on SVC

Table 3. Arterial Doppler Findings

Doppler index	IUGR (n=35), No. (%)	Normal (n=35), No. (%)	*P* value
Normal umbilical artery PI	6 (17)	31 (88.5)	0.000
Abnormal umbilical artery PI (%)	29 (82)	4 (11.4)	0.000
Normal middle cerebral artery PI	32 (91)	35 (100)	0.270
Abnormal middle cerebral artery PI (%)	3 (8)	0 (0)	0.180
Normal SVC PI	6 (20.1)	23 (79.9)	0.000
Abnormal SVC PI (%)	29 (70)	12 (29.2)	0.000

Table 4. Descriptive Statistics of SVC PI in IUGR and Normal Groups

SVC PI	Normal	Moderate IUGR	Severe IUGR
Normal SVC PI	22 (81%)	7 (31%)	0 (0%)
Decreased SVC PI	5 (18%)	15 (68%)	21 (100%)

Table 5. Descriptive statistics of SVC/Ao Ratio in IUGR and Normal groups

Group	Min	Max	Mean ± SD	*P* value
IUGR	0.45	1.41	0.74 ± 0.21	> 0.05
Normal	0.43	0.9	0.66 ± 0.11	

flow in small gestational age (SGA) and FGR fetuses. Stefopoulou et al reported significantly increased SVC diameter and fetal-weight–normalized SVC blood flow using a quantitative flow-based approach, supporting the presence of increased venous return from the brain and upper body during redistribution states, while velocity waveform parameters showed relatively minor changes (32). Uzun Çilingir et al evaluated Doppler indices of the IVC, SVC, and the vena cava ratio (IVC/SVC) in fetuses with growth restriction to assess fetal hemodynamic alterations. The study demonstrated that growth-restricted fetuses showed significant changes in venous Doppler parameters compared with appropriately grown fetuses, reflecting impaired cardiovascular adaptation and increased central venous pressure. In particular, abnormalities in IVC flow patterns and an altered vena cava ratio were associated with fetal compromise. The authors concluded that assessment of vena cava Doppler parameters, especially the vena cava ratio, may provide additional information on fetal circulatory redistribution and cardiac function in growth-restricted pregnancies, complementing conventional arterial Doppler evaluation (33). In addition, Fouron et al showed that placental circulatory insufficiency is associated with early and marked changes in venous hemodynamics—particularly in SVC and IVC flow velocity patterns—linked to elevated central venous pressure and reduced cardiac compliance. Importantly, these venous Doppler abnormalities may precede severe arterial Doppler deterioration, supporting their potential role as early indicators of fetal cardiovascular compromise. Fouron and colleagues emphasized that abnormalities in SVC flow are closely related to cerebral venous drainage and provide insight into fetal cerebral hemodynamic adaptation, while changes in IVC flow indicate deterioration of right ventricular function and global cardiac performance. Importantly, these venous Doppler alterations preceded severe arterial Doppler abnormalities, highlighting their potential as early indicators of fetal cardiovascular compromise in the setting of placental circulatory insufficiency. These findings support the clinical value of incorporating venous Doppler assessment of the SVC and IVC alongside conventional arterial Doppler studies to improve the evaluation of fetal well-being and optimize the timing of intervention in pregnancies complicated by placental insufficiency (34).

From a clinical perspective, our findings suggest that SVC Doppler assessment may serve as a useful adjunct to conventional arterial Doppler parameters in pregnancies complicated by suspected placental insufficiency. Reduced SVC resistance may indicate active central redistribution even when simple vessel diameter ratios remain unchanged. Nevertheless, given the currently moderate predictive performance of quantitative SVC flow indices for adverse outcomes, venous Doppler parameters should presently be considered complementary rather than substitutive markers (31-33).

Strengths and Limitations of the Study

This study has several strengths, including targeted evaluation of SVC Doppler parameters and stratification of IUGR severity, enabling assessment across a clinical spectrum. However, limitations should be acknowledged, including limited sample size, single-center design, and the operator-dependent nature of venous Doppler measurements. We did not perform formal reproducibility testing, longitudinal Doppler follow-up, or detailed correlation of neonatal outcomes, which limits prognostic interpretation. Future multicenter longitudinal studies integrating standardized SVC Doppler measurements with arterial indices and neonatal outcomes are needed to better define the clinical utility of venous Doppler in FGR surveillance (30-33). Overall, our data support the physiological and clinical relevance of SVC Doppler assessment in IUGR and reinforce the concept that venous hemodynamic markers provide meaningful complementary insight into fetal circulatory redistribution in placental insufficiency (28-33).

Conclusions

In conclusion, our findings indicate that SVC Doppler assessment provides meaningful complementary information on fetal hemodynamic adaptation in pregnancies complicated by IUGR. A significant proportion of IUGR fetuses demonstrated reduced SVC Doppler resistance, supporting the concept that venous parameters reflect central circulatory redistribution and altered cerebral venous return in response to placental insufficiency. These results suggest that functional SVC Doppler indices may be more sensitive than static measurements for detecting redistribution physiology. Therefore, integration of venous Doppler—particularly SVC evaluation—alongside established arterial Doppler parameters may improve the comprehensive assessment of fetal compromise. Larger prospective and longitudinal studies are warranted to standardize SVC Doppler measurements and clarify their prognostic value in obstetric and perinatal practice. This study did not include neonatal or perinatal outcome data; therefore, outcome-based validation of Doppler findings was not possible. In addition, Doppler measurements are inherently operator-dependent, which may introduce measurement variability despite the use of a standardized acquisition protocol.

Authors' Contribution
Conceptualization: Elnaz Afsari.
Data curation: Farrin Rajabzadeh.
Formal analysis: Leila Sahebi.
Investigation: Farrin Rajabzadeh.
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Project administration: Shabnam Vazifekhah.
Supervision: Shabnam Vazifekhah, Elnaz Afsari.
Validation: Shabnam Vazifekhah, Elnaz Afsari.
Visualization: Elnaz Afsari.
Writing–original draft: Farrin Rajabzadeh.

Writing–review & editing: Shabnam Vazifekhah, Elnaz Afsari, Farrin Rajabzadeh.

Conflict of Interests

Authors have no conflict of interest.

Ethical Issues

The Research Ethics Committee approved the study (Ref. IR.UMSU.REC 1404.412, approval date: 2025-12-13). Participants were consecutively selected for fetal growth assessment after providing written informed consent. Their information was kept ethically and legally confidential. All procedures, including ultrasound examinations, were performed in accordance with relevant guidelines and regulations. This study was reported in accordance with the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines.

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