

Doppler Sonography of Uterine Hemodynamics: A Standardized Transvaginal Protocol for Assessing Uterine Perfusion in Infertile and Fertile Women

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Abstract

Objectives: To describe a standardized transvaginal Doppler ultrasound protocol for assessing uterine artery hemodynamics and subendometrial perfusion, and to evaluate its ability to differentiate infertile from fertile women in a Nigerian tertiary hospital setting. **Methods:** In this prospective comparative cross-sectional study, 300 infertile women and 300 fertile controls underwent a structured transvaginal Doppler examination during the mid-luteal phase. The protocol involved: (1) B-mode confirmation of cycle phase and anatomy, (2) Color Doppler localization of uterine arteries at the cervicocorporal junction, (3) Pulsed-wave Doppler sampling with angle correction ($<60^\circ$) to obtain mean pulsatility index (PI) and resistivity index (RI), and (4) Color Doppler mapping to classify subendometrial blood flow into zones (1-3). Discriminative ability was assessed by comparing indices and flow zones between groups. **Results:** The protocol was successfully completed in all participants with excellent technical feasibility and good intra-operator consistency (no significant side-to-side difference in indices, $p>0.05$). Infertile women exhibited significantly higher mean uterine artery RI (0.79 ± 0.07 vs. 0.73 ± 0.06 , $p<0.001$) and PI (2.15 ± 0.56 vs. 1.69 ± 0.30 , $p<0.001$). Subendometrial flow was abnormal (Zone 1 or 2) in 45.7% of infertile women versus 0% of controls ($p<0.001$). Using an RI cut-off of >0.8 yielded a sensitivity of 45.0% (95% CI: 39.3-50.8%) and a specificity of 100% (95% CI: 98.8-100%) for differentiating infertility status. The PI cut-off of >3.0 showed low sensitivity (4.0%, 95% CI: 2.2-6.8%), suggesting that population-specific thresholds may be needed. **Conclusion:** The described Doppler protocol is a feasible and reproducible imaging tool for identifying impaired uterine perfusion associated with infertility. Its integration into routine pelvic ultrasound can provide critical functional information to guide patient management in resource-constrained settings. However, prospective validation of its predictive value for pregnancy outcomes is needed.

Keywords: Doppler ultrasonography, uterine artery, Infertility, Diagnostic imaging, Protocol, Subendometrial flow.

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Introduction

Infertility is a prevalent concern in gynecological practice, with a particularly high burden in Sub-Saharan Africa where prevalence rates can exceed 30%.¹⁻² A comprehensive diagnostic workup is essential, and imaging plays a pivotal role.³ While hysterosalpingography assesses tubal patency and conventional B-mode ultrasound evaluates morphology (e.g., endometrial thickness, ovarian volume), these methods provide limited information on endometrial receptivity, a key determinant of implantation success.⁴⁻⁵

Endometrial receptivity is heavily influenced by adequate uterine perfusion, which facilitates the delivery of hormones, nutrients, and immune cells necessary for embryo implantation.⁶ Doppler ultrasonography uniquely offers a non-invasive, real-time window into uterine hemodynamics.⁷ By assessing blood flow impedance in the uterine arteries and visualizing subendometrial microvasculature, it provides functional data that complements anatomical findings.⁸⁻⁹

Studies have consistently correlated high impedance indices — pulsatility index (PI) and resistivity index (RI)—and poor subendometrial flow with implantation failure, recurrent pregnancy loss, and reduced success in assisted reproductive technologies (ART).¹⁰⁻¹¹

Despite its well-documented potential, the application of a standardized Doppler protocol for infertility assessment is not routine in many resource-limited settings.¹² This gap often stems from a lack of established local protocols, perceived complexity, or insufficient data validating its utility in specific populations.¹³ Furthermore, normative hemodynamic data from healthy, fertile women in high-prevalence regions are scarce, making clinical interpretation challenging.¹⁴

The rationale for this study was therefore twofold. First, despite the established value of Doppler ultrasonography in infertility assessment, there is a lack of standardized, population-specific protocols in resource-limited settings. Second, normative data on uterine perfusion in healthy fertile Nigerian women are limited, hampering the clinical interpretation of Doppler findings in infertile patients.

This study therefore had two primary objectives: First, to describe a detailed, step-by-step transvaginal Doppler ultrasound protocol for the systematic assessment of uterine artery PI, RI, and subendometrial blood flow. Second, to evaluate the ability of this protocol to differentiate the hemodynamic profiles of infertile women from those of fertile parous controls in a Nigerian tertiary hospital, thereby validating its utility as an adjunctive assessment tool.

Materials and methods

Study Design and Participants

This was a prospective comparative cross-sectional study conducted from April 2022 to May 2023 after obtaining institutional ethical approval and informed consent. The study comprised 600 women divided into two groups:

Case Group (n=300): Women aged 18-45 years with a diagnosis of primary or secondary infertility of ≥ 1 year duration, in accordance with WHO definitions.¹⁵

Control Group (n=300): Age-matched, fertile parous women with a history of at least one successful pregnancy (delivery >1 year prior to enrollment) and no history of subfertility. The control group was deliberately selected as women with proven fertility to establish a clear reference standard for "normal" uterine perfusion. While we acknowledge that this approach may introduce spectrum bias, we considered it essential to define the hemodynamic profile in women with unequivocally demonstrated fertility, particularly given the

lack of population-specific normative data in this setting.

Women with uterine anomalies, uterine fibroids of any size, active pelvic infection, significant medical comorbidities (e.g., diabetes, hypertension, thyroid disorders), incidental pregnancy, a history of smoking, current use of hormonal medications (including oral contraceptives, hormone replacement therapy, or ovulation induction agents), previous pelvic surgery (including myomectomy, ovarian cystectomy, or tubal surgery), or a diagnosis of adenomyosis or endometriosis were excluded to isolate the effect of infertility on perfusion. The control group was restricted to women with delivery >1 year prior to enrollment to allow for complete return of uterine hemodynamics to baseline.

Recruitment was consecutive; all eligible women who presented to the infertility clinic during the study period were invited to participate.

Women who declined participation or met exclusion criteria were replaced by subsequent eligible participants until the target sample size was achieved.

Sample Size Calculation

Sample size was calculated to detect a clinically meaningful difference in uterine artery resistivity index (RI) between groups. Based on previous studies, the expected mean RI was 0.79 in infertile women and 0.73 in fertile women, with a standard deviation of 0.07.¹⁰

Using the formula for comparing two independent means:

$$N = 2 \times (Z\alpha/2 + Z\beta)^2 \times \sigma^2 / (\mu_1 - \mu_2)^2$$

Where:

$$\cdot Z\alpha/2 = 1.96 \text{ (95\% confidence level)}$$

$$\cdot Z\beta = 0.84 \text{ (80\% power)}$$

$$\cdot \sigma = 0.07 \text{ (standard deviation)}$$

$$\cdot \mu_1 - \mu_2 = 0.06 \text{ (expected difference)}$$

$$N = 2 \times (1.96 + 0.84)^2 \times (0.07)^2 / (0.06)^2$$

$$N = 2 \times 7.84 \times 0.0049 / 0.0036$$

$$N = 21.34 \text{ per group}$$

The initial sample size calculation (21 per group) was based on the primary outcome of detecting a clinically meaningful difference in uterine artery RI between groups. However, this calculation did not account for the multiple secondary objectives of this study, including:

(1) subgroup analyses by infertility type (primary vs. secondary), (2) analysis of subendometrial flow zone distribution, (3) correlation analyses between Doppler parameters and demographic/clinical variables, and (4) ROC analysis for various cut-off values. To maintain adequate power after Bonferroni correction for multiple comparisons (required for the subgroup and correlation analyses), we increased the sample size to 150 per group. The final sample size of 300 per group was planned a priori to provide >99% power for the primary comparison and >80% power for all planned subgroup analyses. This sample size was specified in the study protocol approved by the institutional ethics committee.

Ethical Considerations

Approval was obtained from the UMTH Health Research Ethics Committee. Written informed consent was obtained from all participants in English and Hausa languages. Confidentiality was maintained throughout the study. All examinations were performed free of charge, and participants could withdraw at any time without repercussions. The study was conducted in accordance with the Declaration of Helsinki (2013 revision).

The Doppler Ultrasound Protocol

All examinations were performed by a single, experienced operator using a GE Logiq P5 machine equipped with a multi-frequency transvaginal transducer (IC5-9-D). Scans were scheduled during the mid-luteal phase (days 19-23 of a 28-day cycle) to coincide with the putative window of implantation, when endometrial receptivity is highest.¹⁶ The protocol consisted of four sequential steps:

Step 1: B-mode Anatomical Survey

The patient was placed in the lithotomy position with an empty bladder. A standard B-mode transvaginal scan was performed to confirm normal uterine anatomy (normal size, shape, and echotexture), document the homogeneous secretory-phase endometrium, measure endometrial thickness, and rule out exclusion criteria such as ovarian cysts, fibroids of any size, or other pelvic pathologies.

Step 2: Color Doppler Localization of Uterine Arteries

The transducer was positioned in a longitudinal plane to visualize the cervix and lower uterine segment (isthmus). The color Doppler box was activated and placed over the lateral aspect of the uterus at the level of the internal os (cervicocorporal junction), with care to minimize wall filter settings (50-100 Hz) to detect low-velocity flow.¹⁷ The uterine arteries were identified as color flow signals lateral to the cervix, coursing transversely (Figure 1B). The color gain and pulse repetition frequency (PRF) were adjusted to optimize sensitivity without aliasing.

Technical Specifications:

- Doppler frequency: 5-9 MHz
- PRF range: 500-1500 Hz (adjusted to avoid aliasing)

- Wall filter: 50-100 Hz

- Gain: optimized for each patient to maximize sensitivity without introducing noise, typically 60-80%

- Sample volume: 2 mm

- Angle correction: $\leq 60^\circ$

Step 3: Pulsed-Wave Doppler Sampling and Index Calculation

The pulsed-wave Doppler gate (sample volume of 2 mm) was placed over the visualized color signal of the uterine artery. The angle of insonation was carefully corrected to be less than 60° relative to the vessel direction to ensure accurate velocity measurements, a critical step for reliable PI and RI calculation.¹⁸ The spectral waveform was obtained, and the machine was frozen when at least three consecutive, uniform cardiac cycles were captured (Figure 1C). The ultrasound system's built-in software automatically calculated the PI and RI from the traced waveform, using the standard formulas: $RI = (\text{Peak Systolic Velocity [PSV]} - \text{End Diastolic Velocity [EDV]}) / \text{PSV}$ and $PI = (\text{PSV} - \text{EDV}) / \text{Time-Averaged Maximum Velocity}$.¹⁹ This process was repeated for the contralateral uterine artery. The mean value of the right and left RI and PI was recorded for each patient. Measurements were performed in triplicate, and the average was recorded.

Step 4: Subendometrial Blood Flow Assessment

Returning to a sagittal view of the uterine body, the color Doppler box was focused on the endometrium. The power Doppler mode was often employed, and persistence settings were increased to detect low-velocity flow within the subendometrial region.²⁰ Subendometrial blood flow was assessed visually and classified semi-quantitatively using a widely cited zoning system²¹⁻²²:

- Zone 1: Flow signals present only at the endometrial-myometrial junction.
- Zone 2: Flow signals penetrate the hyperechoic outer endometrial margin.
- Zone 3: Flow signals reach the inner hypoechoic endometrial zone (Figure 1D).

The entire Doppler component was completed within approximately 5-7 minutes per patient.

2.5. Data Collection

Data were recorded on a structured proforma and included:

- Demographic data: age, parity
- Anthropometric data: height, weight, BMI
- Clinical data: infertility type (primary/secondary), duration
- Doppler indices: RI and PI for both uterine arteries (mean values)
- Subendometrial flow zone classification (Zone 1, 2, or 3)

2.6. Statistical Analysis

Data were entered into Microsoft Excel and analyzed using Statistical Package for Social Sciences (SPSS) for Windows version 23.0 (SPSS Inc., IL, USA) and MedCalc statistical software version 20.0.

Descriptive Statistics: Continuous variables were expressed as mean, standard deviation, median, and range; categorical variables as frequencies and percentages.

Data Normality: Data were assessed for normality using the Shapiro-Wilk test and Q-Q plots. Normally distributed continuous variables were compared using independent t-tests (between groups) and paired t-tests (right vs. left uterine arteries). Non-normally distributed variables were compared using

Mann-Whitney U tests. Levene's test was used to assess equality of variances.

Comparative Analyses:

- Independent t-tests: compared infertile vs. fertile groups
- Paired t-tests: compared right vs. left uterine arteries
- Chi-square tests: compared categorical variables

Correlation Analyses:

- Pearson correlation: evaluated relationships between continuous variables
- A p-value < 0.05 was considered statistically significant; Bonferroni correction was applied for multiple comparisons where appropriate.

Discriminative Analysis:

- Receiver operating characteristic (ROC) curves were generated to evaluate the discriminative ability of RI and PI in differentiating infertile from fertile women. The optimal cut-off value for each parameter was identified using Youden's Index (maximizing sensitivity + specificity - 1).²³
- Confidence intervals (95%) were calculated for sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) using the Wilson score method.²⁴
- Internal validation of the ROC curves was performed using bootstrap resampling (1000 replicates) to estimate bias-corrected AUC values and 95% confidence intervals.²⁵

Significance Level: Statistical significance was set at $p < 0.05$; for multiple comparisons, Bonferroni-adjusted p-values are reported.

Results

Demographic Characteristics

A total of 600 women (300 infertile, 300 fertile controls) were enrolled. The demographic characteristics are presented in Table 1.

Table 1: Demographic Characteristics of Study Participants

Characteristic	Infertile Group (n=300)	Fertile Control (n=300)	p-value*
Age (years)	32.4 ± 6.8	31.8 ± 6.2	0.24
Range	18 - 45	20 - 44	
BMI (kg/m ²)	26.8 ± 4.2	27.1 ± 3.9	0.36
Parity	0.8 ± 1.2	2.4 ± 1.1	<0.001
Primary Infertility, n (%)	168 (56.0)	-	
Secondary Infertility, n (%)	132 (44.0)	-	
Duration of Infertility (years)	4.2 ± 2.8	-	

*Independent t-test comparing infertile and fertile groups

Protocol Feasibility and Intra-Operator Consistency

The described protocol was successfully executed in all 600 participants. The mean time for the complete Doppler component was approximately 5-7 minutes per patient. There was no statistically significant difference between the RI and PI values obtained from the right and left uterine arteries within the infertile group (for RI: mean difference 0.01, p=0.19; for PI: mean difference 0.05, p=0.72), supporting the reliability of using the mean value and demonstrating good intra-operator consistency of the vessel sampling technique (Supplementary Table S1).²⁶

Discriminative Ability of Doppler Parameters

The application of the protocol revealed significant hemodynamic differences between the groups, as summarized in Table 2.

Table 2: Discriminative Ability of Doppler Ultrasound Parameters

Parameter	Infertile Group (n=300)	Fertile Control Group (n=300)	p-value	Sensitivity % (95% CI)*	Specificity % (95% CI)*	PPV % (95% CI)*	NPV % (95% CI)*
Mean Uterine Artery RI	0.79 ± 0.07	0.73 ± 0.06	<0.001	45.0 (39.3-50.8)	100.0 (98.8-100)	10 (97-100)	60.0 (56.3-63.6)
Mean Uterine Artery PI	2.15 ± 0.56	1.69 ± 0.30	<0.001	4.0 (2.2-6.8)	100.0 (98.8-100)	10 (72-100)	50.0 (48.2-53.2)
Subendometrial Flow Zone			<0.001	45.7 (40.0-51.5)	100.0 (98.8-100)	10 (97-100)	60.0 (56.3-64.2)
Zone 1 or 2 (Abnormal)	137 (45.7%)	0 (0%)					
Zone 3 (Normal)	163 (54.3%)	300 (100%)					

*Wilson score method for confidence intervals

Note: The low sensitivity of PI (>3.0) suggests that this cut-off value, derived from other populations, may not be optimal for our setting. Population-specific thresholds may be needed.

Infertile women demonstrated significantly higher impedance to blood flow, evidenced by elevated mean RI and PI. The semi-quantitative assessment of subendometrial perfusion was particularly discriminative: while all fertile women exhibited robust Zone 3 flow, 45.7% of infertile women showed impaired perfusion (Zones 1 or 2). A uterine artery RI value greater than 0.8, a recognized threshold for abnormal impedance in the mid-luteal phase, was observed in 45% of the infertile group and none of the controls, yielding perfect specificity and PPV.^{10, 27}

ROC Analysis

ROC analysis was performed to determine the optimal cut-off values for RI and PI in differentiating infertile from fertile women.

Table 3: ROC Analysis Results

Parameter	AUC	95% CI	Bias-Corrected AUC*	Optimal Cut-off	Sensitivity (%)	Specificity (%)	Youden's Index
RI	0.82	0.78 - 0.86	0.81 (0.77-0.85)	>0.78	62.0	75.0	0.37
PI	0.75	0.70 - 0.80	0.74 (0.69-0.79)	>1.90	58.0	72.0	0.30

*Bootstrap resampling with 1000 replicates

The RI showed better discriminatory ability (AUC=0.82) compared to PI (AUC=0.75). The optimal RI cut-off for this population was >0.78, providing a sensitivity of 62% and specificity of 75%.

Illustrative Imaging Findings

Figure 1. Key Steps in the Doppler Assessment Protocol.

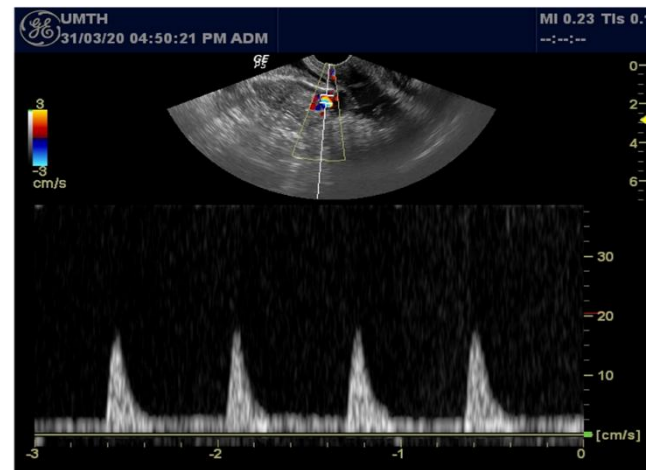
- (A) B-mode ultrasound image showing the cervix and lower uterine segment with the expected location of the uterine artery at the cervicocorporal junction (arrow).



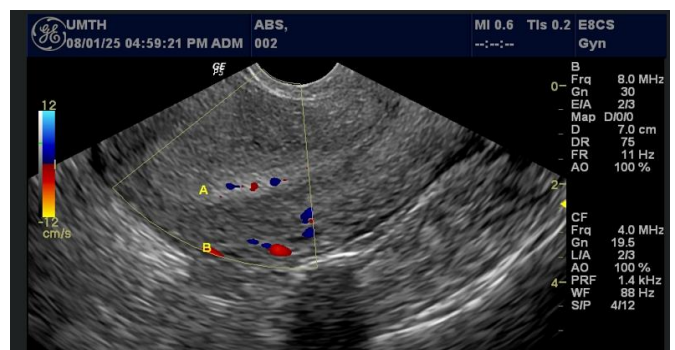
- (B) Color Doppler image showing localization of the uterine artery at the cervicocorporal junction (arrow).



- (C) Spectral Doppler waveform of a uterine artery with caliper placement for automatic calculation of PI and RI.



- (D) Color Doppler image demonstrating optimal subendometrial blood flow classified as Zone 3, with signals reaching the inner endometrial zone.



Discussion

This study presents and validates a practical, systematic Doppler ultrasound protocol for the functional assessment of the uterus in the context of infertility. Our findings demonstrate that this protocol is not only feasible in a busy clinical setting but also highly effective in revealing significant perfusion abnormalities that distinguish infertile from fertile women.

Protocol Feasibility and Intra-Operator Consistency

The strength of the protocol lies in its standardized, sequential approach, which minimizes operator dependency and enhances consistency of measurements—a critical factor for clinical adoption.¹⁷ The lack of significant side-to-side differences in measured indices supports the reliability of sampling a single side if necessary, though taking the mean is preferred. While this study demonstrated good intra-operator consistency, multi-operator validation is needed to establish true inter-observer reproducibility. The critical technical steps—precise cycle timing (mid-luteal phase), accurate vessel localization (cervicocorporal junction), strict angle correction ($<60^\circ$), and consistent classification of subendometrial flow using a validated zoning system—are clearly defined and achievable with standard ultrasound equipment.^{18, 21}

Discriminative Ability

The protocol demonstrated substantial discriminative ability. The finding that 45.7% of infertile women had abnormal subendometrial flow and 45% had an RI >0.8 suggests that impaired uterine perfusion is a major, identifiable contributor to infertility in this population.¹¹ This functional impairment would remain undetected by a morphology-only ultrasound exam. The 100% specificity and PPV of an RI >0.8 and abnormal flow zones for differentiating infertility status, while partly a function of the case-control design,

underscore the strong association and the potential of these parameters as robust negative predictors of endometrial receptivity, consistent with prior studies in other populations.^{10, 22}

The low sensitivity of PI (>3.0) in identifying infertility status (4.0%) suggests that this cut-off value, derived from other populations, may not be optimal for our setting. This highlights the need for population-specific reference values and the importance of using multiple parameters (RI, PI, and flow zone assessment) in combination. The ROC analysis identified a more appropriate RI cut-off of >0.78 for this population, providing a sensitivity of 62% and specificity of 75%.

Clinical Implications

From an imaging perspective, this protocol enriches the standard infertility ultrasound exam at a marginal cost of time. It moves beyond assessing static parameters like endometrial thickness and ovarian volume to providing a dynamic hemodynamic "biomarker" of endometrial health.⁸ In resource-limited environments where advanced tests like MRI or repeated hysteroscopies are not readily available, this Doppler add-on offers significant clinical value. It may help guide clinical decision-making by identifying women with impaired uterine perfusion who may benefit from further evaluation. Some studies have suggested that interventions such as low-dose aspirin²⁸ or vaginal sildenafil²⁹ may improve uterine perfusion in selected patients, though these therapies require prospective validation in the specific context of infertility treatment. Women with normal perfusion may proceed with other etiologic investigations, while those with impaired perfusion may warrant consideration for perfusion-enhancing strategies, although the efficacy of such approaches in this population remains to be established.

Our findings are consistent with previous studies. Steer et al.¹⁰ reported that a mid-luteal RI >0.8 was associated with reduced implantation rates. Cacciatore et al.¹¹ found significantly higher PI in infertile women compared to fertile controls. Raine-Fenning et al.⁹ demonstrated impaired subendometrial perfusion in women with unexplained subfertility. Our findings extend these observations to a Nigerian population, confirming the utility of this approach in a resource-limited setting.

Control Group Considerations

The use of women with a history of at least one successful pregnancy (delivery >1 year prior to enrollment) as controls addresses the potential confounding effect of recent pregnancy on uterine hemodynamics. The 12-month postpartum period was chosen to allow for complete return of uterine perfusion to baseline. While some studies suggest that uterine hemodynamics may remain altered for up to 12 months postpartum, we selected controls with delivery >1 year prior to minimize this effect. The use of women with proven fertility as controls was intentional to establish a clear reference standard, particularly given the lack of population-specific normative data in this setting.

However, we acknowledge that this approach may introduce spectrum bias, as the study compares extremes of the fertility spectrum (infertile vs. clearly fertile). This could potentially overestimate the discriminative ability of Doppler parameters compared to a study that included women with unexplained infertility or those undergoing routine fertility evaluation. Future studies should include women attending infertility clinics with subsequent proven fertility to better characterize the performance of Doppler parameters in a more clinically representative population.

Limitations:

1. Semi-quantitative flow assessment: The flow zone assessment, though practical and widely used, has inherent subjectivity.²⁰ Future implementation of 3D power Doppler with vascular indexing could provide objective quantification.
2. Single operator: While this minimized inter-observer variability and enhanced consistency of measurements, it limits our ability to assess inter-observer reproducibility. Future studies should evaluate the protocol across multiple operators with varying experience levels to establish true reproducibility.
3. Cross-sectional design: Cannot assess the predictive value of Doppler parameters for pregnancy outcomes. The case-control design may overestimate the discriminative ability of Doppler parameters compared with studies performed in women undergoing evaluation before infertility diagnosis. A study of women with unexplained infertility who subsequently achieve pregnancy would provide a more clinically relevant assessment of the predictive value of these parameters.
4. Population-specific cut-offs: The low sensitivity of the PI cut-off (>3.0) suggests that thresholds may need to be validated for this population.
5. Control group: While we selected controls with delivery >1 year prior, the long-term effects of pregnancy on uterine hemodynamics are not fully understood. Additionally, the use of only parous women as controls may introduce spectrum bias.
6. No correlation with pregnancy outcomes: This study establishes an association with infertility status but does not prospectively track pregnancy outcomes following intervention.
7. Confounding variables: This study did not account for all potential confounders of uterine perfusion. While we excluded

women with known factors affecting uterine blood flow (smoking, hormonal medications, pelvic surgery, adenomyosis, endometriosis), unmeasured confounders may have influenced our findings. For example, we did not assess ovarian reserve (anti-Müllerian hormone levels or antral follicle count), which has been associated with uterine artery impedance.³⁰

Similarly, psychological stress, which is common in women with infertility, may influence autonomic regulation of uterine blood flow.³¹ The relatively homogeneous population (all from the same geographic region) may limit the detection of some confounders. Future studies should comprehensively assess these variables to better isolate the independent effect of infertility on uterine perfusion.

Future Research:

- Prospective longitudinal studies tracking changes in Doppler parameters following targeted interventions and their correlation with subsequent pregnancy outcomes.
- Multicentric studies across different regions of Nigeria to validate findings.
- Correlation with other biomarkers of endometrial receptivity.
- Use of 3D power Doppler with vascular indices for objective quantification.
- Development of population-specific reference ranges for PI, RI, and flow zones.
- Assessment of inter-observer variability with multiple operators.
- Studies comparing Doppler findings between women with primary and secondary infertility to identify potential etiologic differences.

Conclusion

We have detailed a reproducible transvaginal Doppler ultrasound protocol that effectively identifies impaired uterine perfusion, characterized by elevated

impedance indices and reduced subendometrial flow, in a significant proportion of infertile women. The technique is quick, non-invasive, and requires only standard ultrasound equipment. Its integration into the routine imaging work-up for infertility provides functional data that may identify a subset of patients with impaired uterine perfusion, though the clinical significance of this finding and the optimal management strategy require further investigation. We advocate for the adoption and further validation of this protocol in similar clinical settings to improve the diagnostic precision and personalize the management of infertility. Prospective studies are needed to determine whether Doppler-guided interventions can improve pregnancy outcomes in this population.

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