Diagnostic Accuracy of Doppler Ultrasonography in the Antenatal Diagnosis of Abnormal Placental Invasion Secondary to Placenta Previa

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Abstract

Objective: To determine the diagnostic accuracy of Doppler ultrasonography in the antenatal diagnosis of abnormal placental invasion secondary to placenta previa, taking operative findings at caesarean section as the gold standard.

Study Design: Cross-sectional diagnostic accuracy study.

Place and Duration of Study: Radiology department, RTEH Indus Hospital MUZAFFARGARH, Recep Tayyip Erdogan Hospital, Muzaffargarh, Pakistan, over a six-month study period after ethical approval.

Methodology: A total of 284 multigravida women aged 20-40 years with gestational age greater than 28 weeks, previous caesarean section and ultrasound-diagnosed placenta previa were included by non-probability consecutive sampling. Doppler ultrasonography was performed using predefined vascular criteria for abnormal placental invasion. Operative findings at caesarean section were used as the reference standard. Sensitivity, specificity, positive predictive value, negative predictive value and diagnostic accuracy were calculated from a 2 x 2 diagnostic table.

Results: The mean age was 29.80 +/- 4.02 years and the mean gestational age was 34.39 +/- 2.29 weeks. Operative findings confirmed abnormal placental invasion in 49 women (17.25%). Doppler ultrasonography identified 57 positive cases (20.07%). The true-positive, false-negative, false-positive and true-negative counts were 42, 7, 15 and 220, respectively. Doppler ultrasonography showed sensitivity of 85.71%, specificity of 93.62%, positive predictive value of 73.68%, negative predictive value of 96.92% and overall diagnostic accuracy of 92.25%.

Conclusion: Doppler ultrasonography demonstrated high sensitivity, high specificity and particularly strong negative predictive value for antenatal detection of abnormal placental invasion in women with placenta previa. These findings support its use as a practical first-line diagnostic tool in high-risk obstetric patients, especially in resource-constrained settings where MRI is not routinely available.

Keywords: placenta previa; placenta accreta spectrum; morbidly adherent placenta; Doppler ultrasonography; abnormal placental invasion; diagnostic accuracy; caesarean section.

Introduction

Placenta previa is an important obstetric condition in which the placenta lies in the lower uterine segment and reaches or covers the internal cervical os. It is clinically important because it increases the probability of antepartum bleeding, emergency admission, caesarean delivery, postpartum haemorrhage, blood transfusion, operative complications and maternal morbidity. Although placenta previa can occur in women without previous uterine surgery, its risk and severity become more clinically concerning when it coexists with a previous caesarean scar. The rising global frequency of caesarean section has therefore made placenta previa with suspected abnormal placental invasion a more common and more complex obstetric problem (Ibrahem et al., 2023; Kong & To, 2020).

The type and location of placenta previa are also relevant to obstetric planning. Complete placenta previa, especially when anterior and implanted over a previous caesarean scar, creates a higher level of suspicion for morbid adherence or invasion than a marginal placenta located away from the scar

site. Contemporary studies indicate that placenta previa is not a single-risk category; rather, maternal and neonatal outcomes may differ according to previa type, placental position, prior uterine surgery and associated obstetric complications (Bi et al., 2021). For that reason, women with placenta previa require structured antenatal assessment instead of routine late-pregnancy follow-up only.

Abnormal placental invasion is now commonly described under the umbrella term placenta accreta spectrum (PAS). PAS includes placenta accreta, increta and percreta, representing abnormal adherence to, invasion into or penetration through the myometrium. The traditional term morbidly adherent placenta remains common in clinical practice, but PAS is preferred in recent literature because it better reflects the range of pathology and clinical severity (American College of Obstetricians and Gynecologists & Society for Maternal-Fetal Medicine [ACOG & SMFM], 2018; Jauniaux et al., 2018). The condition is strongly associated with defective decidualization at the site of uterine scarring, which explains the close relationship among placenta previa, previous caesarean section and abnormal placental invasion.

PAS is feared in obstetric practice because it may convert a planned caesarean section into a major obstetric haemorrhage within minutes. If the placenta does not separate after delivery or if abnormal vessels invade the myometrium, cervix or bladder interface, the patient may require massive transfusion, uterotonics, compression procedures, pelvic devascularization, urinary tract repair, intensive care admission or caesarean hysterectomy. Maternal morbidity and mortality may occur not only because of bleeding but also because of delayed recognition, inadequate blood preparation, unplanned surgery and lack of multidisciplinary support (Horgan & Abuhamad, 2022). Therefore, the goal of antenatal diagnosis is not simply to label disease; it is to prepare the safest possible delivery pathway.

Clinical risk factors remain central in the evaluation of suspected PAS. Advanced maternal age, multiparity, previous caesarean delivery, placenta previa, previous dilatation and curettage, myomectomy and other intrauterine procedures have all been described as relevant predictors. Among these, placenta previa with previous caesarean section is one of the most important combinations because the placenta may implant directly over a scarred and poorly decidualized lower uterine segment (Iacovelli et al., 2020; Yeni et al., 2022). Consequently, diagnostic imaging should be targeted most carefully in women who already carry this high-risk clinical profile.

Ultrasonography is generally considered the first-line imaging modality for antenatal assessment of PAS. Grey-scale ultrasound can identify placental lacunae, loss of the retroplacental clear zone, myometrial thinning, interruption of the bladder wall line and abnormal placental bulging. Doppler ultrasonography adds functional vascular information by demonstrating turbulent flow within placental lacunae, subplacental hypervascularity, bridging vessels and uterovesical interface hypervascularity. The combination of anatomical and vascular signs is particularly useful when the clinical question is whether placenta previa is complicated by abnormal placental invasion (Shainker et al., 2021).

Doppler ultrasonography is especially relevant in low- and middle-resource settings because it is accessible, repeatable, relatively inexpensive, safe for the mother and fetus, and available in many secondary and tertiary hospitals. MRI can provide additional information in selected cases, particularly when ultrasound findings are inconclusive, the placenta is posterior, or surgical mapping

is required. However, MRI is costly and not consistently available for every high-risk pregnant woman in public-sector settings. Evidence also suggests that routine MRI for every suspected case may not be necessary when ultrasound assessment is performed carefully by trained personnel (Hong et al., 2022; Srisajjakul et al., 2021).

International guidance supports a balanced approach in which ultrasound findings are interpreted with clinical risk factors rather than in isolation. ACOG and SMFM emphasize that ultrasound evaluation is important, but absence of ultrasound signs does not completely exclude PAS when clinical risk factors are strong (ACOG & SMFM, 2018). FIGO guidance likewise highlights structured ultrasound screening and standardized terminology for abnormal invasion, while specialist management is recommended for high-risk cases (Jauniaux et al., 2018). This point is important for local practice because a negative Doppler study may reduce suspicion, but it should not override a strongly positive clinical risk profile.

Local diagnostic accuracy evidence is necessary because performance of Doppler ultrasonography is influenced by operator expertise, equipment quality, patient selection, gestational age at examination, placental site, bladder filling, maternal body habitus and reference standard used at delivery. Studies from Pakistan have reported encouraging results, with Doppler ultrasonography showing high sensitivity, specificity and negative predictive value for abnormal placental invasion among women with placenta previa (Khalid et al., 2016; Mahmood et al., 2023). However, more local datasets are needed to strengthen confidence in Doppler-based triage and operative planning.

In the present study, Doppler ultrasonography was evaluated against operative findings at caesarean section as the gold standard. The focus on women with placenta previa, previous caesarean section and gestational age greater than 28 weeks reflects a clinically relevant high-risk group. By estimating sensitivity, specificity, positive predictive value, negative predictive value and overall diagnostic accuracy, the study aims to determine whether Doppler ultrasonography can reliably support antenatal identification of abnormal placental invasion in routine tertiary-care practice. The findings may help improve counselling, referral, blood arrangement, surgical preparedness and maternal safety in similar resource-limited obstetric settings.

Methodology

Study design and setting

This cross-sectional diagnostic accuracy study was conducted in the Radiology department, RTEH Indus Hospital MUZAFFARGARH, Recep Tayyip Erdogan Hospital, Muzaffargarh, Pakistan. The study duration was six months after approval from the institutional ethics review committee.

Study population

The study included pregnant women with placenta previa and risk factors for abnormal placental invasion. Women were recruited by non-probability consecutive sampling from eligible patients referred for obstetric Doppler ultrasonography and subsequently managed by caesarean delivery.

Sample size

The sample size was 284. The sample size was based on the diagnostic accuracy assumptions in the approved synopsis, using expected sensitivity of 85.1%, specificity of 93.8%, prevalence of abnormal placental invasion of 17.3%, 95% confidence level and 10% absolute precision.

Inclusion criteria

Women aged 20-40 years, gestational age greater than 28 weeks on ultrasound, multigravida status, previous caesarean section and ultrasound-diagnosed placenta previa were included.

Exclusion criteria

Women with a history or laboratory evidence of bleeding disorder, deranged coagulation profile, low platelet count or placental abruption on ultrasound were excluded.

Operational definition of placenta previa

Placenta previa was defined as a placenta located within 2 cm of the internal cervical os on transabdominal ultrasound.

Doppler ultrasonographic diagnosis of abnormal placental invasion

Abnormal placental invasion was labelled positive on Doppler ultrasonography when any predefined abnormal vascular feature was present, including diffusely dilated vascular channels with high-velocity pulsatile venous flow, abnormal vessels joining the placenta to the bladder, markedly dilated subplacental vascular channels, vessels crossing placental tissue disruption, abnormal clear space or uterine serosa-bladder wall interface hypervascularity.

Operative diagnosis

Operative diagnosis of abnormal placental invasion was recorded when one or more operative findings were present, including blood vessels invading the uterine myometrium, loss of plane of cleavage between uterus and placenta, invasion into adjacent structures such as the urinary bladder, or failure of placental separation.

Data collection procedure

After informed consent, demographic and obstetric variables were recorded, including age, gestational age, gravida, parity, previous caesarean sections, other intrauterine procedures, gestational hypertension and gestational diabetes. Doppler ultrasonography was performed by an experienced radiologist using the departmental protocol. Caesarean delivery was performed by a consultant obstetrician, and operative findings were recorded on the study proforma.

Data analysis

Data were analysed using SPSS-compatible diagnostic accuracy procedures and independently verified from the Excel raw dataset. Quantitative variables were summarized as mean and standard deviation. Categorical variables were summarized as frequency and percentage. Diagnostic accuracy was calculated using operative findings as the reference standard. Sensitivity, specificity, positive predictive value, negative predictive value, diagnostic accuracy and Wilson 95% confidence intervals were calculated. Associations between selected categorical variables and operative diagnosis were

explored by chi-square or Fisher exact test where appropriate. A p-value less than 0.05 was considered statistically significant.

Results

The final dataset contained 284 pregnant women fulfilling the eligibility criteria. The mean age was 29.80 +/- 4.02 years, while the mean gestational age at assessment was 34.39 +/- 2.29 weeks. The mean gravida and parity were 3.46 +/- 1.15 and 2.47 +/- 1.29, respectively. The mean number of previous caesarean sections was 1.81 +/- 0.88.

Table 1. Demographic and obstetric characteristics of study participants (N = 284)

Variable	Mean +/- SD	Range
Age (years)	29.80 +/- 4.02	20-40
Gestational age (weeks)	34.39 +/- 2.29	29.0-40.3
Gravida	3.46 +/- 1.15	2-7
Parity	2.47 +/- 1.29	1-7
Previous caesarean sections	1.81 +/- 0.88	1-5
Other intrauterine procedures	0.18 +/- 0.42	0-2

Table 2. Clinical and obstetric profile of the study population

Variable	Category	Frequency (%)
Gestational Hypertension	No	249 (87.68%)
Gestational Hypertension	Yes	35 (12.32%)
Gestational Diabetes	No	259 (91.20%)
Gestational Diabetes	Yes	25 (8.80%)
Placenta Previa Type	Complete	138 (48.59%)
Placenta Previa Type	Marginal	58 (20.42%)
Placenta Previa Type	Partial	52 (18.31%)
Placenta Previa Type	Low-lying	36 (12.68%)
Placental Position	Anterior	135 (47.54%)
Placental Position	Posterior	108 (38.03%)
Placental Position	Lateral	41 (14.44%)
Postpartum Hemorrhage	No	214 (75.35%)
Postpartum Hemorrhage	Yes	70 (24.65%)
Caesarean Hysterectomy	No	266 (93.66%)
Caesarean Hysterectomy	Yes	18 (6.34%)

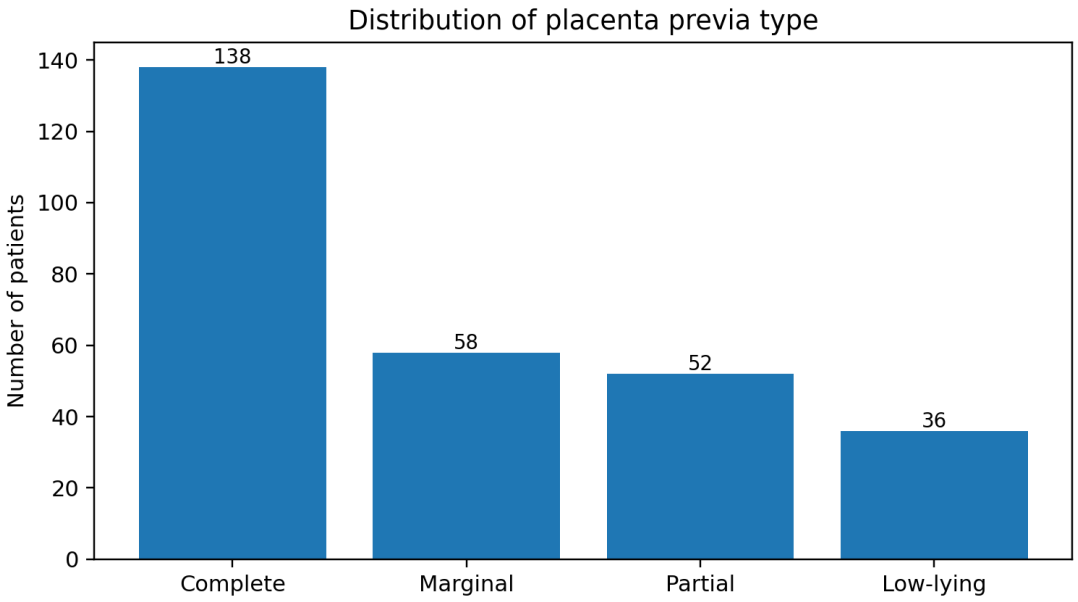

Figure 1. Distribution of placenta previa types in the study population.

Table 3. Doppler ultrasonographic markers observed in the study population

Doppler marker	Present n (%)	Absent n (%)
Placental lacunae	39 (13.73%)	245 (86.27%)
Uterovesical hypervascularity	29 (10.21%)	255 (89.79%)
Subplacental vascularity	40 (14.08%)	244 (85.92%)
Bridging vessels	29 (10.21%)	255 (89.79%)
Cervical vascularity	19 (6.69%)	265 (93.31%)
Abnormal / lost clear space	40 (14.08%)	244 (85.92%)

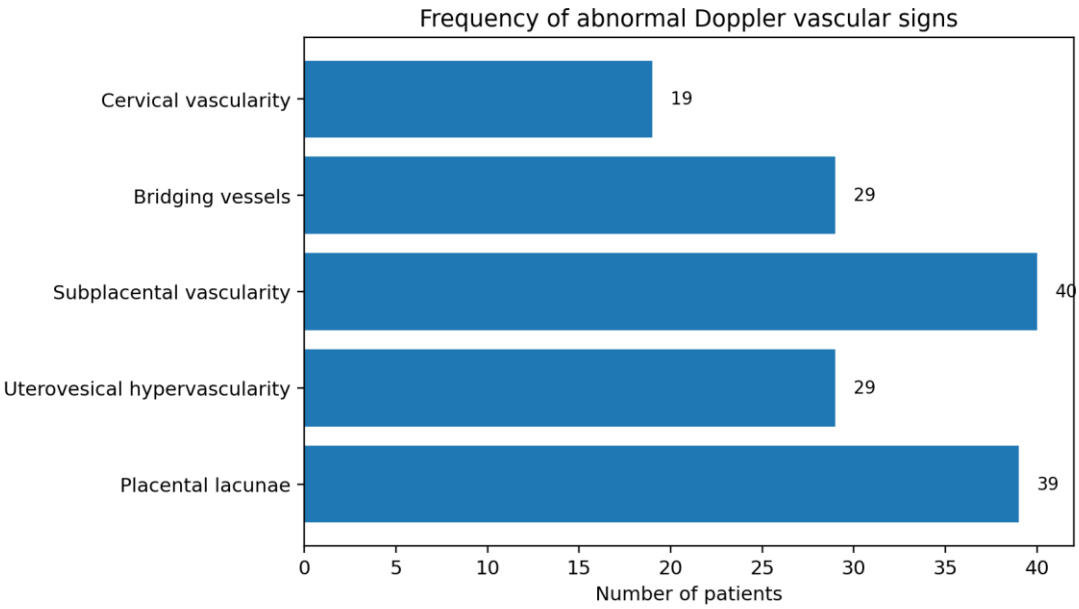

Figure 2. Frequency of abnormal Doppler vascular signs.

Operative findings confirmed abnormal placental invasion in 49 women (17.25%), while 235 women (82.75%) had no operative evidence of invasion. Doppler ultrasonography was positive in 57 cases (20.07%) and negative in 227 cases (79.93%). Compared with operative diagnosis, Doppler ultrasonography produced 42 true-positive results, 7 false-negative results, 15 false-positive results and 220 true-negative results.

Table 4. Two-by-two diagnostic table of Doppler ultrasonography compared with operative findings

Doppler ultrasonography	Operative API/PAS present	Operative API/PAS absent	Total
Positive	42	15	57
Negative	7	220	227
Total	49	235	284

Table 5. Diagnostic accuracy of Doppler ultrasonography using operative findings as gold standard

Parameter	Numerator/denominator	Estimate with 95% CI
Sensitivity	42/49	85.71% (73.33-92.90)
Specificity	220/235	93.62% (89.74-96.09)
Positive predictive value	42/57	73.68% (61.02-83.35)
Negative predictive value	220/227	96.92% (93.77-98.50)
Diagnostic accuracy	262/284	92.25% (88.55-94.83)
Prevalence of operative API/PAS	49/284	17.25% (13.30-22.08)

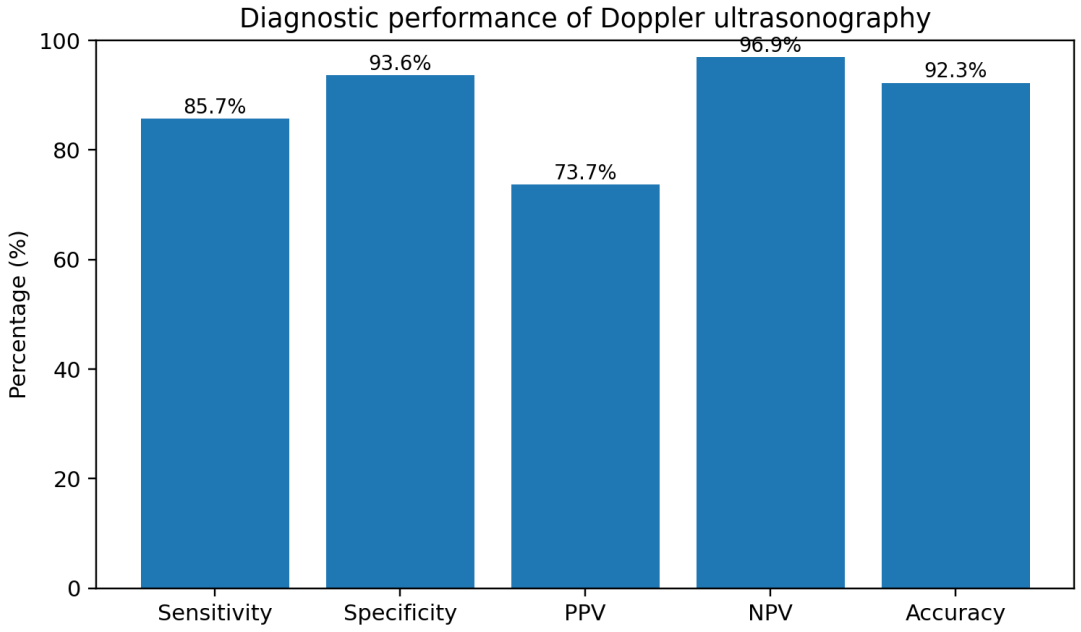

Figure 3. Diagnostic performance of Doppler ultrasonography.

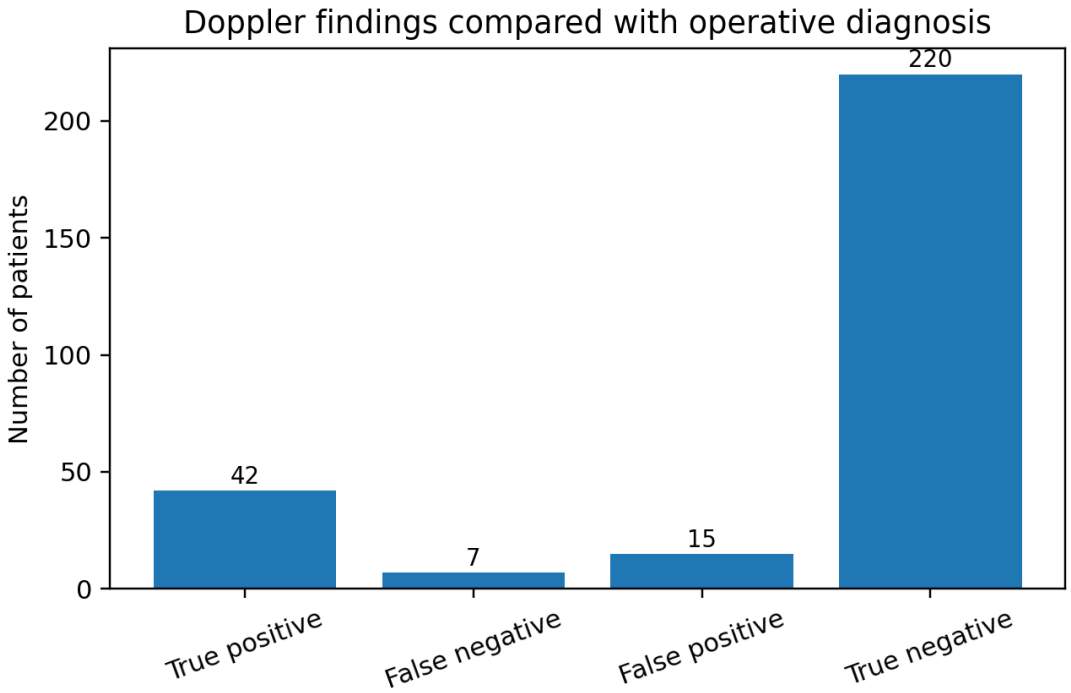

Figure 4. Diagnostic classification counts compared with operative findings.

Table 6. Operative grade among confirmed abnormal placental invasion cases

Operative grade	Frequency among confirmed cases (%)
Accreta	32 (65.31%)
Increta	15 (30.61%)
Percreta	2 (4.08%)

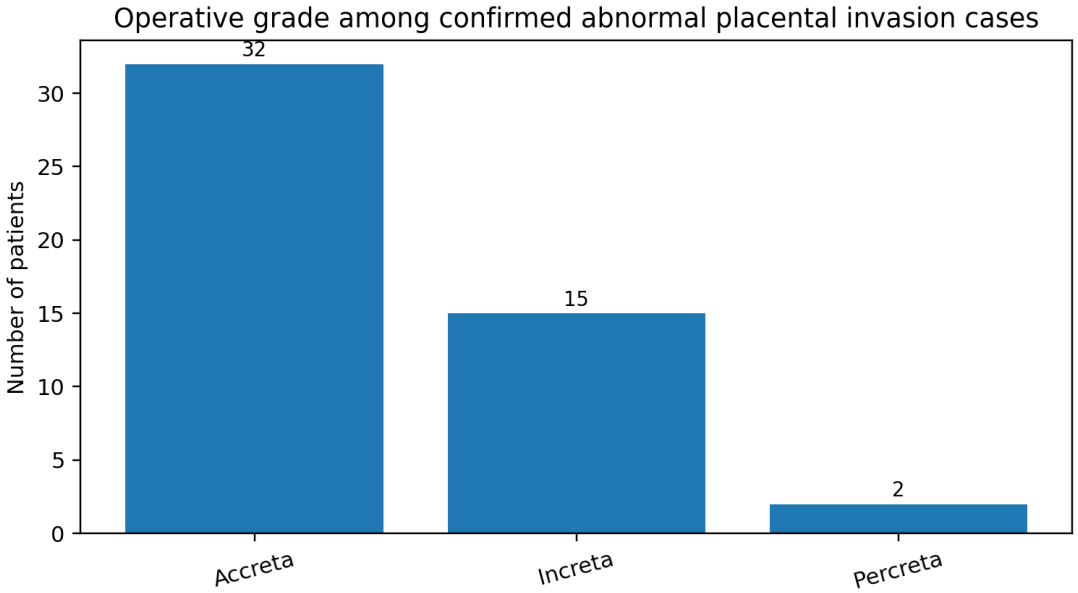

Figure 5. Operative grade distribution among confirmed abnormal placental invasion cases.

Stratified diagnostic accuracy

Post-stratification diagnostic accuracy was recalculated for clinically relevant variables. These analyses are exploratory and should be interpreted cautiously because some strata contain small numbers of confirmed cases.

Table 7. Stratified diagnostic accuracy of Doppler ultrasonography

Stratification variable	Stratum	n	TP/FN/FP/TN	Sensitivity	Specificity	Accuracy
Age group	20-29 years	136	12/2/10/112	85.7%	91.8%	91.2%
Age group	30-40 years	148	30/5/5/108	85.7%	95.6%	93.2%
Gestational age	<=34 weeks	128	14/2/6/106	87.5%	94.6%	93.8%
Gestational age	>34 weeks	156	28/5/9/114	84.8%	92.7%	91.0%
Previous caesarean sections	One	124	5/0/5/114	100.0%	95.8%	96.0%
Previous caesarean sections	Two or more	160	37/7/10/106	84.1%	91.4%	89.4%
Placenta previa type	Complete	138	26/6/9/97	81.2%	91.5%	89.1%
Placenta previa type	Low-lying	36	3/0/2/31	100.0%	93.9%	94.4%
Placenta previa type	Marginal	58	3/1/0/54	75.0%	100.0%	98.3%
Placenta previa type	Partial	52	10/0/4/38	100.0%	90.5%	92.3%
Gestational hypertension	No	249	33/7/15/194	82.5%	92.8%	91.2%
Gestational hypertension	Yes	35	9/0/0/26	100.0%	100.0%	100.0%
Gestational diabetes	No	259	38/7/12/202	84.4%	94.4%	92.7%
Gestational diabetes	Yes	25	4/0/3/18	100.0%	85.7%	88.0%

Table 8. Association of selected clinical variables with operative abnormal placental invasion

Variable	Category	Operative API/PAS present n/total (%)	p-value
Placenta Previa Type	Complete	32/138 (23.19%)	0.0193
Placenta Previa Type	Low-lying	3/36 (8.33%)	
Placenta Previa Type	Marginal	4/58 (6.90%)	
Placenta Previa Type	Partial	10/52 (19.23%)	
Placental Position	Anterior	32/135 (23.70%)	0.0192
Placental Position	Lateral	6/41 (14.63%)	
Placental Position	Posterior	11/108 (10.19%)	
Gestational Hypertension	No	40/249 (16.06%)	0.1578

Gestational Hypertension	Yes	9/35 (25.71%)	
Gestational Diabetes	No	45/259 (17.37%)	1.0000
Gestational Diabetes	Yes	4/25 (16.00%)	
Postpartum Hemorrhage	No	22/214 (10.28%)	0.0000
Postpartum Hemorrhage	Yes	27/70 (38.57%)	
Caesarean Hysterectomy	No	37/266 (13.91%)	0.0000
Caesarean Hysterectomy	Yes	12/18 (66.67%)	

Discussion

This study evaluated Doppler ultrasonography for antenatal diagnosis of abnormal placental invasion among women with placenta previa, using operative findings at caesarean section as the reference standard. In this dataset, operative findings confirmed abnormal placental invasion in 17.25% of participants, which is clinically meaningful because the population was already enriched for risk by including women with placenta previa and previous caesarean section. Doppler ultrasonography demonstrated high sensitivity, high specificity and strong overall accuracy. The most clinically important result was the high negative predictive value, indicating that a negative Doppler assessment was strongly associated with absence of operative invasion in this study population.

The observed sensitivity of 85.71% means that Doppler ultrasonography correctly identified most women who had abnormal placental invasion at surgery. From a clinical perspective, sensitivity is important because missed PAS can lead to unexpected intraoperative haemorrhage, emergency hysterectomy, organ injury and poor maternal outcome. The false-negative rate in the present dataset was 14.29% among operative-positive cases, which also highlights that Doppler findings should not be interpreted in isolation. In a patient with placenta previa, multiple caesarean scars and an anterior low-lying placenta over the scar, clinical suspicion should remain even when Doppler findings are not strongly positive (ACOG & SMFM, 2018).

The specificity of 93.62% indicates that Doppler ultrasonography correctly classified most women without operative invasion. High specificity is important because overdiagnosis of PAS may lead to anxiety, unnecessary referral, more aggressive operative planning and possible overuse of limited tertiary-care resources. However, the positive predictive value was 73.68%, which means that some Doppler-positive patients did not show operative invasion. This pattern is expected in diagnostic accuracy studies because PPV is influenced by disease prevalence. In a population with higher PAS prevalence, PPV may increase, whereas in a lower-risk population it may decrease even when sensitivity and specificity remain similar.

The negative predictive value of 96.92% is particularly useful for clinical triage. In a busy obstetric unit, a high NPV supports the role of Doppler ultrasonography in identifying women who are less likely to have invasive placentation at delivery. Nevertheless, a negative Doppler result should not completely remove the need for preparedness in high-risk women. ACOG and SMFM emphasize that ultrasound findings are important but absence of imaging signs does not fully exclude PAS when risk factors are present (ACOG & SMFM, 2018). Therefore, Doppler should be considered a major component of risk assessment rather than a standalone replacement for clinical judgement.

The overall diagnostic accuracy of 92.25% in this dataset is consistent with local and international evidence supporting ultrasound as the first-line assessment for PAS. Mahmood et al. (2023) reported sensitivity of 85.1%, specificity of 93.8%, PPV of 74.1%, NPV of 96.8% and accuracy of 92.2% for Doppler ultrasonography in women with placenta previa. The present dataset produced very similar results, which strengthens internal consistency with the approved synopsis assumptions and supports the reliability of Doppler-based diagnosis in a comparable high-risk obstetric population. Khalid et al. (2016) also reported high diagnostic accuracy of colour Doppler ultrasound for morbidly adherent placenta, although their sample size was smaller.

The findings are also compatible with the broader imaging literature. Ultrasound remains the principal screening and diagnostic modality for suspected PAS because it is widely accessible and can demonstrate both structural and vascular markers. A systematic review reported comparable overall accuracy of ultrasound and MRI and concluded that routine MRI for all suspected cases may not be necessary, especially considering cost and availability (Hong et al., 2022). This does not reduce the value of MRI in selected complex cases; rather, it supports a practical stepped approach in which Doppler ultrasound is used first and MRI is reserved for equivocal, posterior or surgically complex cases.

Doppler markers in this study included placental lacunae, uterovesical hypervascularity, subplacental vascularity, bridging vessels, cervical vascularity and loss of the clear space. These markers reflect abnormal vascular remodeling and disturbed uteroplacental interface anatomy. The Society for Maternal-Fetal Medicine marker consensus highlights the need for standardized terminology and structured ultrasound evaluation in pregnancies at risk for PAS (Shainker et al., 2021). Standardization is especially important because inconsistent reporting can lead to missed diagnoses, unnecessary alarm or difficulty comparing results across institutions.

The clinical implication of these results is that Doppler ultrasonography can improve antenatal planning in women with placenta previa. When Doppler findings are positive, the obstetric team can arrange consultant-led delivery, adequate blood products, senior anaesthesia, neonatal support, surgical backup and availability of hysterectomy instruments where needed. In suspected bladder or serosal invasion, urology support may also be considered. Planned management is safer than unexpected discovery of abnormal invasion during caesarean section, because the team can avoid forcible placental removal and can follow a predefined haemorrhage-control strategy.

The study setting is important because MRI availability remains limited for many patients in Pakistan and similar resource-constrained health systems. Even where MRI exists, cost, appointment delays and patient affordability can prevent universal use. Doppler ultrasonography is more realistic as a routine antenatal tool because it is already integrated into obstetric care. By generating local diagnostic accuracy estimates, this study supports evidence-based use of Doppler ultrasound for referral decisions and delivery planning in public-sector practice.

The stratified analyses provide additional clinical insight, although they should be interpreted carefully. Diagnostic performance may vary by age, gestational age, number of previous caesarean sections, placenta previa type and associated maternal conditions. Small subgroup counts can make sensitivity and specificity unstable, particularly when the number of operative-positive cases is low. Future studies with larger multicentre samples should evaluate whether diagnostic performance

differs significantly between complete and marginal previa, anterior and posterior placenta, and women with one versus multiple previous caesarean sections.

There are several strengths of the study. First, the study focused on a clearly defined high-risk group rather than a mixed obstetric population. Second, Doppler positivity was based on predefined vascular criteria, reducing ambiguity in the index test. Third, operative findings were used as the gold standard, which is clinically meaningful for surgical decision-making. Fourth, the study calculated the full set of diagnostic accuracy measures rather than reporting only sensitivity or accuracy. Finally, the inclusion of graphs and stratified tables improves interpretation for clinicians and reviewers.

Limitations should also be acknowledged. Doppler ultrasonography is operator dependent, and the results may vary with radiologist experience, machine quality and image acquisition protocol. Operative findings are clinically relevant but may not always equal histopathological confirmation, especially in cases where hysterectomy is not performed. The study was conducted at a single centre, which may limit generalizability. Because the prevalence of abnormal invasion influences PPV and NPV, predictive values may differ in lower-risk populations. Despite these limitations, the findings support Doppler ultrasonography as a valuable and feasible antenatal diagnostic tool in the studied high-risk population.

Conclusion

Doppler ultrasonography demonstrated strong diagnostic performance for antenatal detection of abnormal placental invasion secondary to placenta previa in this 284-patient dataset. Using operative findings as the gold standard, Doppler ultrasonography achieved sensitivity of 85.71%, specificity of 93.62%, positive predictive value of 73.68%, negative predictive value of 96.92% and diagnostic accuracy of 92.25%. These results indicate that Doppler ultrasonography correctly identified most operative-positive cases and accurately excluded disease in most operative-negative cases.

The high negative predictive value is especially important for obstetric practice because it suggests that a negative Doppler study can provide useful reassurance in many high-risk women. However, Doppler findings should always be interpreted alongside clinical risk factors, particularly previous caesarean section, placenta previa type, placental position and prior intrauterine surgery. A negative Doppler result should not completely exclude clinical vigilance when the risk profile is strong.

The findings support Doppler ultrasonography as a practical first-line imaging modality for suspected abnormal placental invasion in women with placenta previa. In settings where MRI is expensive or not readily available, Doppler ultrasound can guide antenatal counselling, referral, timing of delivery, blood arrangement and multidisciplinary operative planning. This makes it highly relevant for public-sector and resource-limited hospitals where early risk identification can prevent emergency decision-making at caesarean section.

Overall, the study reinforces the clinical value of structured Doppler assessment in women with placenta previa and previous caesarean delivery. Wider implementation of standardized Doppler reporting, combined with risk-based obstetric planning, may reduce missed diagnoses, improve surgical preparedness and contribute to safer maternal outcomes. Future multicentre studies with

histopathological confirmation where possible are recommended to validate these findings and refine local protocols for PAS screening and management.

Recommendations

- All women with placenta previa and previous caesarean section should undergo targeted Doppler ultrasonography for assessment of abnormal placental invasion.
- Doppler reports should include standardized PAS markers such as placental lacunae, subplacental hypervascularity, bridging vessels, uterovesical hypervascularity and clear-zone abnormality.
- Positive Doppler findings should prompt planned delivery in a facility with blood bank support, experienced obstetric surgeons, anaesthesia, neonatal care and surgical backup.
- MRI should be reserved for selected cases where ultrasound findings are equivocal, the placenta is posterior or further anatomical mapping is required for operative planning.
- Local hospitals should develop protocols for referral and multidisciplinary management of suspected PAS.

Limitations

- The single-centre design limits generalizability to all obstetric settings.
- Doppler ultrasonography is operator dependent, so diagnostic performance may differ across radiologists and machines.
- Operative findings were used as the gold standard; histopathology may not be available for all cases unless hysterectomy is performed.
- Stratified analyses may be underpowered in some subgroups because the number of operative-positive cases is limited.
- Predictive values may change in populations with a different prevalence of abnormal placental invasion.

Declarations

Ethical approval: The study was conducted after approval from the institutional ethics review committee.

Informed consent: Written informed consent was obtained from all included participants.

Conflict of interest: The author declares no conflict of interest.

Funding: No external funding was received.

Data availability: Data are available from the corresponding author on reasonable request, subject to institutional approval.

Author contribution: Dr. Kashaf Imran conceived the study, supervised data collection, interpreted the findings and prepared the manuscript.

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Appendix A: Diagnostic Accuracy Formulas

- Sensitivity = True positive / (True positive + False negative)
- Specificity = True negative / (True negative + False positive)
- Positive predictive value = True positive / (True positive + False positive)
- Negative predictive value = True negative / (True negative + False negative)
- Diagnostic accuracy = (True positive + True negative) / Total sample size