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Original Article

Assessment of Umbilical Cord Doppler Indices at Placental Insertion, Abdominal Insertion and Free-Floating Region in 2nd Trimester

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ABSTRACT

Background: Umbilical artery Doppler ultrasonography is widely used to assess fetoplacental circulation, but measured Doppler indices may vary according to the anatomical sampling site along the umbilical cord. Objective: To compare umbilical artery pulsatility index, resistive index, and systolic/diastolic ratio measured at placental insertion, fetal abdominal insertion, and the free-floating region of the umbilical cord. Methods: This cross-sectional repeated-measures observational study included 68 pregnant women aged 18–38 years with gestational age ranging from 20 to 38 weeks. Doppler assessment was performed using a 3–5 MHz curvilinear transabdominal transducer with color and pulsed-wave Doppler. Pulsatility index, resistive index, and systolic/diastolic ratio were recorded at the placental insertion, fetal abdominal insertion, and free-floating cord region. Data were analyzed using descriptive statistics, Wilcoxon signed-rank tests for pairwise site comparisons, and Spearman correlation analysis. Results: The placental insertion site showed lower mean pulsatility index, resistive index, and systolic/diastolic ratio values than the abdominal insertion and free-floating regions. Pairwise comparisons showed significant differences between placental and abdominal sites and between placental and free-floating sites for all three indices ($p < 0.001$), while abdominal and free-floating measurements did not differ significantly. Matched Doppler indices showed strong positive correlations across sites. Conclusion: Umbilical artery Doppler values vary by cord sampling site, with lower resistance indices at placental insertion. Standardized documentation of sampling location is important for accurate Doppler interpretation. Keywords: Umbilical artery Doppler; pulsatility index; resistive index; systolic/diastolic ratio; placental insertion; abdominal insertion; free-floating cord; fetoplacental circulation.

INTRODUCTION

The umbilical cord is the principal vascular connection between the fetus and placenta and is essential for fetal oxygenation, nutrient transfer, and metabolic waste exchange throughout pregnancy. Structurally, it is composed of two umbilical arteries and one umbilical vein embedded within Wharton's jelly, a gelatinous connective tissue that protects the vessels from compression during fetal movement and uterine activity. Normal fetal growth depends on low-resistance umbilical arterial flow and adequate placental perfusion, while abnormalities of cord structure, placental insertion, or vascular resistance may contribute to fetal growth restriction, hypertensive pregnancy complications, preterm birth, and stillbirth (1).

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Assessment of fetoplacental circulation has therefore become an important component of obstetric ultrasound surveillance. Umbilical artery Doppler ultrasonography provides a non-invasive functional assessment of blood flow velocity and downstream placental resistance, complementing conventional grayscale imaging by allowing real-time evaluation of vascular hemodynamics. The most commonly used Doppler indices include the pulsatility index, resistive index, and systolic/diastolic ratio, each reflecting different aspects of vascular impedance within the fetoplacental circulation. Increased pulsatility index, resistive index, or systolic/diastolic ratio may indicate increased placental vascular resistance and has been associated with placental insufficiency and adverse perinatal outcomes, particularly in pregnancies complicated by fetal growth restriction or maternal disease (2–5).

Although umbilical artery Doppler assessment is widely used in clinical practice, the anatomical site at which the Doppler waveform is obtained may influence the measured values. Doppler sampling may be performed near the fetal abdominal insertion, at the placental insertion, or from a free-floating loop of the umbilical cord within the amniotic cavity. These regions are not necessarily hemodynamically identical. Measurements obtained near the placental insertion may more directly reflect placental vascular resistance, whereas measurements near the fetal abdominal insertion may be influenced by fetal circulatory dynamics. The free-floating segment is often technically convenient because it is easier to visualize and may be less affected by local insertion anatomy or external compression. However, if Doppler indices differ systematically across these locations, values obtained from different cord sites should not be interpreted interchangeably without considering the sampling site (6,7).

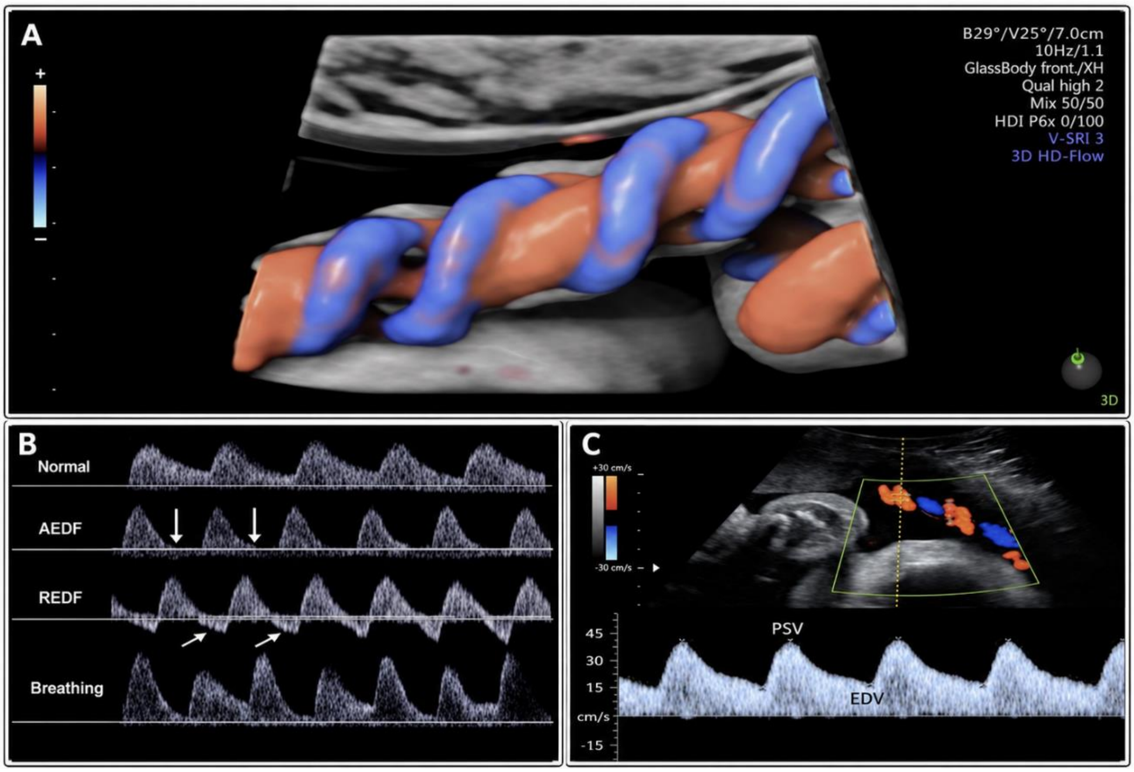

Figure 1 The panelled figure presents representative imaging features relevant to umbilical cord Doppler evaluation. Panel A shows a three-dimensional color Doppler/HD-flow ultrasound image of the umbilical cord, demonstrating the coiled vascular configuration with opposing color signals representing directional blood flow within the cord vessels. Panel B illustrates spectral Doppler waveform patterns used in fetal surveillance, including normal forward diastolic flow, absent end-diastolic flow (AEDF), reversed end-diastolic flow (REDF), and waveform variation associated with fetal breathing movements. Panel C demonstrates pulsed-wave Doppler assessment of the umbilical artery, with color Doppler localization of the vessel and spectral tracing showing peak systolic velocity (PSV) and end-diastolic velocity (EDV). Collectively, the figure highlights the anatomical visualization of umbilical cord vessels and the waveform characteristics used to assess fetoplacental circulation and vascular resistance.

Previous studies have shown that umbilical artery Doppler indices may vary along the length of the umbilical cord, with implications for standardization of obstetric Doppler protocols. This is clinically important because diagnostic interpretation often depends on comparison with reference ranges, and reference values may be misleading if the sampling location is not consistent. Strong correlation between measurements from different cord sites may preserve the relative ranking of patients, but clinically relevant differences in absolute values may still affect classification of vascular resistance. Therefore, site-specific evaluation is necessary to determine whether placental, abdominal, and free-floating measurements produce comparable Doppler values or require separate interpretive consideration (6–8).

Despite the established role of umbilical artery Doppler in fetal surveillance, limited local data are available regarding how pulsatility index, resistive index, and systolic/diastolic ratio differ across placental insertion, fetal abdominal insertion, and free-floating cord regions during mid-to-late pregnancy. This knowledge gap is particularly relevant in routine ultrasound settings, where sampling site may vary depending on fetal position, placental location, operator preference, and image quality. Clarifying whether these three sampling locations yield equivalent or systematically different values may improve Doppler standardization and reduce misclassification of fetoplacental vascular resistance.

The present study was therefore conducted to compare umbilical artery Doppler indices measured at the placental insertion, fetal abdominal insertion, and free-floating region of the umbilical cord among pregnant women between 20 and 38 weeks of gestation. The primary objective was to determine whether pulsatility index, resistive index, and systolic/diastolic ratio differ significantly across these three anatomical cord sites. The study hypothesized that umbilical artery Doppler indices would vary according to measurement site, with lower vascular resistance indices at the placental insertion compared with the abdominal and free-floating regions.

MATERIALS AND METHODS

This study was designed as a cross-sectional repeated-measures observational study to compare umbilical artery Doppler indices measured at three anatomical sites of the umbilical cord within the same pregnancy examination. The repeated-measures structure was selected because pulsatility index, resistive index, and systolic/diastolic ratio were assessed from the placental insertion, fetal abdominal insertion, and free-floating cord region in each participant, allowing within-subject comparison while reducing between-participant variability. The study was conducted in the gynecology and obstetric ultrasound unit of a private hospital over a three-month period after institutional approval.

Pregnant women attending the radiology or obstetric ultrasound department were recruited after assessment of eligibility and provision of written informed consent. Participants were eligible if they were aged 18 to 40 years, had a viable pregnancy between 20 and 38 weeks of gestation, and were able to undergo transabdominal Doppler ultrasound examination with adequate visualization of the umbilical cord. Pregnancies were excluded if they were complicated by maternal hypertension, preeclampsia, known fetal growth restriction, diagnosed fetal pathology, or technical limitations preventing reliable Doppler assessment at the required cord sites, including poor image quality, excessive fetal movement, or inability to obtain consistent waveforms. Fetal count was recorded as a baseline characteristic so that singleton and twin pregnancies could be described transparently and considered during interpretation of Doppler findings.

The sample consisted of 68 pregnant women. The sample size was determined according to the available study period, eligible ultrasound attendance, and feasibility of obtaining complete Doppler measurements at all three umbilical cord sites. Recruitment was performed among eligible women presenting during the study period, and demographic and obstetric information was recorded using a structured data collection proforma. Maternal age, gestational age, fetal count, previous Doppler assessment history, and Doppler indices at the three predefined cord sites were documented. Gestational age was determined from the available obstetric record and ultrasound assessment.

All Doppler assessments were performed using a real-time ultrasound machine equipped with grayscale imaging, color Doppler, pulsed-wave Doppler, and spectral Doppler capabilities. A curvilinear transabdominal transducer operating at 3–5 MHz was used for all examinations. Participants were positioned supine or in a slight left lateral tilt to maintain comfort and optimize visualization. A standard obstetric ultrasound assessment was initially performed to confirm fetal viability, assess gestational age, identify placental location, and visualize the umbilical cord. Color Doppler was then used to identify umbilical arterial flow before spectral Doppler sampling.

Umbilical artery Doppler waveforms were obtained from three anatomical regions: the fetal abdominal insertion, the placental insertion, and a free-floating loop of the umbilical cord within the amniotic cavity. At each site, the Doppler sample gate was placed over a single umbilical artery, avoiding areas of visible cord compression or excessive fetal motion. The insonation angle was maintained below 30 degrees where possible, and excessive transducer pressure was avoided. Measurements were obtained during relative fetal quiescence, and at least three consecutive uniform waveforms were recorded at each sampling site. The pulsatility index, resistive index, and systolic/diastolic ratio were calculated from the spectral Doppler waveform, and the recorded values were entered into the study proforma for analysis.

The primary outcome variables were the umbilical artery pulsatility index, resistive index, and systolic/diastolic ratio measured at the placental insertion, fetal abdominal insertion, and free-floating cord region. The main exposure variable was anatomical sampling site. Maternal age, gestational age, fetal count, and previous Doppler history were treated as descriptive variables and potential sources of variation. To reduce measurement bias, the Doppler protocol used predefined anatomical sampling sites, consistent transducer frequency, standardized waveform acquisition, avoidance of cord compression, and recording of repeated uniform waveforms before final measurement entry. Data integrity was supported through use of a structured proforma, direct entry of numerical values into the analysis sheet, and review of data for completeness and range plausibility before statistical analysis.

Data were analyzed using Statistical Package for the Social Sciences version 25. Continuous variables, including maternal age, gestational age, pulsatility index, resistive index, and systolic/diastolic ratio, were summarized as mean and standard deviation with minimum and maximum values. Categorical variables, including fetal count and history of previous Doppler assessment, were summarized as frequencies and percentages. Because Doppler indices were measured repeatedly across three anatomical sites within the same participants and the distributional assumptions for parametric repeated-measures analysis were not treated as established, site-wise comparisons were performed separately for each Doppler index using the Friedman test. Pairwise comparisons between placental insertion, fetal abdominal insertion, and free-floating region were performed using Wilcoxon signed-rank tests. Associations between matched Doppler indices across cord sites were assessed using Spearman rank correlation coefficients. A p-value below 0.05 was considered statistically significant, and very small p-values were reported as $p < 0.001$ rather than $p = 0.000$.

The study was conducted in accordance with institutional ethical requirements. Written informed consent was obtained from all participants before data collection. Participants were informed about the non-invasive nature of Doppler ultrasound assessment, voluntary participation, confidentiality of data, and their right to withdraw from the study at any stage. Personal identifiers were not used in the analysis dataset, and study records were stored securely with restricted access. The analysis was based on anonymized study data and reported in aggregate form only.

RESULTS

A total of 68 pregnant women were included in the final analysis. Maternal age ranged from 18 to 38 years, with a mean age of 27.63 ± 5.86 years. Gestational age ranged from 20 to 38 weeks, with a mean of 30.24 ± 4.38 weeks. Singleton pregnancies accounted for 58 cases (85.3%), while 10 pregnancies

(14.7%) were twin pregnancies. Previous Doppler assessment had been performed in 32 participants (47.1%), whereas 36 participants (52.9%) had no previous Doppler assessment.

Table 1. Baseline Maternal and Obstetric Characteristics of the Study Participants

Characteristic	Category/Unit	n	Value
Maternal age	years	68	27.63 ± 5.86
Maternal age	range, years	68	18–38
Gestational age	weeks	68	30.24 ± 4.38
Gestational age	range, weeks	68	20–38
Fetal count	Singleton	68	58 (85.3)
Fetal count	Twin	68	10 (14.7)
Previous Doppler assessment	No	68	36 (52.9)
Previous Doppler assessment	Yes	68	32 (47.1)

Values are presented as mean ± SD, range, or n (%).

The baseline profile showed that participants were predominantly singleton pregnancies, with twin pregnancies representing 14.7% of the sample. The mean gestational age was 30.24 weeks, indicating that the analyzed sample included pregnancies across a broad mid-to-late gestational range rather than a narrowly defined second-trimester population. Previous Doppler exposure was nearly evenly distributed between participants with and without prior Doppler assessment.

Table 2. Site-Specific Umbilical Artery Doppler Indices

Doppler index	Cord site	n	Mean ± SD	Minimum	Maximum	Mean difference vs placental	Difference vs placental, %
Pulsatility Index	Placental insertion	68	1.0219 ± 0.2121	0.59	1.37	0.0000	0.0
Pulsatility Index	Abdominal insertion	68	1.1188 ± 0.2097	0.70	1.43	0.0969	9.5
Pulsatility Index	Free-floating region	68	1.1249 ± 0.2176	0.67	1.48	0.1030	10.1
Resistive Index	Placental insertion	68	0.5782 ± 0.0809	0.42	0.71	0.0000	0.0
Resistive Index	Abdominal insertion	68	0.6265 ± 0.0767	0.49	0.75	0.0483	8.4
Resistive Index	Free-floating region	68	0.6300 ± 0.0775	0.45	0.78	0.0518	9.0
Systolic/Diastolic ratio	Placental insertion	68	2.8069 ± 0.6327	1.69	3.90	0.0000	0.0
Systolic/Diastolic ratio	Abdominal insertion	68	3.0585 ± 0.6227	1.92	4.07	0.2516	9.0
Systolic/Diastolic ratio	Free-floating region	68	3.0501 ± 0.6307	1.87	4.19	0.2432	8.7

Mean differences and percentage differences were calculated using the placental insertion mean as the reference value.

Umbilical artery Doppler indices showed a consistent anatomical gradient across cord sites. For all three indices, the lowest mean values were observed at the placental insertion. Compared with placental insertion, the abdominal insertion showed higher mean pulsatility index by 0.0969, resistive index by 0.0483, and systolic/diastolic ratio by 0.2516. The free-floating region showed a similar pattern, with mean values higher than placental insertion by 0.1030 for pulsatility index, 0.0518 for resistive index, and 0.2432 for systolic/diastolic ratio. The abdominal insertion and free-floating region had closely comparable mean values across all three Doppler indices.

Pairwise analysis confirmed that placental insertion measurements differed significantly from both abdominal insertion and free-floating region measurements for all three Doppler indices. Pulsatility index, resistive index, and systolic/diastolic ratio were all significantly different between placental and abdominal insertion sites, and between placental insertion and the free-floating region, with all p-values below 0.001. In contrast, abdominal insertion and free-floating region measurements did not differ significantly for pulsatility index, resistive index, or systolic/diastolic ratio.

Table 3. Pairwise Site Comparisons of Umbilical Artery Doppler Indices

Doppler index	Site comparison	Z	p-value
Pulsatility Index	Placental insertion vs abdominal insertion	-7.178	<0.001
Pulsatility Index	Placental insertion vs free-floating region	-7.173	<0.001
Pulsatility Index	Abdominal insertion vs free-floating region	-1.057	0.290
Resistive Index	Placental insertion vs abdominal insertion	-7.193	<0.001
Resistive Index	Placental insertion vs free-floating region	-7.032	<0.001
Resistive Index	Abdominal insertion vs free-floating region	-1.375	0.169
Systolic/Diastolic ratio	Placental insertion vs abdominal insertion	-7.170	<0.001
Systolic/Diastolic ratio	Placental insertion vs free-floating region	-6.999	<0.001
Systolic/Diastolic ratio	Abdominal insertion vs free-floating region	-0.541	0.589

Wilcoxon signed-rank test was used for pairwise repeated-measures comparisons.

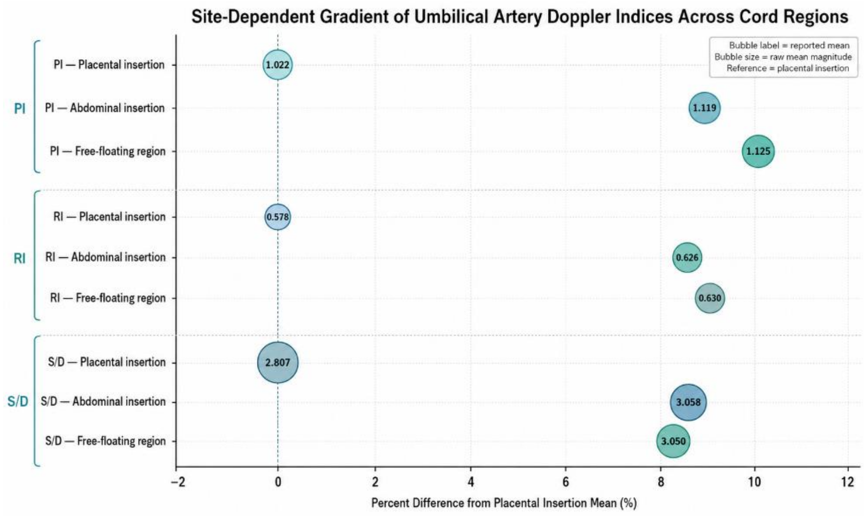

Figure 2 Site-Dependent Gradient of Umbilical Artery Doppler Indices Across Cord Regions

The figure demonstrates a consistent site-dependent Doppler gradient when placental insertion is used as the reference site. Mean pulsatility index increased from 1.0219 at the placental insertion to 1.1188 at the abdominal insertion and 1.1249 at the free-floating region, corresponding to approximate increases of 9.5% and 10.1%, respectively. Mean resistive index increased from 0.5782 at the placental insertion to 0.6265 at the abdominal insertion and 0.6300 at the free-floating region, representing approximate increases of 8.4% and 9.0%. The systolic/diastolic ratio showed a similar pattern, rising from 2.8069 at the placental insertion to 3.0585 at the abdominal insertion and 3.0501 at the free-floating region, with approximate increases of 9.0% and 8.7%. These gradients support the interpretation that placental insertion produces systematically lower Doppler resistance indices, whereas abdominal insertion and free-floating cord measurements remain closely aligned.

Table 4. Correlation of Matched Doppler Indices Across Umbilical Cord Sites

Doppler index	Site comparison	Spearman's ρ	p-value
Pulsatility Index	Abdominal insertion vs placental insertion	0.988	<0.001
Pulsatility Index	Abdominal insertion vs free-floating region	0.971	<0.001
Pulsatility Index	Placental insertion vs free-floating region	0.970	<0.001
Resistive Index	Abdominal insertion vs placental insertion	0.974	<0.001
Resistive Index	Abdominal insertion vs free-floating region	0.951	<0.001
Resistive Index	Placental insertion vs free-floating region	0.939	<0.001
Systolic/Diastolic ratio	Abdominal insertion vs placental insertion	0.985	<0.001
Systolic/Diastolic ratio	Abdominal insertion vs free-floating region	0.980	<0.001
Systolic/Diastolic ratio	Placental insertion vs free-floating region	0.973	<0.001

Matched Doppler indices showed very strong positive correlations across all cord sites. Pulsatility index correlations ranged from 0.970 to 0.988, resistive index correlations ranged from 0.939 to 0.974, and systolic/diastolic ratio correlations ranged from 0.973 to 0.985. These findings indicate that although absolute Doppler values varied by anatomical sampling site, participants with relatively higher or lower values at one cord site generally maintained similar rank ordering across the other sites.

Table 5. Summary of Site-Dependent Doppler Pattern

Doppler index	Lowest mean site	Abdominal vs free-floating p-value	Placental vs abdominal p-value	Placental vs free-floating p-value
Pulsatility Index	Placental insertion	0.290	<0.001	<0.001
Resistive Index	Placental insertion	0.169	<0.001	<0.001
Systolic/Diastolic ratio	Placental insertion	0.589	<0.001	<0.001

The overall pattern was consistent across pulsatility index, resistive index, and systolic/diastolic ratio. The placental insertion was the lowest-resistance site for all three indices, while abdominal insertion and free-floating cord measurements were statistically comparable. This indicates that the placental insertion should not be treated as interchangeable with the other two sites when interpreting absolute umbilical artery Doppler values, even though the strong correlations suggest that relative patient ranking is preserved across sampling locations.

DISCUSSION

This cross-sectional repeated-measures observational study compared umbilical artery Doppler indices at three anatomical sampling sites of the umbilical cord: placental insertion, fetal abdominal insertion, and the free-floating cord region. The principal finding was that Doppler indices differed according to sampling site, with the placental insertion consistently showing lower pulsatility index, resistive index, and systolic/diastolic ratio values than the abdominal insertion and free-floating region. This pattern indicates that the absolute magnitude of umbilical artery Doppler indices is influenced by the anatomical location of measurement, even when measurements are obtained within the same pregnancy examination. The finding is clinically relevant because umbilical artery Doppler interpretation depends on comparison with expected values, and non-standardized sampling sites may contribute to variation in the classification of fetoplacental vascular resistance.

The lower Doppler values observed at the placental insertion are physiologically plausible because this site is closest to the placental vascular bed, where progressive branching of fetal vessels and reduced downstream impedance may influence the waveform profile. In the present data, the mean pulsatility index was 1.0219 at the placental insertion compared with 1.1188 at the abdominal insertion and 1.1249 at the free-floating region. Similarly, the mean resistive index was 0.5782 at the placental insertion compared with 0.6265 and 0.6300 at the abdominal and free-floating sites, respectively, while the mean systolic/diastolic ratio was 2.8069 at the placental insertion compared with 3.0585 and 3.0501. These differences support the interpretation that the placental end of the cord may represent a lower-resistance measurement site than the other two cord regions. Similar site-dependent variation in umbilical artery Doppler indices has been reported previously, emphasizing that values recorded along different points of the cord may not be directly interchangeable (37).

The abdominal insertion and free-floating cord region showed closely comparable Doppler values, and pairwise analysis did not demonstrate statistically significant differences between these two sites for pulsatility index, resistive index, or systolic/diastolic ratio. This suggests that, in this sample, measurements obtained from the free-floating loop and fetal abdominal insertion had similar hemodynamic behavior. In practical scanning conditions, the free-floating cord segment is often easier to identify and sample, whereas the fetal abdominal insertion may be affected by fetal position and technical visualization limitations. The similarity between these two sites may therefore support the clinical use of free-floating cord measurements when abdominal insertion sampling is technically difficult, although this interpretation should remain cautious because the study did not assess diagnostic accuracy against fetal outcomes.

The study also demonstrated very strong positive correlations between matched Doppler indices across the three cord sites. Pulsatility index correlations ranged from 0.970 to 0.988, resistive index correlations ranged from 0.939 to 0.974, and systolic/diastolic ratio correlations ranged from 0.973 to 0.985. These findings indicate that participants with relatively higher or lower Doppler values at one site tended to maintain a similar relative ranking at other sites. However, strong correlation does not imply agreement or interchangeability. The absolute values still differed significantly between the placental insertion and the other two sites, meaning that a measurement taken at one site may not be directly substituted for another without considering the sampling location. This distinction is important for Doppler standardization and aligns with previous work describing the importance of reference ranges and consistent measurement protocols for umbilical artery Doppler interpretation (38,39).

The present findings should be interpreted in the context of the reported gestational age range. Although the original study title refers to the second trimester, the analyzed sample included pregnancies from 20 to 38 weeks of gestation, with a mean gestational age of 30.24 weeks. Because umbilical artery Doppler indices change with advancing gestation, the findings are more appropriately interpreted as reflecting mid-to-late pregnancy rather than a purely second-trimester population. This issue is methodologically important because gestational-age-specific reference values are required for clinical interpretation. Future analyses should either restrict the sample to a clearly defined gestational window or stratify results by gestational age group to determine whether the site-dependent gradient remains stable across pregnancy.

Another important consideration is the inclusion of twin pregnancies. The reported sample included 58 singleton and 10 twin pregnancies, although the initial eligibility criteria described inclusion of singleton pregnancies only. Twin pregnancies may differ from singleton pregnancies in placental structure, cord insertion patterns, and fetal hemodynamics, and their inclusion may influence Doppler distributions. The current results should therefore be interpreted as applying to the analyzed mixed sample unless a sensitivity analysis excluding twin pregnancies is performed. A refined analysis limited to singleton pregnancies would strengthen the validity of the findings and improve comparability with standard umbilical artery Doppler reference ranges.

The study has several limitations. First, the sample size was modest and recruited from a single private hospital, which may restrict generalizability. Second, the gestational age range was broad, and the analysis did not provide gestational-age-stratified results. Third, twin pregnancies were included in the results despite the intended singleton eligibility framework, creating a potential source of heterogeneity. Fourth, fetal and neonatal outcomes were not analyzed, so the study cannot determine whether site-specific Doppler differences improve prediction of placental insufficiency, fetal growth restriction, or adverse perinatal outcomes. Fifth, although the Doppler protocol described standardized waveform acquisition, the study did not report interobserver or intraobserver reliability, operator blinding, or machine-specific reproducibility checks. These limitations do not invalidate the observed site-dependent differences, but they restrict the extent to which the results can be translated into clinical reference standards.

Despite these limitations, the study contributes useful local evidence that anatomical sampling site affects umbilical artery Doppler values. The consistent reduction in pulsatility index, resistive index, and systolic/diastolic ratio at the placental insertion suggests that clinicians and researchers should document the sampling location when reporting umbilical artery Doppler measurements. The findings support the need for larger prospective studies with singleton-only analysis, gestational-age stratification, standardized Doppler acquisition, reproducibility assessment, and linkage with fetal growth and perinatal outcomes. Such studies would help determine whether site-specific interpretation improves diagnostic accuracy and clinical decision-making in fetal surveillance.

CONCLUSION

Umbilical artery Doppler indices varied according to the anatomical site of measurement along the umbilical cord in this cross-sectional repeated-measures observational study. The placental insertion site showed consistently lower pulsatility index, resistive index, and systolic/diastolic ratio values than the fetal abdominal insertion and free-floating cord region, while abdominal and free-floating measurements were closely comparable. Strong positive correlations across sites indicated preserved relative ranking of Doppler values, but the significant absolute differences confirm that sampling sites should not be treated as fully interchangeable. These findings emphasize the importance of standardized documentation of Doppler sampling location during obstetric ultrasound and support further gestational-age-stratified and outcome-linked studies before site-specific reference ranges can be recommended for routine clinical practice.

REFERENCES

1. Hammad IA, Blue NR, Allshouse AA, Silver RM, Gibbins KJ, Page JM, et al. Umbilical cord abnormalities and stillbirth. Obstet Gynecol. 2020;135(3):644-52.

2. Anuk AT, Tanacan A, Yetiskin FD, Buyuk GN, Senel SA, Keskin HL, et al. Doppler assessment of the fetus in pregnant women recovered from COVID-19. J Obstet Gynaecol Res. 2021;47(5):1757-62.

3. Buca D, Rizzo G, Gustapane S, Mappa I, Leombroni M, Bascietto F, et al. Diagnostic accuracy of Doppler ultrasound in predicting perinatal outcome in appropriate for gestational age fetuses: a prospective study. Ultraschall Med. 2021;42(4):404-10.

4. Kale RM, Tirupathi RG, Sheela S, Kale M. Role of ultrasonography and color Doppler in the assessment of high-risk pregnancies and their accuracy in predicting fetal outcome. Cureus. 2023;15(5).

5. Moraitis AA, Bainton T, Sovio U, Brocklehurst P, Heazell AE, Thornton JG, et al. Fetal umbilical artery Doppler as a tool for universal third trimester screening: a systematic review and meta-analysis of diagnostic test accuracy. Placenta. 2021;108:47-54.

6. Khare M, Paul S, Konje JC. Variation in Doppler indices along the length of the cord from the intraabdominal to the placental insertion. Acta Obstet Gynecol Scand. 2006;85(8):922-8.

7. Acharya G, Wilsgaard T, Berntsen GK, Maltau JM, Kiserud T. Reference ranges for serial measurements of umbilical artery Doppler indices in the second half of pregnancy. Am J Obstet Gynecol. 2005;192(3):937-44.

8. Degani S. Doppler flow velocity waveforms in the fetal and maternal circulations. Semin Perinatol. 2001;25(4):260-72.

9. Ayhan SG, Tanacan A, Atalay A, Sinaci S, Tokalioglu EO, Sahin D, et al. Assessment of fetal Doppler parameters in pregnant women with COVID-19 infection: a prospective case-control study. J Perinat Med. 2021;49(6):697-701.

10. Anantaworapot A, Puttanavijarn L. Difference between paired umbilical arteries Doppler velocimetry indices in singleton pregnancy. Thai J Obstet Gynaecol. 2024:429-39.

11. Brahmandam G, Lipsett B. Anatomy, abdomen and pelvis: umbilical cord. StatPearls. 2025.

12. Choi YJ, Lee HK, Kim SK. Doppler ultrasound investigation of female infertility. Obstet Gynecol Sci. 2023;66(2):58-68.

13. Chen J, Wu L, Ye L, Hong Y, Li Z, Wu X. Alterations in maternal arterial stiffness and maternal and fetal Doppler measurements in pregnancy complicated by fetal growth restriction. BMC Pregnancy Childbirth. 2025;25(1):1235.

14. Drukker L, Droste R, Ioannou C, Impey L, Noble JA, Papageorghiou AT. Function and safety of SlowflowHD ultrasound Doppler in obstetrics. Ultrasound Med Biol. 2022;48(6):1157-62.

15. Gomes De Melo Tavares Ferreira A. An evaluation of the physiological variability inherent in common maternal-fetal Doppler parameters. Sydney: UNSW Sydney; 2021.

16. He X, Yang F, Zhang K. The efficacy of different ultrasound Doppler parameters in predicting adverse fetal outcomes in pregnancies with hypertensive disorders: a systematic review and meta-analysis. Quant Imaging Med Surg. 2026;16(3):243.

17. Ismail KI, Hannigan A, O'Donoghue K, Cotter A. Role of 2-dimensional ultrasound imaging in placental and umbilical cord morphometry: literature and pictorial review. J Ultrasound Med. 2019;38(12):3131-40.

18. Jabaz D, Abed M. Sonography 2nd trimester assessment, protocols, and interpretation. 2021.

19. Jasani B, Torgalkar R, Ye XY, Syed S, Shah PS. Association of umbilical cord management strategies with outcomes of preterm infants: a systematic review and network meta-analysis. JAMA Pediatr. 2021;175(4):e210102.

20. Kuckian P, Mahendru AA. Doppler ultrasound in obstetrics. Obstet Gynaecol Reprod Med. 2021;31(12):327-34.

21. Kalluru PKR, Kalluru HR, Allagadda TR, Talur M, Gonepogu MC, Gupta S. Abnormal umbilical cord coiling and association with pregnancy factors. J Turk Ger Gynecol Assoc. 2024;25(1):44.

22. Kindwall-Keller TL, Ballen KK. Umbilical cord blood: the promise and the uncertainty. Stem Cells Transl Med. 2020;9(10):1153-62.

23. Kaplan CG. Anatomy and pathology of the umbilical cord. In: Benirschke's Pathology of the Human Placenta. Cham: Springer; 2021. p. 345-402.

24. Lin X, Liu LL, Zheng LJ, Yang CY. Evaluation of Doppler indices (MCA & UA) and fetal outcomes: a retrospective case-control study in women with hypertensive disorders of pregnancy. J Matern Fetal Neonatal Med. 2023;36(1):2183471.

25. Medjedovic E, Kurjak A. The importance of Doppler analysis of uterine circulation in pregnancy for a better understanding of preeclampsia. Med Arch. 2021;75(6):424.

26. Ochoa JH, Cafici D. Fetal Doppler assessment in pregnancy. Best Pract Res Clin Obstet Gynaecol. 2025;100:102594.

27. Pinette MG, Tropepe M. Umbilical cord abnormalities. Clin Obstet Gynecol. 2025;68(1):111-8.

28. Perkovic-Kepeci S, Cirkovic A, Milic N, Dugalic S, Stanisavljevic D, Milincic M, et al. Doppler indices of the uterine, umbilical and fetal middle cerebral artery in diabetic versus non-diabetic pregnancy: systematic review and meta-analysis. Medicina. 2023;59(8):1502.

29. Patil S. Role of Doppler indices in the prediction of adverse perinatal outcome in preeclampsia: a case series study. Bengaluru: Rajiv Gandhi University of Health Sciences; 2018.

30. Shi L, Huang L, Liu L, Yang X, Yao D, Chen D, et al. Diagnostic value of transvaginal three-dimensional ultrasound combined with color Doppler ultrasound for early cesarean scar pregnancy. Ann Palliat Med. 2021;10(10):10486-94.

31. Sadiq R, Latif M, Tauqir J, Ali N, Butt SA, Haider Z, et al. Comparison of Doppler sampling locations in the umbilical artery for detecting fetal growth restriction. Imaging. 2025;17(1):57-65.

32. Sánchez-Trujillo L, García-Montero C, Fraile-Martinez O, Guijarro LG, Bravo C, De Leon-Luis JA, et al. Considering the effects and maternofoetal implications of vascular disorders and the umbilical cord. Medicina. 2022;58(12):1754.

33. Sherer DM, Al-Haddad S, Cheng R, Dalloul M. Current perspectives of prenatal sonography of umbilical cord morphology. Int J Womens Health. 2021;13:939-71.

34. Tonni G, Lituania M, Grisolia G, Pinto A, Bonasoni MP, Rizzo G, et al. Placental and umbilical cord anomalies detected by ultrasound as clinical risk factors of adverse perinatal outcome: case series review of selected conditions. Part 2: umbilical cord abnormalities. J Clin Ultrasound. 2025;53(4):832-62.

35. Turan S, Bucak M, Turan OM. Arterial and venous Doppler in evaluation of the “at-risk” fetus. Clin Obstet Gynecol. 2024;67(4):721-9.

36. Tian Y, Yang X. A review of roles of uterine artery Doppler in pregnancy complications. Front Med. 2022;9:813343.

37. Rabe H, Mercer J, Erickson-Owens D. What does the evidence tell us? Revisiting optimal cord management at the time of birth. Eur J Pediatr. 2022;181(5):1797-807.

38. Rane BM, Malau-Aduli BS, Alele F, O'Brien C. Prognostic accuracy of antenatal Doppler ultrasound measures in predicting adverse perinatal outcomes for pregnancies complicated by diabetes: a systematic review. AJOG Glob Rep. 2023;3(3):100241.

39. Tarygina TA, Gasanova RM, Marzoeva OV, Sypchenko EV, Leonova EI, Lyapin VM, et al. Anatomical pathology of the umbilical cord in cases of fetal congenital heart disease. Obstet Gynecol. 2024;(8):48-57.