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Original Article

Evaluation Of Hemodynamic Changes of Fetal Renal Artery in Relation with Increased or Decreased Amniotic Fluid Index of Gestating Women in 3rd Trimester

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ABSTRACT

Background: Amniotic fluid volume is an important marker of fetal well-being, placental function, and fetal renal activity during late pregnancy. Because fetal urine contributes substantially to amniotic fluid volume in the third trimester, fetal renal artery Doppler indices may provide adjunctive information regarding renal perfusion in pregnancies with abnormal amniotic fluid index. Objective: To evaluate fetal renal artery Doppler indices among third-trimester pregnant women with normal AFI, oligohydramnios, and polyhydramnios. Methods: This cross-sectional observational study included 40 singleton third-trimester pregnancies assessed at The Doctors Hospital, Gujrat. Participants were categorized as normal AFI, oligohydramnios, or polyhydramnios. Fetal renal artery pulsatility index, resistive index, and systolic-to-diastolic ratio were measured using Doppler ultrasonography. Data were analyzed using descriptive statistics, one-way ANOVA, Pearson and Spearman correlation, and multiple linear regression in IBM SPSS Statistics version 27. Results: Normal AFI was observed in 21 participants (52.5%), oligohydramnios in 12 (30.0%), and polyhydramnios in 7 (17.5%). Fetal renal artery PI and RI showed borderline differences across AFI categories, with p-values of 0.051 and 0.062, respectively. Spearman correlation showed a significant inverse association between AFI and renal artery RI (rho = −0.322, p = 0.043). Renal artery S/D ratio and estimated fetal weight were significantly associated with AFI in regression analysis. Conclusion: Fetal renal artery Doppler indices, particularly RI, showed clinically relevant association with AFI in third-trimester pregnancies. Renal artery Doppler may provide adjunctive information during AFI assessment, although larger studies are needed. Keywords: Amniotic Fluid Index; Doppler Ultrasonography; Fetal Renal Artery; Oligohydramnios; Polyhydramnios; Pulsatility Index; Resistive Index

INTRODUCTION

Amniotic fluid is a dynamic intrauterine medium that supports fetal growth, protects the fetus from mechanical injury, permits musculoskeletal movement, contributes to pulmonary and gastrointestinal development, and reflects the combined functional status of the placenta, fetal membranes, and fetal organ systems. During early gestation, amniotic fluid is derived mainly from maternal and transmembranous sources, but as pregnancy advances, fetal urine becomes a major contributor to amniotic fluid volume, particularly during the second half of pregnancy. Because fetal renal perfusion directly influences urine production, abnormalities in amniotic fluid volume may provide indirect evidence of altered fetal renal and placental physiology. Assessment of amniotic fluid volume is therefore a central component of obstetric ultrasonography and fetal surveillance, especially in the third trimester when fetal urine output plays a dominant role in maintaining amniotic fluid balance (1,2).

The amniotic fluid index is widely used as a non-invasive sonographic measure of amniotic fluid volume and is commonly obtained by summing the deepest vertical pockets measured in the four uterine quadrants. Abnormalities of amniotic fluid volume are clinically important because both reduced and excessive fluid levels are associated with adverse maternal, fetal, and neonatal outcomes. Oligohydramnios is generally defined by a markedly reduced amniotic fluid volume, commonly an AFI of 5 cm or less, and has been associated with fetal growth restriction, umbilical cord compression, meconium-stained liquor, fetal distress, congenital renal anomalies, increased operative delivery, low birth weight, and higher perinatal morbidity. In contrast, polyhydramnios is characterized by excessive amniotic fluid accumulation, commonly defined by an AFI of 25 cm or more, and may be associated with maternal diabetes, fetal structural anomalies, chromosomal disorders, macrosomia, preterm labor, malpresentation, placental abruption, cord prolapse, and postpartum hemorrhage (3–8).

The fetal kidneys play a central role in maintaining amniotic fluid homeostasis during late pregnancy. Adequate renal arterial perfusion is necessary for glomerular filtration and urine formation, and therefore hemodynamic changes in the fetal renal circulation may contribute to or reflect variations in amniotic fluid volume. Doppler ultrasonography provides a non-invasive method for evaluating fetal vascular resistance through quantitative indices such as the pulsatility index, resistive index, and systolic-to-diastolic ratio. These indices reflect downstream vascular impedance and may offer additional information beyond AFI measurement alone, particularly when abnormal fluid volume suggests altered renal perfusion or fetal compensatory circulation (9–11).

Previous studies have suggested that pregnancies complicated by oligohydramnios tend to show higher fetal renal artery resistance indices, whereas pregnancies with polyhydramnios may demonstrate relatively lower resistance patterns. These findings support the biological plausibility that reduced renal perfusion may be associated with decreased fetal urine production and lower AFI, while comparatively increased renal perfusion may contribute to excessive amniotic fluid in some pregnancies. However, reported associations vary across studies because of differences in gestational age, case definitions, sample size, maternal risk profile, Doppler technique, and statistical methods. Furthermore, although fetal renal artery Doppler has been investigated internationally, local evidence from Pakistani obstetric populations remains limited, particularly for simultaneous comparison of normal AFI, oligohydramnios, and polyhydramnios in third-trimester pregnancies (12–16).

This gap is clinically relevant because AFI assessment alone provides an estimate of fluid volume but does not directly evaluate fetal renal hemodynamics. In settings where Doppler ultrasonography is already available during obstetric scanning, renal artery Doppler may serve as an adjunctive tool to improve interpretation of abnormal AFI and support timely fetal surveillance. A clearer understanding of the relationship between fetal renal artery indices and AFI categories may help determine whether renal Doppler parameters provide clinically useful information in pregnancies with reduced or excessive amniotic fluid. Therefore, this study aimed to evaluate fetal renal artery Doppler indices, including pulsatility index, resistive index, and systolic-to-diastolic ratio, among third-trimester pregnant women with normal AFI, oligohydramnios, and polyhydramnios. The study was guided by the research question: are fetal renal artery Doppler indices associated with amniotic fluid index category among third-trimester pregnant women?

MATERIAL AND METHODS

This cross-sectional observational study was conducted at The Doctors Hospital, Gujrat, over a period of 90 days after approval of the study synopsis. The study was designed to evaluate fetal renal artery Doppler indices among third-trimester pregnant women and to compare these indices across amniotic fluid index categories. A cross-sectional design was selected because the objective was to assess the relationship between AFI status and fetal renal artery hemodynamic parameters at the time of obstetric ultrasound examination, rather than to evaluate longitudinal change or treatment response.

The study included 40 pregnant women who underwent obstetric ultrasonography during the third trimester. Participants were selected through convenience sampling from eligible women presenting for antenatal ultrasound assessment during the study period. Women were considered eligible if they had a singleton pregnancy, gestational age between 26 and 40 weeks, maternal age below 35 years, and an AFI category documented as normal, oligohydramnios, or polyhydramnios. Women were excluded if they had hypertension, a previous history of any type of diabetes, fetal congenital anomaly, gestational age below 26 weeks, or maternal age above 35 years. Pregnancies with maternal hypertension and diabetes were excluded to reduce confounding because these conditions can independently affect placental perfusion, fetal growth, renal circulation, and amniotic fluid volume.

All ultrasound examinations were performed using a Toshiba Xario color Doppler ultrasound machine with a curved-array transducer. Maternal age, gestational age, fetal presentation, placental position, amniotic fluid index, estimated fetal weight, and fetal renal artery Doppler parameters were recorded. AFI was measured sonographically using the four-quadrant technique, and participants were categorized into AFI groups using consistent operational thresholds: oligohydramnios was defined as AFI ≤ 5 cm, normal AFI as >5 cm and <25 cm, and polyhydramnios as AFI ≥ 25 cm. Estimated fetal weight was obtained from routine obstetric biometric measurements generated during the ultrasound examination. Fetal renal artery Doppler assessment was used to obtain the pulsatility index, resistive index, and systolic-to-diastolic ratio, which were treated as the principal Doppler outcome variables. AFI category was treated as the main grouping variable for comparative analysis, while continuous AFI was also used for correlation and regression analyses.

Data were entered and analyzed using IBM SPSS Statistics version 27. Continuous variables were summarized as mean ± standard deviation when approximately normally distributed, while categorical variables were summarized as frequencies and percentages. Descriptive analysis was performed for maternal age, gestational age, AFI, estimated fetal weight, fetal renal artery pulsatility index, fetal renal artery resistive index, and renal artery systolic-to-diastolic ratio. Categorical variables, including AFI category, placental position, and fetal presentation, were presented using frequency distributions. One-way analysis of variance was used to compare continuous clinical and Doppler parameters across AFI categories when parametric assumptions were considered acceptable. Pearson correlation analysis was used to assess linear relationships between AFI and renal artery Doppler indices, while Spearman correlation analysis was used to assess monotonic associations, particularly where skewness or outlying values were suspected. Multiple linear regression analysis was performed to evaluate the association of renal artery Doppler indices and obstetric variables with AFI as the outcome variable. Predictor variables included renal artery systolic-to-diastolic ratio, renal artery resistive index, renal artery pulsatility index, fetal presentation, placental position, estimated fetal weight, and gestational age. Statistical significance was assessed at $p<0.05$.

To improve internal validity, eligibility criteria were restricted to singleton pregnancies without documented maternal hypertension, diabetes, or fetal congenital anomaly, thereby reducing major clinical sources of confounding. Data were checked for completeness before analysis, and only available recorded values were included in the final statistical analysis. Continuous variables were reviewed for extreme values because renal artery Doppler indices, particularly systolic-to-diastolic ratio, may be affected by very low diastolic flow, fetal movement, image quality, or measurement artifact. The same ultrasound equipment platform was used for Doppler and obstetric measurements to maintain procedural consistency. Data integrity was supported by structured recording of maternal, fetal, AFI, and Doppler variables before entry into SPSS, followed by review of descriptive outputs to identify implausible or inconsistent values.

RESULTS

A total of 40 third-trimester pregnant women were included in the analysis. The mean maternal age was 29.00 ± 3.36 years, and the mean gestational age was 242.90 ± 18.30 days. The mean amniotic fluid index was 11.48 ± 8.86 cm, indicating wide variability in fluid volume across the study population. The mean estimated fetal weight was 2514.78 ± 618.41 g. Among fetal renal artery Doppler indices, the mean pulsatility index was 1.91 ± 0.71 and the mean resistive index was 0.82 ± 0.14. The renal artery systolic-to-diastolic ratio showed substantial dispersion, with a mean of 34.72 ± 116.12 and a maximum value of 532.63, suggesting marked skewness or the presence of an extreme value requiring cautious interpretation.

Table 1. Descriptive Characteristics of Maternal, Fetal, and Fetal Renal Artery Doppler Variables

Variable	n	Minimum	Maximum	Mean ± SD
Maternal age, years	40	21	34	29.00 ± 3.36
Gestational age, days	40	186	279	242.90 ± 18.30
Amniotic fluid index, cm	40	2	33	11.48 ± 8.86
Estimated fetal weight, g	40	950	3732	2514.78 ± 618.41
Fetal renal artery pulsatility index	40	0.57	3.40	1.91 ± 0.71
Fetal renal artery resistive index	40	0.56	1.03	0.82 ± 0.14
Renal artery systolic-to-diastolic ratio	40	2.28	532.63	34.72 ± 116.12

The distribution of amniotic fluid index categories showed that 21 participants had normal AFI, representing 52.5% of the sample. Oligohydramnios was present in 12 participants, accounting for 30.0%, while polyhydramnios was observed in 7 participants, accounting for 17.5%. This distribution allowed comparison across normal, reduced, and increased amniotic fluid groups, although the relatively small polyhydramnios subgroup should be considered when interpreting comparative findings.

Table 2. Distribution of Amniotic Fluid Index Categories

AFI category	n	%
Normal	21	52.5
Oligohydramnios	12	30.0
Polyhydramnios	7	17.5
Total	40	100.0

Anterior placental location was the most frequent placental position, observed in 19 participants, representing 47.5% of the sample. Posterior placental position was observed in 9 participants, while fundal posterior, fundal anterior, and fundal placental positions were observed in 6, 4, and 2 participants, respectively. Placental position did not differ significantly across AFI categories on one-way ANOVA, with F = 0.941 and p = 0.399.

Table 3. Distribution of Placental Position

Placental position	n	%
Anterior	19	47.5
Posterior	9	22.5
Fundal	2	5.0
Fundal anterior	4	10.0
Fundal posterior	6	15.0
Total	40	100.0

Cephalic fetal presentation was observed in 36 participants, representing 90.0% of the study population, while breech presentation was observed in 4 participants, representing 10.0%. Fetal presentation did not differ significantly across AFI categories in the comparative analysis, with F = 0.086 and p = 0.918.

Table 4. Distribution of Fetal Presentation

Fetal presentation	n	%
Cephalic	36	90.0
Breech	4	10.0
Total	40	100.0

Comparison of clinical and fetal renal artery Doppler parameters across AFI categories showed no statistically significant differences at the 0.05 level. Fetal renal artery pulsatility index showed a borderline association across AFI categories, with F = 3.222 and p = 0.051. Fetal renal artery resistive index also showed a borderline pattern, with F = 3.006 and p = 0.062. Estimated fetal weight, fetal presentation, placental position, renal artery systolic-to-diastolic ratio, and gestational age did not show statistically significant differences across AFI categories.

Table 5. Comparison of Clinical and Fetal Renal Artery Doppler Parameters Across AFI Categories

Variable	Sum of Squares	df	Mean Square	F	p-value
Estimated fetal weight, g	1,525,154	2	762,577	2.107	0.136
Fetal presentation	0.017	2	0.008	0.086	0.918
Placental position	4.308	2	2.154	0.941	0.399
Fetal renal artery pulsatility index	2.923	2	1.461	3.222	0.051
Renal artery systolic-to-diastolic ratio	32,122	2	16,061	1.204	0.312
Fetal renal artery resistive index	0.101	2	0.050	3.006	0.062
Gestational age, days	858.59	2	429.29	1.298	0.285

Pearson correlation analysis showed weak inverse correlations between AFI and fetal renal artery pulsatility index, with r = −0.245 and p = 0.127, and between AFI and fetal renal artery resistive index, with r = −0.294 and p = 0.066. AFI showed a weak positive correlation with the renal artery systolic-to-diastolic ratio, with r = 0.154 and p = 0.342. Among Doppler indices, pulsatility index showed a strong positive correlation with resistive index, with r = 0.776 and p < 0.001, while pulsatility index and resistive index also correlated positively with the systolic-to-diastolic ratio.

Table 6. Pearson Correlation Analysis Between AFI and Fetal Renal Artery Doppler Indices

Variable pair	r	p-value
AFI and fetal renal artery pulsatility index	−0.245	0.127
AFI and fetal renal artery resistive index	−0.294	0.066
AFI and renal artery systolic-to-diastolic ratio	0.154	0.342
Fetal renal artery pulsatility index and resistive index	0.776	<0.001
Fetal renal artery pulsatility index and systolic-to-diastolic ratio	0.487	0.001
Fetal renal artery resistive index and systolic-to-diastolic ratio	0.359	0.023

Spearman correlation analysis demonstrated a statistically significant inverse correlation between AFI and fetal renal artery resistive index, with rho = −0.322 and p = 0.043. AFI showed a borderline inverse correlation with fetal renal artery pulsatility index, with rho = −0.306 and p = 0.055, while its correlation with the systolic-to-diastolic ratio was not statistically significant. Strong positive monotonic correlations were observed among fetal renal artery Doppler indices, particularly between resistive index and systolic-to-diastolic ratio, with rho = 0.897 and p < 0.001.

Table 7. Spearman Correlation Analysis Between AFI and Fetal Renal Artery Doppler Indices

Variable pair	rho	p-value
AFI and fetal renal artery pulsatility index	−0.306	0.055
AFI and fetal renal artery resistive index	−0.322	0.043
AFI and renal artery systolic-to-diastolic ratio	−0.248	0.123
Fetal renal artery pulsatility index and resistive index	0.799	<0.001
Fetal renal artery pulsatility index and systolic-to-diastolic ratio	0.714	<0.001
Fetal renal artery resistive index and systolic-to-diastolic ratio	0.897	<0.001

Multiple linear regression analysis was performed with AFI as the outcome variable. Renal artery systolic-to-diastolic ratio was positively associated with AFI, with B = 0.003, β = 0.407, t = 2.071, and p = 0.046. Estimated fetal weight was negatively associated with AFI, with B = −0.001, β = −0.789, t = −2.109, and p = 0.043. Renal artery resistive index, renal artery pulsatility index, fetal presentation, placental position, and gestational age were not statistically significant predictors in the model. Given the sample size of 40 and the inclusion of multiple predictors, these regression findings should be interpreted cautiously.

Overall, the results showed clinically suggestive variation in fetal renal artery Doppler indices across AFI categories, although the primary ANOVA comparisons for pulsatility index and resistive index did not reach conventional statistical significance. The most consistent association was the inverse Spearman correlation between AFI and fetal renal artery resistive index, indicating that lower AFI values were associated with higher renal vascular resistance. The strong correlations among pulsatility index, resistive index, and systolic-to-diastolic ratio further suggest that these indices reflect related aspects of fetal renal arterial impedance. However, the extreme dispersion in systolic-to-diastolic ratio and the limited sample size require cautious interpretation of both correlation and regression findings.

Table 8. Multiple Linear Regression Analysis of Factors Associated With Amniotic Fluid Index

Predictor	B	Standard Error	β	t	p-value
Constant	0.929	2.750	—	0.338	0.738
Renal artery systolic-to-diastolic ratio	0.003	0.001	0.407	2.071	0.046
Fetal renal artery resistive index	−2.254	1.595	−0.398	−1.413	0.167
Fetal renal artery pulsatility index	0.025	0.311	0.023	0.080	0.936
Fetal presentation	−0.071	0.430	−0.028	−0.166	0.869
Placental position	−0.102	0.089	−0.200	−1.144	0.261
Estimated fetal weight, g	−0.001	0.000	−0.789	−2.109	0.043
Gestational age, days	0.021	0.016	0.510	1.369	0.180

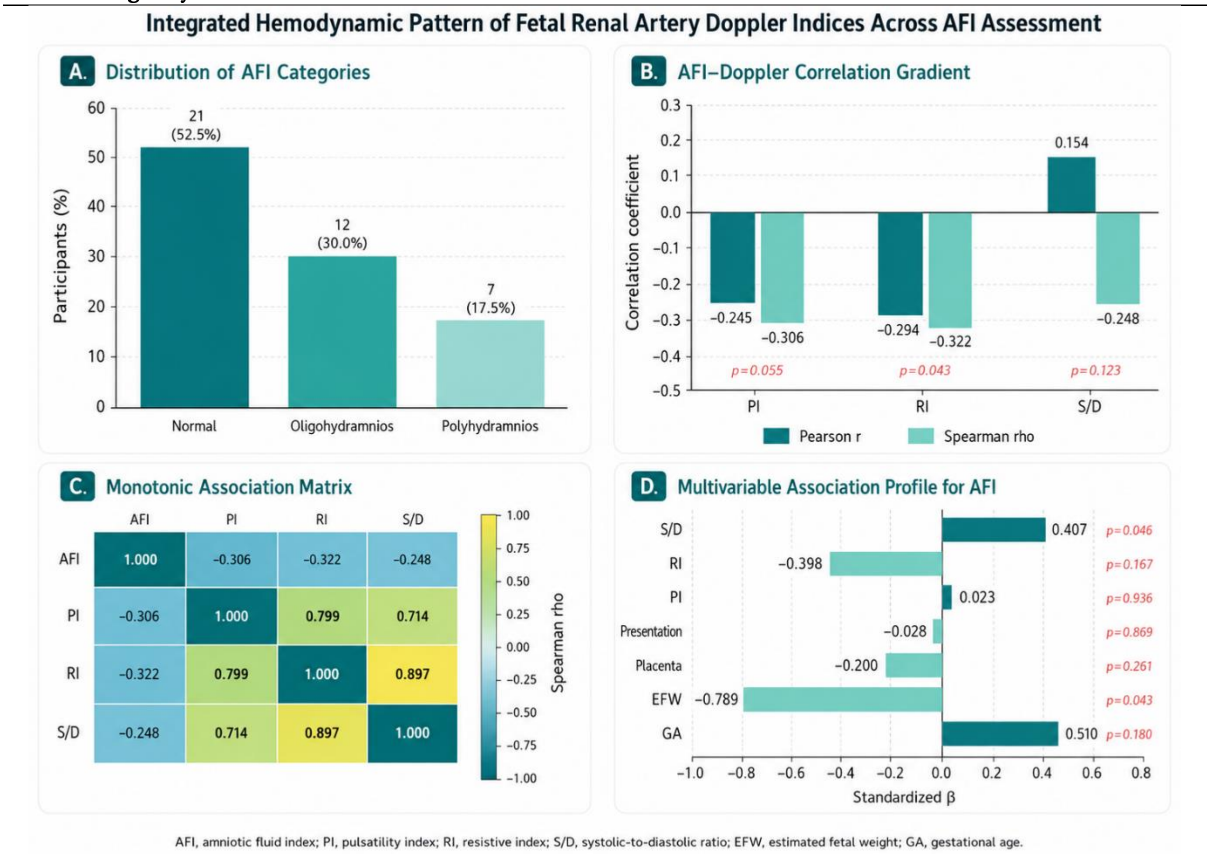

Figure 1. Integrated Hemodynamic Pattern of Fetal Renal Artery Doppler Indices Across AFI Assessment

The panelled figure summarizes the distributional, correlational, and multivariable patterns linking amniotic fluid index with fetal renal artery Doppler indices. Normal AFI was observed in 21 participants (52.5%), oligohydramnios in 12 (30.0%), and polyhydramnios in 7 (17.5%). AFI showed inverse monotonic correlations with fetal renal artery PI (rho = −0.306, p = 0.055), RI (rho = −0.322, p = 0.043), and S/D ratio (rho = −0.248, p = 0.123), with the RI association reaching statistical significance. The Doppler indices were strongly interrelated, particularly RI with S/D ratio (rho = 0.897), PI with RI (rho = 0.799), and PI with S/D ratio (rho = 0.714), indicating that these measures reflect closely linked components of renal arterial impedance. In the multivariable model, renal artery S/D ratio showed a positive association with AFI (β = 0.407, p = 0.046), whereas estimated fetal weight showed a negative association ($\beta = -0.789$, $p = 0.043$). Overall, the visual pattern supports a clinically relevant inverse relationship between AFI and renal vascular resistance, particularly for RI, while also highlighting the need for cautious interpretation because of the small sample size and marked dispersion in S/D ratio values.

DISCUSSION

This cross-sectional study evaluated fetal renal artery Doppler indices in relation to amniotic fluid index among third-trimester pregnant women with normal AFI, oligohydramnios, and polyhydramnios. The findings suggest a clinically relevant pattern in which lower AFI was associated with higher fetal renal arterial resistance, particularly for the resistive index. Although group-wise ANOVA comparisons for fetal renal artery pulsatility index and resistive index did not reach the conventional threshold for statistical significance, both parameters showed borderline associations across AFI categories, with PI showing $F = 3.222$ and $p = 0.051$ and RI showing $F = 3.006$ and $p = 0.062$. These findings indicate a trend toward altered fetal renal artery impedance across AFI groups, but they should not be interpreted as definitive group differences without larger sample confirmation and group-wise post-hoc analysis.

The significant inverse Spearman correlation between AFI and fetal renal artery resistive index provides the most consistent evidence from the present study. AFI was negatively correlated with RI, with rho = -0.322 and $p = 0.043$, indicating that lower amniotic fluid levels were associated with higher renal vascular resistance. This association is biologically plausible because fetal urine production becomes a major contributor to amniotic fluid volume during late pregnancy, and increased renal vascular impedance may reduce fetal renal perfusion and contribute to lower urine output. Pearson correlation showed a similar inverse direction for AFI with both PI and RI, although these associations did not reach statistical significance. The stronger performance of Spearman correlation may reflect the skewed distribution of Doppler measures, particularly the renal artery systolic-to-diastolic ratio, which showed an extreme maximum value and substantial dispersion.

The strong positive correlations among fetal renal artery PI, RI, and S/D ratio indicate that these Doppler indices represent closely related aspects of fetal renal arterial impedance. In the present study, Spearman correlation showed strong associations between PI and RI, PI and S/D ratio, and RI and S/D ratio. This internal coherence supports the physiological relevance of the Doppler measurements, although the marked variability in S/D ratio requires cautious interpretation. Extremely high S/D values may occur when diastolic flow is very low, but they may also reflect measurement artifact, fetal movement, suboptimal Doppler angle, or data-entry error. For this reason, future analysis should verify raw Doppler waveforms and consider reporting median and interquartile range for S/D ratio rather than relying only on mean and standard deviation.

The present findings are broadly consistent with previous studies reporting increased fetal renal artery impedance in pregnancies complicated by oligohydramnios. Benzer et al. reported that fetal renal artery Doppler indices may have predictive value in pregnancies with abnormal amniotic fluid volume, supporting the concept that renal arterial resistance is linked to fluid balance in low-risk pregnancies (17). Jain et al. similarly observed altered renal artery hemodynamics among normohydramnios, oligohydramnios, and polyhydramnios groups during the third trimester, with higher resistance patterns in oligohydramnios (18). Refaat et al. also reported that fetal renal artery Doppler indices differed in idiopathic oligohydramnios and polyhydramnios, suggesting that renal Doppler assessment may provide useful adjunctive information in pregnancies with abnormal AFI (20). The present study adds local evidence from a Pakistani clinical setting and supports the need for further evaluation of fetal renal artery Doppler as part of fetal assessment when AFI is abnormal.

The regression analysis showed that renal artery S/D ratio and estimated fetal weight were statistically associated with AFI in the multivariable model. The S/D ratio showed a positive association with AFI, while estimated fetal weight showed a negative association. However, this model should be interpreted carefully because the sample size was limited and multiple predictors were included. With 40 participants and seven predictors, the model may be overfitted, and the estimates may be unstable. In addition, estimated fetal weight and gestational age are biologically related, and collinearity between fetal growth and gestational maturity may influence regression estimates. The absence of reported model-fit statistics, confidence intervals, collinearity diagnostics, and residual assessment further limits interpretation. Therefore, the regression results should be viewed as exploratory rather than confirmatory.

The clinical relevance of this study lies in its focus on fetal renal artery Doppler assessment as an adjunct to conventional AFI measurement. AFI provides information about amniotic fluid volume but does not directly assess fetal renal perfusion. Renal artery Doppler, by contrast, can provide insight into fetal renal vascular resistance and may help identify hemodynamic adaptation in pregnancies with oligohydramnios or polyhydramnios. In practical obstetric imaging, this may be especially relevant when abnormal AFI is detected but the underlying fetal hemodynamic status is uncertain. Nevertheless, the current findings do not justify routine universal renal artery Doppler screening. Rather, they support further research into whether fetal renal artery RI and PI can improve risk stratification when used alongside AFI, fetal growth assessment, umbilical artery Doppler, and clinical risk factors.

Several limitations should be considered. First, the sample size was small, particularly in the polyhydramnios group, which included only seven participants. This limited statistical power and may explain why clinically suggestive differences in PI and RI did not reach statistical significance. Second, the single-center design and convenience sampling limit generalizability to broader obstetric populations. Third, pregnancies complicated by hypertension, diabetes, multiple gestation, and fetal congenital anomaly were excluded; therefore, the findings cannot be extrapolated to all high-risk pregnancies. Fourth, the Doppler acquisition protocol was not sufficiently detailed to assess examiner variability, angle correction, side of renal artery measurement, or repeatability. Fifth, the renal artery S/D ratio showed extreme dispersion, which may indicate skewness, outliers, or measurement artifact. Future studies should use larger multicenter samples, standardized Doppler protocols, raw waveform verification, non-parametric analysis for skewed variables, and longitudinal follow-up to determine whether fetal renal artery Doppler indices predict perinatal outcomes.

CONCLUSION

Fetal renal artery Doppler indices showed clinically suggestive variation across amniotic fluid index categories in third-trimester pregnancies, with lower AFI tending to be associated with higher renal vascular resistance. The strongest finding was a statistically significant inverse Spearman correlation between AFI and fetal renal artery resistive index, indicating that reduced amniotic fluid volume was associated with increased renal arterial impedance. Although PI and RI showed borderline differences across AFI categories, these findings did not reach conventional statistical significance and should be interpreted cautiously. Renal artery S/D ratio and estimated fetal weight were associated with AFI in exploratory regression analysis, but the small sample size and model limitations restrict confirmatory interpretation. Overall, fetal renal artery Doppler may provide useful adjunctive information during evaluation of abnormal AFI, but larger multicenter studies with standardized Doppler protocols and perinatal outcome follow-up are required before routine clinical implementation can be recommended.

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