INTERNATIONAL JOURNAL OF ADVANCED RESEARCH
International Peer-Reviewed Research Journal
ISSN (Online): 3106-7980 | ISSN (Print): 3106-7972
Volume 3 • Issue 5 • September 2026

DIAGNOSTIC ACCURACY OF COMBINED FETAL BIOPHYSICAL PROFILE AND UTERINE ARTERY DOPPLER IN DETECTING FETAL COMPROMISE IN HIGH-RISK PREGNANCIES

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DOI: https://doi.org/10.5281/zenodo.23118785

Keywords
Diagnostic accuracy, Fetal Biophysical Profile, Uterine Artery Doppler, High Risk Pregnancy, Fetal Compromise, Doppler Ultrasonography.

Article History
Received: 01 June 2026
Accepted: 23 August 2026
Published: 30 September 2026

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ABSTRACT

Background

High-risk pregnancies are related with increased perinatal morbidity and mortality, largely due to placental insufficiency and fetal hypoxia. Early and accurate identification of fetal compromise is essential to optimize antenatal management and prevent adverse outcomes. A popular ultrasound-based technique called the Biophysical Profile (BPP) measures fetal respiratory movements, gross body movements, fetal tone, amniotic fluid content, and non-stress test to assess fetal well-being. However, BPP primarily reflects established fetal compromise and may fail to detect early placental dysfunction. Uterine artery Doppler ultrasound evaluates uteroplacental circulation and provides indirect information regarding placental resistance. Abnormal uterine artery Doppler indices are recognized markers of impaired placentation and reduced uterine perfusion. Combining fetal physiological assessment with placental hemodynamic evaluation may improve detection of immediate fetal compromise during a single ultrasound encounter.

Objective

To evaluate the diagnostic accuracy of combined fetal Biophysical Profile and uterine artery Doppler in identifying fetal compromise in high risk pregnancies.

Methodology

Biophysical profile (BPP) and uterine artery Doppler ultrasonography were used to evaluate fetal well-being in 96 high-risk pregnancies. The relationship between fetal compromise and BPP components and uterine artery Doppler indices was assessed. Mean, median and standard deviation were used to analyze the data, while sensitivity, specificity, and diagnostic odds ratio (DOR) were used to evaluate diagnostic performance.

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Results

Here in this study 96 pregnant women with a mean gestational age of 33.73 ± 2.70 weeks and a mean mother age of 28.27 ± 4.37 years. At a cut-off of ≤6, the whole biophysical profile (BPP) score showed 100% sensitivity and 100% specificity in identifying fetal impairment. Mean UtA PI (≥0.99) and right UtA S/D (≥3.03), two uterine artery Doppler measurements, demonstrated 100% sensitivity but low specificity of 19.0% and 12.7%, respectively. Right and left UtA RI revealed sensitivities of 35.3% and 76.5% with specificities of 78.5% and 25.3%, respectively, whereas right and left UtA PI showed sensitivities of 64.7% and 82.4% with specificities of 53.2% and 32.9%. The left UtA S/D showed 63.3% specificity and 58.8% sensitivity. 100% sensitivity and 97.5% specificity were attained by the combined BPP and mean UtA PI model. Due to the lack of false-positive or false-negative results, the diagnostic odds ratios for BPP, mean UtA PI, right UtA S/D, and the combined model were infinite, whereas the DORs for individual Doppler parameters ranged from 1.102 to 2.463.

Conclusion

When it came to identifying fetal compromise, BPP performed really well. BPP and mean UtA PI together preserved 100% sensitivity and increased specificity, suggesting potential utility as a combined evaluation for fetal compromise.

INTRODUCTION

Because high-risk pregnancies are strongly linked to higher rates of morbidity and mortality in mothers, fetuses, and newborns, they continue to be a major global public health concern. Despite the fact that pregnancy is typically seen as a normal physiological process, there are a number of maternal, fetal, and placental diseases that can make gestation more difficult and put the mother and fetus at serious risk. High-risk pregnancies are those that are complicated by hypertensive disorders, gestational diabetes mellitus, oligohydramnios, polyhydramnios, fetal growth restriction (FGR), anemia, placental abnormalities, post-term pregnancy, recurrent pregnancy loss, and maternal systemic diseases because these conditions put the fetus at risk for intrauterine compromise, hypoxia, and acidosis (1). Reliable and non-invasive fetal surveillance techniques that can precisely detect fetal distress and direct prompt obstetric intervention are becoming more and more necessary due to the rising incidence of high-risk pregnancies, especially in developing nations. A medical condition known as fetal compromise occurs when the fetus is unable to maintain proper oxygenation and metabolic homeostasis because of either placental insufficiency or compromised uteroplacental circulation. Severe consequences such as intrauterine growth restriction, brain damage, meconium aspiration syndrome, birth asphyxia, preterm birth, and intrauterine fetal mortality can result from chronic fetal hypoxia (2). Therefore, lowering unfavorable prenatal outcomes and increasing neonatal survival depend on early diagnosis of fetal impairment. The goal of antepartum fetal surveillance is to assess fetal health and identify vulnerable pregnancies before permanent hypoxic harm takes place. The ability of doctors to monitor fetal status during high-risk pregnancies has been greatly enhanced by developments in obstetric ultrasound and Doppler imaging. Maternal fetal movement counts, cardiotocography, non-stress test (NST), contraction stress test, fetal biophysical profile (BPP), and Doppler velocimetry are some of the antepartum monitoring techniques being used to evaluate fetal welfare (3).Because they are non-invasive, safe, repeatable, and able to provide

critical physiological and hemodynamic information regarding the fetus and placenta, the fetal biophysical profile and Doppler ultrasound have grown in importance among these modalities. In obstetric practice, these imaging modalities are frequently employed to track pregnancies complicated by fetal growth anomalies and placental insufficiency. Manning et al. first presented the fetal biophysical profile as a thorough ultrasound-based evaluation of fetal health in 1980 (4). Fetal breathing motions, gross fetal body movements, fetal tone, amniotic fluid volume, and non-stress test responsiveness are among the five biophysical characteristics that the BPP evaluates using ultrasonography and fetal heart rate monitoring. The maximum total score is 10, with each parameter receiving a value of either 0 or 2. Fetal hypoxia and potential acidemia are suggested by a low score, while adequate oxygenation and neurological integrity are indicated by a normal score. The BPP's theoretical foundation is the finding that fetal biophysical activity are controlled by the central nervous system and gradually repressed in a predictable order during hypoxic stress (5). Fetal breathing patterns, gross body movements, fetal tone, and heart rate reactivity are examples of acute indicators of fetal health that show the state of oxygenation and immediate neurological function. On the other hand, because prolonged fetal hypoxia causes decreased renal perfusion and decreased fetal urine production, resulting in oligohydramnios, amniotic fluid volume serves as a chronic index of placental function (6). As a result, both acute and chronic fetal impairment are thought to be indicated by aberrant BPP readings. Poor biophysical profile scores have been linked in numerous studies to metabolic acidosis, fetal discomfort during birth, poor Apgar scores, admission to the neonatal intensive care unit (NICU), and higher perinatal mortality (7). The fetal biophysical profile has some drawbacks despite its extensive clinical use. Longer examination times may be needed for the test, particularly if fetal sleep cycles interfere with evaluation. Furthermore, aberrant BPP alterations may appear relatively late in the fetal hypoxia progression, which could postpone the identification of placental insufficiency (8). Furthermore, operator experience and interpretation may have an impact on the BPP's accuracy. These restrictions have prompted scientists to investigate other techniques that can detect fetal impairment earlier. One of the most useful methods for assessing the circulation of the mother and fetus in high-risk pregnancies is Doppler ultrasonography. In addition to measuring blood flow velocity within blood vessels, Doppler ultrasound offers crucial details about placental perfusion and vascular resistance. Fetoplacental and uteroplacental circulation are frequently evaluated by Doppler investigations of the uterine artery, umbilical artery, middle cerebral artery, and ductus venous (9). Among these, uterine artery Doppler is especially important for assessing placental function and forecasting unfavorable pregnancy outcomes linked to aberrant placentation. Trophoblastic invasion during a typical pregnancy converts the mother's spiral arteries into low-resistance blood channels that can adequately nourish the growing placenta. Placental insufficiency, decreased uteroplacental perfusion, and prolonged high vascular resistance are the outcomes of this physiological change failing (10). These anomalies are frequently seen in pregnancies accompanied by fetal compromise, intrauterine growth restriction, and preeclampsia. Blood flow waveforms are evaluated by uterine artery Doppler, which also computes indicators including pulsatility index (PI), resistive index (RI), systolic/diastolic ratio (S/D ratio), and early diastolic notching. Persistent diastolic notching and elevated resistance indices are regarded as aberrant findings that point to poor placental circulation (11). The clinical value of uterine artery Doppler in predicting unfavorable obstetric outcomes has been shown in a number of research. Preeclampsia, fetal growth limitation, placental abruption, premature delivery, low birth weight, and intrauterine fetal death have all been linked to elevated uterine arterial resistance (12). Doppler ultrasound is regarded as a useful tool for the early detection of placental insufficiency because

aberrant uterine artery Doppler findings may manifest before fetal biophysical alterations become clinically apparent. Doppler ultrasonography is also generally accessible, non-invasive, and reasonably priced, which makes it particularly helpful in healthcare environments with limited resources. By identifying fetuses at risk for hypoxia and determining the best time for delivery, Doppler ultrasound's incorporation into regular fetal surveillance has revolutionized the management of high-risk pregnancies. Research has demonstrated that Doppler velocimetry can lower perinatal mortality and avoidable obstetric procedures in high-risk pregnancies (13). However, uterine artery Doppler does not directly evaluate fetal neurological function or oxygen reserve, even if it offers useful information about placental blood flow. The fetal biophysical profile, on the other hand, assesses the functional condition of the fetus but could miss early hemodynamic alterations that precede fetal distress. Consequently, a more thorough and precise evaluation of fetal health may be obtained by combining the two methods. Fetal biophysical profile and uterine artery Doppler together provide a physiological and hemodynamic assessment of the placenta and fetus. While the BPP can evaluate the extent of fetal adaptability and neurological damage brought on by hypoxia, Doppler ultrasound can identify aberrant placental perfusion prior to fetal hypoxia causing behavioral changes in the fetus (14).Thus, the sensitivity, specificity, and overall diagnostic accuracy for identifying fetal impairment in high-risk pregnancies may be enhanced by combining these two modalities. When compared to each approach alone, integrated fetal surveillance techniques may offer better predictive value for unfavorable perinatal outcomes, according to a number of researchers. Studies assessing integrated fetal surveillance strategies have shown encouraging results. In high-risk pregnancies, Morris et al. showed that umbilical artery Doppler significantly predicted fetal compromise and unfavorable newborn outcomes (15). According to Manning et al., fetal distress, NICU admission, low Apgar scores, low umbilical cord pH, intrauterine growth restriction, and perinatal mortality were all substantially correlated with declining biophysical profile (BPP) scores (16). Abnormal umbilical artery Doppler findings have also been linked to fetal growth limitation, low Apgar scores, surgical delivery for fetal distress, and neonatal death in pre-eclamptic pregnancies (17, 18). Additionally, in high-risk pregnancies, simultaneous fetal surveillance with Doppler and BPP has been linked to better prediction of unfavorable neonatal outcomes and decreased significant newborn morbidity (19). Combined sonographic evaluation using BPP and multivessel Doppler parameters showed superior prediction of unfavorable fetal outcomes in pregnancies complicated by fetal growth restriction compared to individual monitoring tests (20). Similarly, studies comparing modified BPP with Doppler ultrasonography found that combining these methods improved the detection of non-reassuring fetal status compared with either method alone (21). Additionally, uterine artery Doppler has been useful in identifying pregnancies at higher risk of fetal growth limitation, preterm birth, pre-eclampsia, and other unfavorable pregnancy outcomes, allowing for closer fetal surveillance (22, 23). According to more recent research, severe small-for-gestational-age birth, iatrogenic preterm birth, and perinatal loss are linked to an increase in the uterine artery Doppler pulsatility index (24). Together, these results imply that BPP, which represents the fetus's current physiological state, and Doppler evaluation of placental and fetoplacental circulation offer complementary information and may enhance the detection of fetal compromise, especially in pregnancies complicated by fetal growth restriction, pre-eclampsia, and other high-risk conditions. The current study aims to assess the diagnostic precision of combined fetal biophysical profile and uterine artery Doppler in detecting fetal impairment in high-risk pregnancies. The study's goal is to determine whether combining these modalities enhances their sensitivity, specificity, and predictive value as compared to employing them independently. Better perinatal outcomes in high-risk pregnancies, early fetal distress diagnosis,

timely obstetric care, and improved fetal surveillance techniques could all benefit from this study's findings.

Objective

To evaluate the diagnostic accuracy of combined fetal Biophysical Profile and uterine artery Doppler in identifying fetal compromise in high-risk pregnancies.

Methodology

A prospective cross-sectional analytical study was carried out at Farooq Hospital in Lahore. Ninety six pregnant women with singleton pregnancies at ≥28 weeks of gestation who were deemed high-risk because of pregnancy-induced hypertension, preeclampsia, intrauterine growth restriction, diabetes mellitus, oligohydramnios, or a history of poor obstetric outcomes were included in the study. Non-probability sampling was used to recruit participants. Incomplete clinical data, known fetal congenital abnormalities, numerous pregnancies, and low-quality ultrasound images were all grounds for exclusion. Using the diagnostic accuracy formula and assuming a predicted sensitivity of 80%, an 8% margin of error, and a 95% confidence level, the necessary sample size was first determined to be 96. After giving their informed consent, each subject had a standard ultrasound and Doppler evaluation utilizing a real-time ultrasound system with a 2-5 MHz curvilinear transducer and Doppler capability. Fetal respiratory movements, gross body movements, fetal tone, amniotic fluid volume, and, if relevant, non-stress testing were used to evaluate the fetal biophysical profile (BPP). A total score of 10 was obtained by assigning a score of 0 or 2 to each component; a BPP score of ≤6 was deemed abnormal. A transabdominal uterine artery Doppler examination was carried out. The systolic/diastolic (S/D) ratio, resistance index (RI), pulsatility index (PI), and the existence of an early diastolic notch were all noted. When PI or RI exceeded reference values relevant to gestational age or when there was a persistent diastolic notch, Doppler results were deemed abnormal. SPSS version 26 was used for data entry and analysis. The clinical results and participant characteristics were summarized using descriptive statistics. Sensitivity, specificity, positive predictive value, negative predictive value, and total diagnostic accuracy were used to assess the diagnostic performance of BPP alone, uterine artery Doppler alone, and their combined use. To evaluate diagnostic performance, receiver operating characteristic (ROC) curves were also created. Statistical significance was defined as a p-value of less than 0.05. The appropriate Institutional Review Board granted ethical approval. All subjects provided written informed permission, and study confidentiality was upheld. It was entirely voluntary to participate, and clinical care was unaffected by withdrawal at any moment. The routine ultrasound and Doppler assessment were the only methods used in the examinations, and the treatment team was informed of any clinically noteworthy findings.

RESULTS

Table 4.1 Maternal Age (Years) & Gestational Age (weeks)

Statistics							
	N		Mean	Median	Std. Deviation	Minimum	Maximum
	Valid	Missing					
Maternal Age Years	96	0	28.27	28.00	4.371	20	40
Gestational Age (weeks)	96	0	33.727	33.850	2.7019	28.0	39.0

Table 4.1 showing the study included **96 participants**. With a mean maternal age was **28.27 ± 4.37 years**, with a median age of **28 years** and a range of **20-40 years**. The mean gestational age was **33.73 ± 2.70 weeks**, with a median of **33.85 weeks** and a range of **28-39 weeks**.

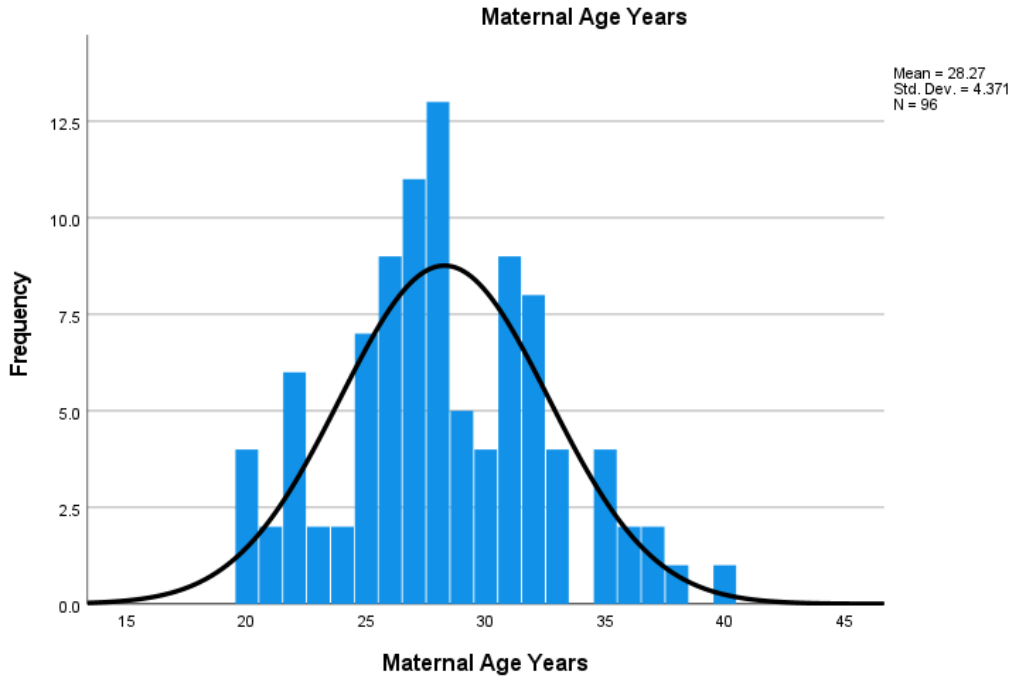


Figure 4.1(a) Histogram showing the descriptive statistics of maternal age.

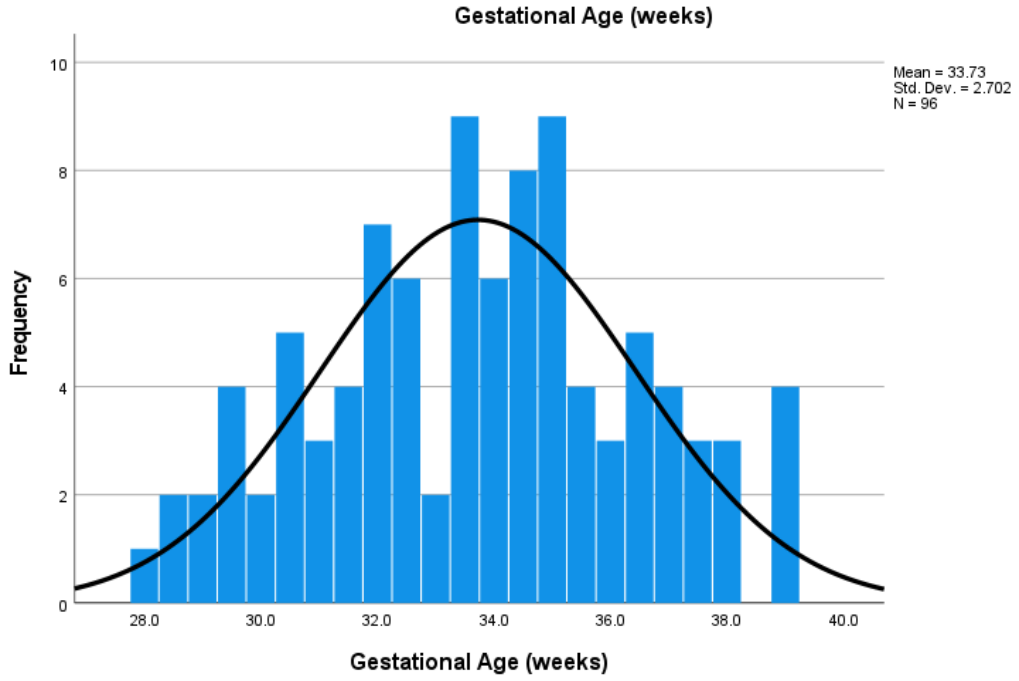


Figure 4.1 (b) Histogram showing the descriptive statistics of gestational age

Table 4.2 Total BPP Score (cut-off: ≤6)

Test classification	Fetal compromise: Yes	Fetal compromise: No
Positive	TP = 17	FP = 0
Negative	FN = 0	TN = 79

Sensitivity = 100.0%, Specificity = 100.0%

Table 4.2 showing the total BPP score showed 100% sensitivity and 100% specificity, correctly identifying all pregnancies with and without fetal compromise in this study. This indicates excellent diagnostic performance at the selected cut-off.

Table 4.3 Mean UtA PI (cut-off: ≥0.99)

Test classification	Fetal compromise: Yes	Fetal compromise: No
Positive	TP = 17	FP = 64
Negative	FN = 0	TN = 15
Sensitivity = 100.0%, Specificity = 19.0%		

Table 4.20 showing Mean UtA PI demonstrated **100% sensitivity but low specificity (19.0%),** identifying all cases of fetal compromise but also classifying many non-compromised pregnancies as positive.

Table 4.4 Right UtA PI (cut-off: ≥1.28)

Test classification	Fetal compromise: Yes	Fetal compromise: No
Positive	TP = 11	FP = 37
Negative	FN = 6	TN = 42
Sensitivity = 64.7%, Specificity = 53.2%		

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Table 4.4 showing Right UtA PI showed **64.7% sensitivity and 53.2% specificity,** indicating moderate ability to identify fetal compromise while providing limited discrimination among pregnancies without compromise.

Table 4.5 Left UtA PI (cut-off: ≥1.08)

Test classification	Fetal compromise: Yes	Fetal compromise: No
Positive	TP = 14	FP = 53
Negative	FN = 3	TN = 26
Sensitivity = 82.4%, Specificity = 32.9%		

Table 4.5 showing Left UtA PI demonstrated relatively high **sensitivity (82.4%)** but low **specificity (32.9%)**, detecting most compromised pregnancies but producing a considerable number of false-positive results.

Table 4.6 Right UtA RI (cut-off: ≥0.56)

Test classification	Fetal compromise: Yes	Fetal compromise: No
Positive	TP = 6	FP = 17
Negative	FN = 11	TN = 62
Sensitivity = 35.3%, Specificity = 78.5%		

Table 4.6 showing Right UtA RI showed **35.3% sensitivity and 78.5% specificity,** indicating that it was better at identifying pregnancies without fetal compromise than detecting those with compromise

Table 4.7 Left UtA RI (cut-off: ≥0.50)

Test classification	Fetal compromise: Yes	Fetal compromise: No
Positive	TP = 13	FP = 59
Negative	FN = 4	TN = 20
Sensitivity = 76.5%, Specificity = 25.3%		

Table 4.7 showing Left UtA RI demonstrated **76.5% sensitivity and 25.3% specificity**, suggesting good detection of fetal compromise but relatively poor ability to correctly exclude non-compromised pregnancies.

Table 4.8 Right S/D (cut-off: ≥3.03)

Test classification	Fetal compromise: Yes	Fetal compromise: No
Positive	TP = 17	FP = 69
Negative	FN = 0	TN = 10
Sensitivity = 100.0%, Specificity = 12.7%		

Table 4.8 showing Right S/D demonstrated **100% sensitivity but only 12.7% specificity**, detecting all cases of fetal compromise but producing a high proportion of false-positive classifications.

Table 4.9 Left S/D (cut-off: ≥3.45)

Test classification	Fetal compromise: Yes	Fetal compromise: No
Positive	TP = 10	FP = 29
Negative	FN = 7	TN = 50
Sensitivity = 58.8%, Specificity = 63.3%		

Table 4.9 showing Left S/D showed **58.8% sensitivity and 63.3% specificity**, demonstrating moderate performance in distinguishing pregnancies with fetal compromise from those without it.

Table 4.10 Combined BPP + Mean UtA PI (cut-off: Predicted probability ≥0.327)

Test classification	Fetal compromise: Yes	Fetal compromise: No
Positive	TP = 17	FP = 2
Negative	FN = 0	TN = 77
Sensitivity = 100.0%, Specificity = 97.5%		

Table 4.10 showing the combined BPP and Mean UtA PI model demonstrated 100% sensitivity and 97.5% specificity, correctly identifying nearly all pregnancies according to their fetal compromise status. This indicates strong discriminatory performance of the combined assessment.

Table 4.11 True Positive, True Negative, False Positive, False Negative, Sensitivity and Specificity

Test	Cut-off	TP	TN	FP	FN	Sensitivity (%)	Specificity (%)
Total BPP Score	≤6	17	79	0	0	100.0	100.0
Mean UtA PI	≥0.99	17	15	64	0	100.0	19.0
Right UtA PI	≥1.28	11	42	37	6	64.7	53.2

Left UtA PI	≥1.08	14	26	53	3	82.4	32.9
Right UtA RI	≥0.56	6	62	17	11	35.3	78.5
Left UtA RI	≥0.50	13	20	59	4	76.5	25.3
Right S/D	≥3.03	17	10	69	0	100.0	12.7
Left S/D	≥3.45	10	50	29	7	58.8	63.3
Combined BPP + Mean UtA PI	≥0.327	17	77	2	0	100.0	97.5

Table 4.11 showing that the total BPP score (≤6) showed excellent diagnostic performance, with 100% sensitivity and 100% specificity, correctly identifying all cases with and without fetal compromise. Among the uterine artery Doppler parameters, mean UtA PI (≥0.99) and right Ut.A S/D (≥3.03) achieved 100% sensitivity, but their specificity was low at 19.0% and 12.7%, respectively. The remaining Doppler indices showed variable sensitivity and specificity. Notably, the combined BPP + mean UtA PI demonstrated 100% sensitivity and 97.5% specificity, indicating excellent diagnostic accuracy and improved specificity compared with mean UtA PI alone. Overall, the findings suggest that BPP, particularly when combined with mean UtA PI, provided the most effective discrimination of fetal compromise in the study population.

Table 4.12 Diagnostic Odds Ratio (DOR)

Test	Cut-off	TP	TN	FP	FN	DOR
Total BPP Score	≤6	17	79	0	0	∞
Mean UtA PI	≥0.99	17	15	64	0	∞
Right UtA PI	≥1.28	11	42	37	6	2.081
Left UtA PI	≥1.08	14	26	53	3	2.289
Right UtA RI	≥0.56	6	62	17	11	1.989
Left UtA RI	≥0.50	13	20	59	4	1.102
Right S/D	≥3.03	17	10	69	0	∞
Left S/D	≥3.45	10	50	29	7	2.463
Combined BPP + Mean UtA PI	≥0.327	17	77	2	0	∞

Table 4.12 showing the Diagnostic Odds Ratio (DOR) of the BPP score and uterine artery Doppler parameters for detecting fetal compromise. The total BPP score (≤6) demonstrated an infinite DOR (∞) because there were no false-positive or false-negative results, indicating perfect discrimination in this study population. Similarly, mean UtA PI (≥0.99), right UtA S/D (≥3.03), and combined BPP + mean UtA PI (≥0.327) showed an infinite DOR due to the absence of false-negative cases. Among the individual Doppler parameters with finite values, left UtA S/D had the highest DOR (2.463), followed by left UtA PI (2.289), right UtA PI (2.081), right UtA RI (1.989), and left UtA RI (1.102). Overall, the findings indicate that BPP and the combined BPP + mean UtA PI provided the strongest diagnostic discrimination, while the individual UtA Doppler indices showed comparatively lower diagnostic performce.

Discussion

The present study evaluated the diagnostic performance of the biophysical profile (BPP) and uterine artery Doppler parameters in identifying fetal compromise. The total BPP score at a cut-off of ≤6 demonstrated 100% sensitivity and 100% specificity, correctly classifying all pregnancies with and without fetal compromise in the present study population. This excellent performance may be attributed to the composite nature of BPP, which incorporates multiple indicators of fetal physiological well-being. Previous studies have established BPP as an important method of antepartum fetal assessment, although diagnostic performance may vary according to the scoring system, population and outcome definition (25). The performance of the uterine artery Doppler parameters was more inconsistent. The mean UtA PI demonstrated 100% sensitivity but only 19.0% specificity, meaning that while all affected pregnancies were identified, a sizable portion of non-compromised pregnancies were also categorized as positive. In a similar vein, the right UtA S/D showed 12.7% specificity but 100% sensitivity. These results imply that elevated uteroplacental resistance is not always specific for established fetal impairment but may be susceptible to pregnancies with unfavorable conditions. Increased uterine artery PI has been linked to poor pregnancy outcomes in earlier research; nevertheless, diagnostic performance varies depending on gestational age, demographic, and outcome. In a meta-analysis of 55,974 women, Velauthar et al. (2014) found that while aberrant uterine artery Doppler was linked to unfavorable outcomes, sensitivity was significantly lower than specificity for a number of outcomes (26). Significant variance was also seen in the individual UtA PI and RI readings. While the left UtA PI showed greater sensitivity (82.4%) but poorer specificity (32.9%), the right UtA PI showed 64.7% sensitivity and 53.2% specificity. While left UtA RI showed 76.5% sensitivity and 25.3% specificity, right UtA RI showed comparatively greater specificity (78.5%) but poor sensitivity (35.3%). These results suggest that the diagnostic ability of particular uterine artery Doppler indices is restricted and inconsistent. This is corroborated by Adefisan et al. (2020), who found significant differences in sensitivity and specificity between PI and RI and poor predictive capacity of second-trimester uterine artery Doppler indices for unfavorable pregnancy outcomes in a low-risk cohort (27). With 100% sensitivity and 97.5% specificity, the combined BPP and mean UtA PI model showed the best diagnostic performance. Significantly, while sensitivity stayed at 100%, specificity rose significantly from 19.0% for mean UtA PI alone to 97.5% when paired with BPP. The complimentary data from the two evaluations could account for this improvement. While uterine artery PI gives information about maternal uteroplacental vascular resistance, BPP mainly represents fetal physiological health. Its utility as a marker of aberrant placental vascular function is supported by prior research demonstrating that sustained elevation of uterine artery PI is linked to unfavorable pregnancy outcomes (Gomez et al., 2015) (28). Overall, the findings **suggest** that BPP

performed excellently in the present study, while individual uterine artery Doppler parameters showed variable diagnostic performance. The combination of BPP and mean UtA PI provided substantially better discrimination than mean UtA PI alone. However, the results should be interpreted cautiously because only 17 pregnancies had fetal compromise, and the combined model was evaluated in the same study population. Therefore, larger prospective studies with independent validation are required to confirm the observed 100% sensitivity and 97.5% specificity and to establish the generalizability of the combined model. The results of this study are in line with the known function of the biophysical profile (BPP) as an all-encompassing fetal surveillance technique. Because there were no false-positive or false-negative results in the current investigation, the overall BPP score (≤6) showed an infinite DOR, demonstrating full discriminating between fetuses with and without fetal impairment. The utility of BPP for detecting prenatal hypoxia and unfavorable neonatal outcomes is also supported by prior research, even though these investigations have often indicated high diagnostic accuracy rather than perfect performance. For instance, a research carried out in a high-risk population in Peshawar found that BPP had a sensitivity of 79.1% and a specificity of 92.9% for identifying fetal hypoxia, but another study found a sensitivity of 85.7% and a specificity of 94.8% (29). The artery in the uterus Although its diagnostic effectiveness varied significantly depending on the Doppler parameter and threshold, Doppler results also indicate the function of aberrant maternal uteroplacental blood flow as an indication of a poor pregnancy outcome. Since there were no false-negative results in the current investigation, mean UtA PI and right UtA S/D displayed infinite DOR; nevertheless, their comparatively large false-positive rates decreased specificity. This heterogeneity is in line with other research demonstrating the helpful but generally moderate predictive accuracy of uterine artery Doppler, with performance impacted by population risk, gestational age, and the chosen cut-off. While another meta-analysis discovered that irregular uterine artery Doppler had varying accuracy for unfavorable perinatal outcomes, a meta-analysis of 27 trials including 81,673 women reported moderate sensitivity and high specificity for UtA PI in predicting pre-eclampsia (30). Crucially, the current study's combined BPP + mean UtA PI achieved an infinite DOR with 100% sensitivity and 97.5% specificity, indicating that combining placental vascular assessment using UtA Doppler with functional fetal assessment using BPP may offer more thorough discrimination of fetal compromise than depending solely on individual Doppler indices (31).

Conclusion

With a BPP score of ≤6 attaining 100% sensitivity and specificity, the current study demonstrated the BPP's great efficacy in detecting fetal impairment. The diagnostic performance of uterine artery Doppler measures varied, however the combination of BPP and mean UtA PI exhibited better discrimination, with 97.5% specificity and 100% sensitivity. Fetal compromise was also substantially correlated with abnormal amniotic fluid volume. Overall, the results are consistent with the use of uterine artery Doppler, BPP, and amniotic fluid evaluation as complimentary methods for fetal surveillance in high-risk pregnancies.

Limitations

The study's limited sample size from a single hospital may have limited how broadly the results may be applied. Unstable estimations of diagnostic performance may also have been caused by the lack of false-positive and false-negative examples for some metrics. To validate these results, larger multicenter trials are required.

Recommendations

Larger prospective and multicenter studies are recommended to validate the diagnostic

performance of BPP and uterine artery Doppler, particularly their combined use. Future research should include standardized assessment methods, independent validation, and evaluation of additional measures such as predictive values, likelihood ratios, and ROC analysis. In clinical practice, amniotic fluid and Doppler findings should be interpreted alongside the complete BPP and other maternal and fetal clinical factors rather than as isolated indicators.

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