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# Myocardial Performance Index Versus Umbilical Artery Doppler in Growth-Restricted Fetuses for Prediction of Neonatal Outcomes

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**ABSTRACT**

**Background & Objective:** Fetal Growth Restriction (FGR) is a major cause of perinatal morbidity and mortality. Early prediction of adverse neonatal outcomes is critical for management. To compare the predictive value of Myocardial Performance Index (MPI) and umbilical artery Doppler in early-onset FGR.

**Materials & Methods:** A prospective cohort study was conducted at Ain Shams University Maternity Hospital between April 2022 and April 2024. Thirty singleton pregnant women with antenatally diagnosed early-onset FGR were enrolled. All participants underwent serial evaluations of umbilical artery Doppler (Resistance Index [RI] and Pulsatility Index [PI]) and MPI. Outcomes assessed included Apgar scores, Neonatal Intensive Care Unit (NICU) admissions, intrauterine fetal death, neonatal death, and respiratory distress.

**Results:** A statistically significant difference in the umbilical artery Resistance Index (RI) was observed between neonates with good outcomes (0.65±0.11) and those with poor outcomes (0.76±0.12; P=0.015). In contrast, the MPI did not show a significant association with neonatal outcome (P=0.257). The area under the ROC curve (AUC) for RI was 0.775 (P=0.0015), indicating good predictive value, while the AUC for MPI was 0.678 (P=0.1037), indicating fair but non-significant predictive ability. A cutoff RI value of >0.79 yielded a specificity of 94.44% and a positive predictive value of 85.7% for predicting adverse outcomes.

**Conclusion:** In early-onset FGR, umbilical artery Doppler, particularly resistance index, is superior to myocardial performance index in predicting adverse neonatal outcomes. Modified myocardial performance index (Mod-MPI) does not offer reliable predictive value in this clinical setting compared to umbilical artery Doppler surveillance.

**Keywords:** Fetal growth restriction, Umbilical artery doppler, Myocardial performance index, Neonatal outcomes, Early-onset FGR

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## 1. Introduction

Fetal Growth Restriction (FGR) occurs when a fetus fails to achieve its full growth potential due to various factors (1). According to the World Health Organization, it is defined as a fetal weight below the third percentile. The American College of Obstetrics and Gynecology, on the other hand, considers a fetal weight below the 10th percentile, often linking it to inadequate placental function. Additionally, an abdominal circumference below the 10th percentile is frequently used as a diagnostic criterion for FGR (2).

FGR is a complication in about 5-10% pregnancies, which can be a crucial cause for prenatal morbidity and mortality (2).

Fetal Growth Restriction (FGR) can arise from maternal, fetal, genetic, or placental factors, either individually or in combination. Several maternal influences, such as age, health status, pregnancy intervals (less than 6 months or over 120 months), infections, and behavioral habits, are known to impact fetal growth and contribute to FGR (2). In some instances, fetal malformations, chromosomal anomalies, or metabolic disorders may also play a role. Advances in molecular biology and genetics have further underscored the significance of genetic variations in the mother, fetus, and placenta in the development of FGR (3).

Identifying Fetal Growth Restriction (FGR) during pregnancy is crucial for strategies aimed at preventing stillbirth, particularly in the late third trimester, as approximately 30% of stillbirth cases are linked to FGR (4).

Umbilical artery Doppler is one of the primary ultrasound tools used to assess Fetal Growth Restriction (FGR) **(5)**. Abnormal blood flow patterns through the umbilical artery on Doppler ultrasound are consistently and reliably associated with adverse pregnancy outcomes **(6)**. An elevated umbilical artery Doppler resistance index indicates that resistance in placental vasculature is high **(7)**.

Various methods are used for monitoring and diagnosing the deterioration in the FGR fetuses. One of these methods is the Myocardial Performance Index (MPI) which has a potential predictor of overall cardiac function that is not influenced by ventricular geometry or heart rate **(8)**. This index is increasingly used to monitor fetuses for potential complications. The modified myocardial performance index (Mod-MPI) is a Doppler-derived measure of global cardiac function that is independent of heart rate and geometry **(9)**.

The literature found that the abnormality in MPI appeared in earlier stages of fetal deterioration than the appearance of abnormal findings in the Doppler study **(9,10)**. This study aims to compare the effectiveness of the Myocardial Performance Index (MPI) and umbilical artery Doppler, when performed antenatally, in predicting adverse neonatal outcomes among fetuses with early-onset growth restriction.

## 2. Materials and Methods

This prospective cohort pilot study took place at the Maternity Hospital of Ain Shams University, located in Cairo, Egypt, over the period April 2022- April 2024, and the Ethical Research Committee of the Obstetrics and Gynecology Department at Ain Shams University in Cairo, Egypt, approved this study. The study was conducted on 30 women with singleton pregnancies who had an antenatal diagnosis of early-onset FGR (diagnosed according to ISUOG criteria) who were recruited from patients attending an obstetric clinic at Ain Shams University Maternity Hospital. Umbilical artery Doppler and MPI were evaluated in all selected patients. Patients were followed up until delivery to detect neonatal outcomes.

The study included pregnant women with early-onset FGR (diagnosed according to ISUOG criteria), singleton pregnancy, gestational age above 28 weeks, maternal age from 20 to 37 years, and BMI from 20-30 kg/m$^2$,while patients with chronic maternal illness and congenitally anomalous fetuses were excluded from this study.

**Sample Size and Study Design Clarification**

This study included 30 pregnant women with early-onset Fetal Growth Restriction (FGR) in a prospective observational cohort design. Due to the relatively rare nature of early-onset FGR and strict eligibility criteria, patient recruitment was inherently limited, and no formal power calculation was performed prior to enrollment. Therefore, this study is considered pilot in nature, intended to generate preliminary evidence and guide future large-scale research. While the sample size restricts the statistical power and generalizability of the findings, the observed trends particularly the stronger predictive value of the umbilical artery Resistance Index (RI) over the Myocardial Performance Index (MPI) offer important clinical insights that warrant confirmation in broader, multi-center studies.

Prior to study enrollment, all participants provided written informed consent after receiving a thorough explanation of the study's objectives.

All women meeting the inclusion criteria underwent a comprehensive assessment comprising the following steps:

**1. Detailed History Taking**

This included personal, present, past, obstetric, menstrual, and family medical histories.

**2. Clinical Examination**

a. General Examination: Assessment of vital signs, body weight, and blood pressure.
b. Local (Abdominal) Examination: Inspection and palpation to assess fundal height.

**3. Radiological Investigations**

A. **Abdominal Ultrasound (U/S):** Fetal biometry performed using a SAMSUNG U/S machine with a CA1-7A probe.

B. **Doppler Ultrasound:** Evaluation of the umbilical artery using the same machine and probe.

- All ultrasound examinations in this study were performed at Ain Shams University Maternity Hospital Fetal Medicine Unit by the same senior staff radiologist, "DR. Mohamed El-sherbiny". Doppler examinations were performed with the woman placed in a recumbent or semi-recumbent position. A SAMSUNG ultrasound machine equipped with pulsed and color Doppler options is used with the probe frequency of 3-5 MHz.

C. **Myocardial performance index**: Performed using this formula: myocardial performance index (MPI)=isovolumetric contraction time (IVCT)+isovolumetric relaxation time (IVRT) / ejection time (ET) **(11)**.

- Criteria for recognizing the early-onset FGR according to ISUOG:
  - GA <32 weeks, without any congenital anomalies with AC/EFW <3rd ppppppercentile or UA-AEDF

or

1. AC/EFW <10th centile combined with

2. UtA-PI > 95th centile and/or

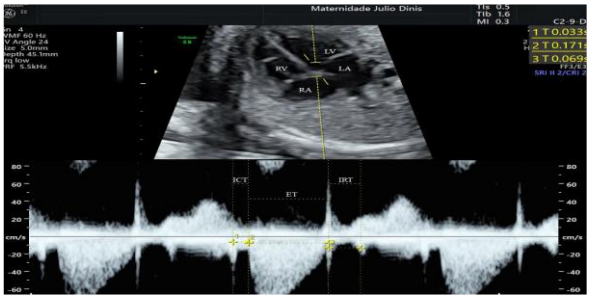
3. UA-PI > 95th centile

**→ At first patient encounter:**

Gestational age was determined based on the last menstrual period and confirmed with a first-trimester ultrasound. All patients underwent transabdominal ultrasound exams using a curvilinear probe. Standard fetal measurements were recorded, and the Estimated Fetal Weight (EFW) was calculated using a well-established formula. Doppler ultrasound of the umbilical artery and Myocardial Performance Index (MPI) were assessed for all patients. The Doppler study was conducted on the mid-portion of the umbilical cord, avoiding areas near the placenta and fetus. Flow velocity waveforms were obtained during periods of fetal rest and apnea. MPI was evaluated through a cross-sectional image of the fetal chest at the four-chamber view, ensuring the heart was positioned apically. Accurate measurements of Isovolumetric Relaxation Time (IVRT), Isovolumetric Contraction Time (IVCT), and Ejection Time (ET) were obtained using the aortic valve clicks as reference.

- MPI was calculated from the average of each interval using this formula:

Myocaridal performance index (MPI) = Isovolumetric contraction time (IVCT) +I sovolumetric relaxation time (IVRT) / ejection time (ET) **(10)**.




Mod-MPI Doppler waveform, showing the time intervals (ICT, IRT and ET) **(11)**

**Patients follow up:**

- Umbilical artery Doppler and MPI were repeated every two weeks until the time of termination of pregnancy. In case of the presence of Doppler changes, the Doppler indices and MPI were performed as follows: MPI was performed weekly. If umbilical artery diastolic flow was decreased (EDV present), wwwwweekly→performance of umbilical artery Doppler was done to monitor the development of absent or reversed blood flow **(12)**. If absent or reversed end diastolic blood flow (AREDV)→ Daily non-stress tests or biophysical profiles were performed to delay delivery if reversed flow till 32 weeks or if absent flow till 34 weeks as long as the NST did not suggest fetal compromise and the BPP remained normal. Delivery was initiated immediately if the BPP or NST became abnormal **(13)**.

Course of antenatal steroids A was administeredas multiple series have found that both spontaneous and indicated preterm deliveries are more common in growth-restricted fetuses **(14)**.

- The neonates were assessed after delivery as regards the following outcomes:
  - Apgar score at 1 and 5 minutes.
  - Fetal morbidities and/or mortalities: "Intrauterine fetal death, neonatal death, NICU admission and the cause for admission, respiratory distress syndrome."
  - Gestational age at time of delivery and mode of delivery.
- The results of umbilical artery Doppler and MPI were correlated with the neonatal outcomes to clarify which was more predictive for the development of each of the outcomes.

**Outcomes**

- The primary outcome was the Apgar score at 1 and 5 minutes after birth.
- The secondary outcomes included:
  - Neonatal morbidity or mortality, including:
    - Intrauterine Fetal Death (IUFD)
    - Early neonatal death
    - Admission to Neonatal Intensive Care Unit (NICU) and duration of stay
    - Respiratory Distress Syndrome (RDS)
  - Gestational age at delivery
  - Mode of delivery

To facilitate statistical analysis, neonatal outcomes were classified into two categories:

- **Good outcome:** Absence of the adverse conditions listed below.
- **Poor outcome:** Defined by the presence of the following:
  - Intrauterine Fetal Death (IUFD)
  - Early neonatal death
  - NICU admission exceeding 5 days
  - Severe respiratory distress (RDS grade 4).

**Elimination of bias**

- All ultrasound examinations in this study were performed at Ain Shams University Maternity Hospital Fetal Medicine Unit by the same

senior staff radiologist, "DR. Mohamed El-Sherbiny.

- SAMSUNG ultrasound machine equipped with pulsed and color Doppler options used with the probe frequency of 3-5 MHz in all patients.

**Data Management and Analysis**

The gathered data were reviewed, coded, and organized before being entered into a computer using the Statistical Package for Social Sciences (SPSS 25). The data were then presented, and suitable analyses were conducted based on the type of data from each parameter.

**i. Descriptive statistics**

1- Frequency and percentage of categorical data.

2- Mean, standard deviation (± SD), and range for numerical data.

**ii. Analytical statistics**

**The student T-test** was used to statistically determine if there were significant differences between the means of the two study groups.

**Correlation analysis (using Pearson's method)**

To determine the degree of association between two quantitative variables. The correlation coefficient ("r") measures the strength and direction of the linear relationship between two quantitative variables

- Very weak: 0.19
- Weak: 0.20-0.39
- Moderate: 0.40-0.59
- Strong: 0.60-0.79
- Very strong: 0.80-1

The ROC curve (Receiver Operating Characteristic) is used to evaluate the performance of diagnostic tests in distinguishing between two groups by analyzing their sensitivity and specificity.

## 3. Results

Table 1 shows that the mean age of mothers was 29.23±5.91 years and the Body Mass Index (BMI) had a mean of 28.05±2.09.

Table 2 shows that most growth-restricted fetuses (66.7%) fall into the less than 3% fetal growth restriction (FGR) category. The remaining fetuses are almost evenly split between the 3-10% and greater than 10% FGR categories.

Table 3 presents a comprehensive analysis of various parameters for predicting neonatal outcomes in growth-restricted fetuses. The Resistance Index shows a mean of 0.69±0.12, and the Pulsatility Index (PI) and Myocardial Performance Index (MPI) demonstrate wider ranges. The APGAR scores, which assess newborns' health, show an average improvement from 5.21 at 1 minute to 7.86 at 5 minutes. The gestational age at delivery averages 33.86 weeks, within a typical range for growth-restricted fetuses.

Table 4 shows that the NICU admission rate was 50% of neonates admitted and 50% not admitted. Respiratory Distress (RD) shows a higher incidence in grade 3, affecting 40% of the cases. The average duration of the condition reported is 6±3.82 days.

Table 5 shows that 60% of the fetuses had a good outcome. Only one fetus experienced Intrauterine Fetal Demise (IUFD), and 3 (10%) had early neonatal death.

Table 6 shows that Cesarean Section (CS) was the predominant mode of delivery, accounting for 93.3% of the cases. The causes of delivery highlight fetal distress and Preeclampsia (PET) as the most frequent reasons, constituting 32.1% and 39.3%, respectively.

Table 7 shows that RI shows a moderate positive correlation with PI last & age and a negative correlation with APGAR scores at 1 and 5 minutes, GA at delivery, and MPI last.

Table 8 shows that the Resistance Index (RI) had a significant difference between good (0.65±0.11) and poor (0.76±0.12) outcomes, with a t-value of -2.58 and a p-value of 0.015, indicating statistical significance. Conversely, the Pulsatility Index (PI) last and MPI last do not demonstrate a significant difference, as reflected by their Non-Significant (NS) p-values of 0.655 and 0.257, respectively.

Table 9 and Figure 1 compared the Myocardial Performance Index (MPI) and Umbilical Artery Doppler Indices (PI and RI) as predictors of neonatal outcomes in growth-restricted fetuses. The Area Under the ROC Curve (AUC) for MPI is 0.678, indicating a moderate predictive ability, although it is not statistically significant (P=0.1037). On the other hand, the AUC for the Resistance Index (RI) is 0.775, demonstrating a stronger predictive capacity and statistical significance (P=0.0015). An RI cutoff value of >0.79 provides a high specificity of 94.44% and a Positive Predictive Value (PPV) of 85.7%, suggesting that the RI may be a more reliable clinical indicator for predicting adverse neonatal outcomes.

Table 10 demonstrated the diagnostic performance of the umbilical artery Resistance Index (RI) for predicting poor neonatal outcomes in early-onset fetal growth restriction. An RI cutoff value of >0.72 was identified as optimal, showing a sensitivity of 84.6% and specificity of 81.8%. The Positive Predictive Value (PPV) at this cutoff was 84.6%, and the Negative Predictive Value (NPV) was 81.8%, confirming the RI's clinical utility not only in detecting high-risk cases but also in reliably identifying those at lower risk. These values support the use of umbilical artery Doppler RI as a reliable and non-invasive marker in the

antenatal monitoring of early-onset FGR, outperforming the Mod-MPI in both predictive power and practical applicability.

**Table 1.** Demographic characteristics among the studied cases

| | Mean ± SD | Range |
|---|---|---|
| **Age** | 29.23±5.91 | 23.32-35.14 |
| **BMI** | 28.05±2.09 | 22.1-30 |

**Table 2.** Percentile of fetal growth restriction among the studied cases

| | | N | % |
|---|---|---|---|
| **FGR %** | <3 | 20 | 66.7% |
| | 3-10 | 5 | 16.6% |
| | >10 | 5 | 16.6% |

**Table 3.** Parameters used for predicting neonatal outcomes in growth-restricted fetuses

| | Mean ± SD | Range |
|---|---|---|
| **RI last** | 0.69±0.12 | 0.5-0.98 |
| **PI last** | 0.83±0.26 | 0.5-1.77 |
| **MPI last** | 0.52±0.16 | 0.32-0.97 |
| **APGAR 1** | 5.21±1.83 | 2-8 |
| **APGAR 5** | 7.86±1.21 | 5-9 |
| **GA AT DELIVERY** | 33.86±2.51 | 28.86-37 |

**Table 4.** Neonatal ICU admission rate, cause, and duration

| | | N | % |
|---|---|---|---|
| **NICU** | no | 15 | 50.0% |
| | yes | 15 | 50.0% |
| **RD** | 2 | 3 | 20.0% |
| | 3 | 6 | 40.0% |
| | 4 | 3 | 20.0% |
| **Grower** | | 6 | 40.0% |
| | | Mean±SD | Range |
| **DURATION** | | 6±3.82 | 1-15 |

**Table 5.** Outcomes of the fetuses among the studied cases

| | | N | % |
|---|---|---|---|
| **Outcome** | Good | 18 | 60.0% |
| | Poor | 12 | 40.0% |
| **IUFD** | no | 29 | 96.7% |
| | yes | 1 | 3.3% |
| **EARLY Neonatal death** | no | 27 | 90.0% |
| | yes | 3 | 10.0% |

**Table 6.** Mode and cause of delivery among the studied cases

| | | N | % |
|---|---|---|---|
| **MODE** | CS | 28 | 93.3% |
| | Vaginal | 2 | 6.7% |
| **CAUSE OF DELIVERY** | Fetal distress | 9 | 32.1% |
| | PET | 11 | 39.3% |
| | In Labor | 6 | 21.4% |
| | Elective | 2 | 7.1% |

**Table 7.** Correlations of umbilical artery resistance index

| | | PI | MPI | APGAR 1 | APGAR 5 | GA AT DELIVERY | Age | BMI | |
|---|---|---|---|---|---|---|---|---|---|
| **RI** | r | 0.515 | -0.404 | -0.308 | -0.466 | -0.410 | 0.361 | 0.022 | |
| | P-value | 0.004 | 0.027 | 0.110 | 0.012 | 0.027 | 0.050 | 0.907 | |
| **PI** | r | | -0.205 | -0.112 | -0.203 | 0.198 | 0.077 | -0.050 | |
| | P-value | | 0.277 | 0.570 | 0.301 | 0.304 | 0.685 | 0.792 | |
| **MPI** | r | | | 0.220 | 0.299 | 0.348 | -0.181 | -0.086 | |
| | P-value | | | 0.262 | 0.123 | 0.064 | 0.340 | 0.651 | |

The table shows that RI shows a moderate positive correlation with PI last & age and a negative correlation with APGAR scores at 1 and 5 minutes, GA at delivery, and MPI last.

**Table 8.** Comparison between the results of PI, RI and MPI among the cases studied

| | Outcome | | t-test | | |
|---|---|---|---|---|---|
| | Good (N=18) | Poor (N=12) | t | P-value | sig. |
| **RI last** | 0.65±0.11 | 0.76±0.12 | -2.58 | 0.015 | S |
| **PI last** | 0.85±0.33 | 0.8±0.11 | 0.45 | 0.655 | NS |
| **MPI last** | 0.55±0.16 | 0.48±0.15 | 1.16 | 0.257 | NS |

**Table 9.** ROC curves of different predictors of poor fetal outcomes

| | Area under the ROC curve (AUC) | 95% CI | P-value | sig. |
|---|---|---|---|---|
| **MPI last** | 0.678 | 0.484 to 0.836 | 0.1037 | NS |
| **PI last** | 0.572 | 0.379 to 0.750 | 0.5014 | NS |
| **RI last** | 0.775 | 0.587 to 0.907 | 0.0015 | S |

**Table 10.** RI cutoff points and correlation to sensitivity, specificity, and positive and negative predictive values

| Cutoff | Sensitivity | Specificity | +PV | -PV |
|---|---|---|---|---|
| **>0.58** | 100 | 33.33 | 50 | 100 |
| **>0.59** | 91.67 | 38.89 | 50 | 87.5 |
| **>0.61** | 83.33 | 55.56 | 55.6 | 83.3 |
| **>0.62** | 75 | 61.11 | 56.3 | 78.6 |
| **>0.63** | 75 | 66.67 | 60 | 80 |
| **>0.67** | 66.67 | 72.22 | 61.5 | 76.5 |
| **>0.72** | 50 | 72.22 | 54.5 | 68.4 |
| **>0.79** | 50 | 94.44 | 85.7 | 73.9 |
| **>0.83** | 16.67 | 94.44 | 66.7 | 63 |
| **>0.92** | 8.33 | 100 | 100 | 62.1 |

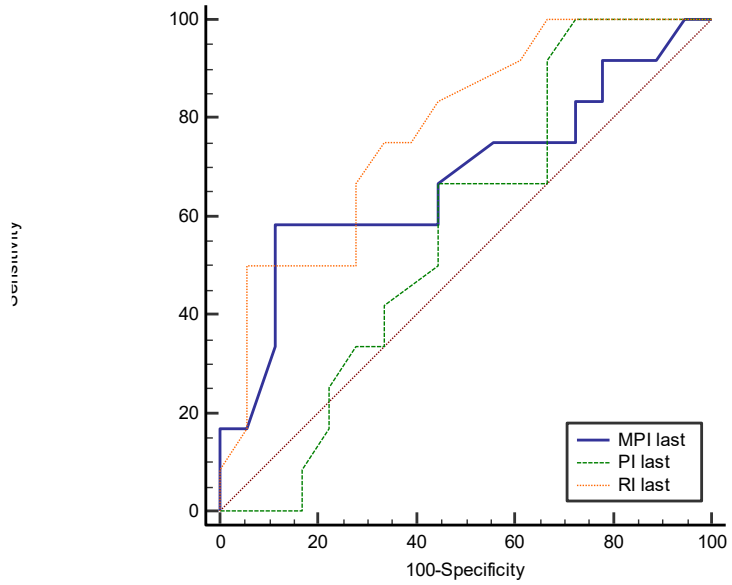



**Figure 1. ROC curves of different predictors of poor fetal outcomes**

## 4. Discussion

Fetal Growth Restriction (FGR) can result from maternal, fetal, genetic, or placental factors and can result from a combination of these factors. The recent advancements in molecular biology and genetics have highlighted the genetic variations within mothers, fetuses, and the placenta in the development of Fetal Growth Restriction (FGR) **(15)**.

The Myocardial Performance Index (MPI) is a potential predictor of overall cardiac function that is not influenced by ventricular geometry or heart rate **(16)**.

The literature found that the abnormality in MPI appeared in earlier stages of fetal deterioration than the appearance of abnormal findings in the Doppler study **(17)**.

The current study presented a comprehensive analysis of various parameters for predicting neonatal outcomes in growth-restricted fetuses. The Resistance Index showed a mean of 0.69±0.12, the Pulsatility Index (PI) a mean of 0.83±0.26, and the Myocardial Performance Index (MPI) a mean of 0.52±0.16, which are wider ranges for the latter two parameters.

The study showed that the umbilical artery Resistive Index (RI) had a significant difference between good (0.65±0.11) and poor (0.76±0.12) outcomes, with a t-value of -2.58 and a P-value of 0.015, indicating statistical significance. Conversely, the MPI did not demonstrate a significant difference (0.48±0.15), as reflected by its Non-Significance (NS) P-values of 0.257.

This agrees with results from Gomez et al., **(18)**, which reported that abnormal umbilical artery Doppler results were predictive of perinatal outcome in FGR fetuses.

However, Oros et al., **(19)** found that normal Umbilical Artery (UA) blood flow in patients with FGR associated with less severity of placental insufficiency.

Additionally, Nassr et al., **(20)** reported an MPI of 0.40±0.004 to be predictive of adverse fetal outcome. The study found that MPI could be a valuable tool in assessing fetuses suspected of having FGR. This is crucial for differentiating between pregnancies with high and low FGR risk and also can predict neonatal outcomes.

Also, Zhang et al., **(12)** found that MPI was higher in fetuses with FGR, suggesting that MPI was a good indicator for monitoring fetal growth restriction.

The study also classified Fetal Growth Restriction (FGR) into groups based on normal and abnormal Doppler findings to examine the temporal relationship between changes in Myocardial Performance Index (MPI) and Doppler results. Both FGR groups, regardless of Doppler status, showed elevated MPI values compared to the control group. However, no significant difference in MPI was found between the normal and abnormal Doppler groups, suggesting that changes in myocardial function may precede hemodynamic changes.

Additionally, a comparison was made between the Myocardial Performance Index (MPI) and Umbilical Artery Doppler (PI and RI) in predicting neonatal outcomes in growth-restricted fetuses.

The area under the ROC Curve (AUC) for MPI is 0.678, indicating a fair predictive value, but the P-value of 0.1037 was not statistically significant.

In contrast, the RI has an AUC of 0.775, showing a good predictive ability with a P-value of 0.0015, which is statistically significant.

The RI cutoff value of >0.79 yields a high specificity of 94.44% and a Positive Predictive Value (PPV) of 85.7%, suggesting that this could be a more reliable indicator in clinical settings for predicting adverse neonatal outcomes.

These results agree with Alici-Davutoglu et al., **(21)**, who found that Mod-MPI may be a good indicator of myocardial dysfunction but did not appear to have a value in the prediction of adverse perinatal outcomes.

Additionally, Bhorat et al., **(22)** reported that there is an association between the severity of adverse perinatal outcomes and elevation rates of the MPI and different cut-off values for Mod MPI that predict adverse outcomes have also been reported at 0.54 with a specificity of 75% and sensitivity of 87%.

Furthermore, Zhang et al., **(12)** reported that when the cutoff value had been 0.50, the Mod-MPI that predicted adverse outcomes had a sensitivity of 65% and specificity of 70%.

However, Şimşek and Köse **(23)** found that in fetuses that have late-onset FGR and SGA Mod-MPI has useful value in predicting adverse perinatal outcomes.

On the other hand, Zhang et al., **(12)** found that to provide Mod-MPI for adverse outcomes across FGR and SGA subgroups with a sensitivity of 63% and specificity of 75%. The cutoff value was ≥0.41.

Additionally, a study by Henry et al., **(24)** found that MPI lacks clinical utility in the evaluation and management of Small-for-Gestational-Age (SGA) or Fetal Growth Restriction (FGR) fetuses. This conclusion was based on their observations of 38 early-onset FGR cases and 14 late-onset FGR cases.

**Study Limitations:** This study has several limitations that should be considered when interpreting the results. First, the sample size was relatively small (n=30), which may limit the statistical power to detect subtle differences between the Myocardial Performance Index (MPI) and umbilical artery Doppler. The findings should thus be interpreted as preliminary and hypothesis-generating rather than definitive. Second, this was a single-center study conducted at a tertiary care hospital, which may limit the generalizability of results to broader or lower-resource clinical settings.

Third, the study lacked longitudinal postnatal follow-up, which restricted the assessment of long-term neonatal outcomes and limited evaluation of how prenatal indices relate to developmental trajectories. Future studies with larger, multi-center cohorts and extended follow-up periods are needed to validate and expand upon these findings.

## 5. Conclusion

In this study, Mod-MPI did not demonstrate significant predictive value for adverse neonatal outcomes in cases of early-onset Fetal Growth Restriction (FGR), whereas the umbilical artery Resistance Index (RI) showed a statistically significant association with outcome severity. These findings suggest that umbilical artery Doppler remains a more reliable tool than Mod-MPI in the antenatal monitoring of early-onset FGR.

From a clinical perspective, these results support prioritizing umbilical artery Doppler in routine surveillance protocols for high-risk pregnancies, particularly when resources or time constraints limit the use of multiple advanced fetal assessments. Further large-scale, longitudinal studies are needed to explore whether Mod-MPI may have a role in refining risk stratification in specific subgroups or when integrated into multiparametric fetal evaluations.

## 6. Declarations

### Acknowledgments

The authors would like to thank the medical and ultrasound staff at the Obstetrics and Gynecology Department, Ain Shams University Maternity Hospital, for their valuable support in data collection and patient care. We also extend our gratitude to the patients who participated in this study for their cooperation and trust.

### Ethical Considerations

Ethical approval for this study was obtained from the Research Ethics Committee of Ain Shams University, Faculty of Medicine (Approval No. [insert if available]). All procedures were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki Declaration and its later amendments. Written informed consent was obtained from all participants prior to enrollment.

### Authors' Contributions

Each author contributed significantly to the work reported, approved the final version for publication, agreed on the journal to which the paper was submitted, and agreed to take responsibility for all elements of the work.

### Conflict of Interest

The authors declare that there are no conflicts of interest related to this study.

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