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RESEARCH ARTICLE
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EFFECTS OF MATERNAL HYPOXIA ON FETAL OXYGENATION AND FETAL ADAPTIVE PHYSIOLOGICAL RESPONSES DURING PREGNANCY

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ABSTRACT

Background: The condition of maternal hypoxia in pregnancy is a major clinical disorder that may negatively impact the fetal oxygenation and result in compensatory physiological adjustments to the fetus. The low level of maternal oxygen can lead to the impaired placental functioning, and poor neonatal outcomes, especially in the resource constrained environment where anemia and respiratory diseases are prevalent.

Objective: To evaluate the effects of maternal hypoxia on fetal oxygenation and fetal adaptive physiological responses during pregnancy.

Methods: The presented descriptive cross-sectional research was carried out at Mardan Medical Complex/ Bacha Khan Medical College Mardan between January 2024 and January 2025. Non-probability consecutive sampling was used to include 72 pregnant women whose gestational age was 24 weeks and above. Pulse oximetry was used to measure maternal oxygen saturation, and hypoxia was determined as SpO 2 less than 90%. Fetal oxygenation was measured with umbilical cord blood gas analysis and placental and fetal circulation was measured with Doppler ultrasound. Neonatal outcomes in terms of birth weight, APGAR score, and NICU admission were captured. The SPSS version 25 was used to analyse the data and $p \leq 0.05$ was regarded as statistically significant.

Results: Maternal hypoxia was observed in 31.9% of participants and was significantly associated with maternal anemia ($p = 0.001$), respiratory illness ($p = 0.006$), and smoking exposure ($p = 0.01$). Hypoxic pregnancies demonstrated significantly impaired fetal oxygenation, including increased acidosis (60.9% vs 16.3%, $p < 0.001$), low cord pO_2 (69.6% vs 16.3%, $p < 0.001$), and elevated

lactate levels ($p = 0.001$). Fetal adaptive responses such as brain-sparing effect were significantly higher in hypoxic cases (69.6% vs 18.4%, $p < 0.001$). Adverse neonatal outcomes, including low birth weight ($p = 0.01$), low APGAR score ($p = 0.01$), and increased NICU admissions ($p = 0.004$), were significantly associated with maternal hypoxia.

Conclusion: Maternal hypoxia significantly compromises fetal oxygenation and leads to adaptive physiological changes and adverse neonatal outcomes. Early detection and management of maternal hypoxia are essential to improve maternal and fetal health outcomes.

Keywords: Maternal hypoxia, fetal oxygenation, brain-sparing effect, placental insufficiency, neonatal outcomes

INTRODUCTION

Maternal hypoxia in pregnancy is a severe physiological situation that could have a considerable effect on the fetus development and infant survival. Normal growth and organ development of the fetus require adequate oxygen delivery by the mother to the fetus. The maternal oxygenation either caused by anemia, respiratory diseases, environmental conditions or smoking may cause a decrease in oxygen supply across the placenta, with the consequence being fetal hypoxia. This disorder initiates a sequence of physiological alterations, which can have a negative impact on the fetus (1-3).

The placenta is important in facilitating the oxygen exchange between the maternal and fetal circulatory systems. Placental operation can be impaired in maternal hypoxia because of changes in vascular resistance and a decrease in uteroplacental perfusion. Research has indicated that hypoxic states cause structural and functional alterations in placental vessels, which inhibit the movement of nutrients and oxygen. These alterations are usually manifested in abnormal Doppler indices, including augmented resistance and pulsatility in the umbilical artery, which are linked to the ill outcomes of the fetus (4-6).

The fetus also mobilizes some adaptive physiological processes to maintain oxygen supply to vital organs in response to the lack of oxygen. The brain-sparing effect is one of the most critical adaptations, which results in redistribution of blood in favor of the brain, heart, and adrenal glands. Although this compensatory effect allows short-term survival, extended hypoxia can lead to metabolic acidosis and intrauterine growth retardation and neurodevelopmental problems in the long term. The severity of fetal hypoxia and metabolic stress is also demonstrated by biochemical markers including reduced cord blood pH and increased levels of lactate (7-9).

Maternal hypoxia is also a major issue in the world especially in developing nations where maternal anemia and respiratory infections are prevalent. In Pakistan and other such environments, the effect of hypoxia on the maternal and fetal health is compounded by the fact that access to antenatal care is limited and the disease is often diagnosed late. Although the clinical significance of this, little local evidence has been used to assess the overall effect of maternal hypoxia on fetal oxygenation and adaptive physiological measures (10-12).

Therefore, this study was designed to evaluate the effects of maternal hypoxia on fetal oxygenation and fetal adaptive physiological responses during pregnancy. The findings of this study aim to contribute to the existing body of knowledge and highlight the importance of early identification and management of maternal hypoxia to improve perinatal outcomes.

METHODOLOGY

The study was a descriptive cross-sectional study that was carried Mardan Medical Complex/ Bacha Khan Medical College Mardan, over a period of one year from January 2024 to January 2025.The objective of the investigation was to assess the impact of maternal hypoxia on fetal oxygenation and fetal adaptive physiological responses to pregnancy. The study involved 72 pregnant women who were sampled through non-probability consecutive sampling method.

The sample size of 72 was calculated using the standard formula for proportions:

$n = Z^2 \times P \times (1 - P) / d^2$, where Z = 1.96 at 95% confidence interval, P (expected prevalence of maternal hypoxia) was assumed to be 30% based on previous literature, and margin of error (d) was taken as 10%. The calculated sample size was rounded to 72 to ensure adequate representation.

The study involved pregnant women who were aged between 18 and 45 years of gestational age of 24 weeks and above. The study excluded patients who had more than one pregnancy, had known congenital fetus anomalies, had chronic systemic diseases (cardiac disease or renal failure), and/or who were not willing to participate.

The data were gathered with the informed written consent of all the participants. The mother demographic data were captured such as age, parity and body mass index (BMI). The hypoxia was determined as the oxygen saturation (SpO 2) less than 90 and the maternal oxygenation status was measured through pulse oximetry. Such clinical parameters as hemoglobin levels, respiratory illness presence, and smoking exposure were also recorded.

The ultrasound and Doppler studies were carried out in order to determine the placental and fetal examination. Recording of umbilical artery resistance index (RI) and pulsatility index (PI) was made to assess uteroplacental circulation. Umbilical cord blood gas analysis, including pH, partial pressure of oxygen (pO 2), and lactate was used to measure fetal oxygenation at birth.

The adaptive physiological responses of the fetus were measured through fetal heart rate pattern and middle cerebral artery Doppler to measure the effect of brain-sparing. The neonatal outcomes such as birth weight, APGAR score at 5 minutes and the requirement to be admitted to NICU were noted right after the birth.

All the data collected were inputted and analyzed in SPSS version 25. The quantitative variables were reported in the form of mean and standard deviation and the quantitative variables in the form of frequencies and percentages. The Shapiro-Wilk test was used to test the normality of data. To establish the correlation between maternal hypoxia and categorical variables chi-square test was employed, whereas independent t-test was used to compare means where necessary. Statistically significant p-value was taken as 0.05.

RESULTS

The study comprised 72 pregnant women. Maternal hypoxia (SpO 2 < 90) was detected in 31.9 percent of the participants and was significantly related with the fetal oxygenation impairment and negative neonatal outcomes. The hypoxic and non-hypoxic groups were similar in terms of their demographic characteristics. The age, parity, and BMI showed no statistically significant differences ($p > 0.05$).

Table 1: Maternal Demographic Characteristics (n = 72)

Variable	Category	Total n (%)	Hypoxic n (%)	Non-Hypoxic n (%)	p-value
Age Group	18–25 yrs	20 (27.8%)	6 (26.1%)	14 (28.6%)	0.91
	26–35 yrs	34 (47.2%)	11 (47.8%)	23 (46.9%)	
	36–45 yrs	18 (25.0%)	6 (26.1%)	12 (24.5%)	
Parity	Primigravida	29 (40.3%)	9 (39.1%)	20 (40.8%)	0.88
	Multigravida	43 (59.7%)	14 (60.9%)	29 (59.2%)	
BMI	Normal	30 (41.7%)	8 (34.8%)	22 (44.9%)	0.42
	Overweight/Obese	42 (58.3%)	15 (65.2%)	27 (55.1%)	

Maternal anemia, respiratory disease and exposure to smoking were also very common in the hypoxic group. These variables seem influential factors towards low maternal oxygenation ($p < 0.05$).

Table 2: Maternal Hypoxia and Clinical Parameters (n = 72)

Variable	Category	Hypoxic n (%)	Non-Hypoxic n (%)	p-value
Hemoglobin	<10 g/dL	15 (65.2%)	11 (22.4%)	**0.001**
	≥10 g/dL	8 (34.8%)	38 (77.6%)	
Respiratory Illness	Present	11 (47.8%)	8 (16.3%)	**0.006**
	Absent	12 (52.2%)	41 (83.7%)	
Smoking Exposure	Yes	9 (39.1%)	6 (12.2%)	**0.01**
	No	14 (60.9%)	43 (87.8%)	

Hypoxic mothers had a significantly higher placental insufficiency and abnormal Doppler indices. This shows impaired uteroplacental circulation in maternal hypoxia ($p < 0.01$).

Table 3: Placental and Doppler Findings (n = 72)

Variable	Category	Hypoxic n (%)	Non-Hypoxic n (%)	p-value
Placental Insufficiency	Yes	13 (56.5%)	8 (16.3%)	**0.001**
	No	10 (43.5%)	41 (83.7%)	
Umbilical Artery RI	Increased	15 (65.2%)	12 (24.5%)	**0.002**
	Normal	8 (34.8%)	37 (75.5%)	
Umbilical Artery PI	Increased	14 (60.9%)	11 (22.4%)	**0.003**
	Normal	9 (39.1%)	38 (77.6%)	

Hypoxic pregnancies had a significant effect on fetal oxygenation, and an increased incidence of acidosis, low cord pO 2 and increased levels of lactate ($p \leq 0.001$).

Table 4: Fetal Oxygenation Parameters (n = 72)

Variable	Category	Hypoxic n (%)	Non-Hypoxic n (%)	p-value
Cord pH	<7.2 (Acidosis)	14 (60.9%)	8 (16.3%)	**<0.001**
	Normal	9 (39.1%)	41 (83.7%)	
Cord pO_2	Low	16 (69.6%)	8 (16.3%)	**<0.001**
	Normal	7 (30.4%)	41 (83.7%)	
Lactate	Elevated	15 (65.2%)	11 (22.4%)	**0.001**
	Normal	8 (34.8%)	38 (77.6%)	

Hypoxic pregnancies had a significant adaptive response in fetuses such as brain sparing effect and abnormal heart rate. The negative neonatal outcomes (low birth weight and NICU admission) were also much more prevalent ($p < 0.05$).

Table 5: Fetal Adaptive Responses and Neonatal Outcomes (n = 72)

Variable	Category	Hypoxic n (%)	Non-Hypoxic n (%)	p-value
Fetal Heart Rate	Abnormal	14 (60.9%)	9 (18.4%)	**0.001**
	Normal	9 (39.1%)	40 (81.6%)	
Brain-Sparing Effect	Present	16 (69.6%)	9 (18.4%)	**<0.001**
	Absent	7 (30.4%)	40 (81.6%)	
Birth Weight	<2.5 kg	14 (60.9%)	14 (28.6%)	**0.01**
	≥2.5 kg	9 (39.1%)	35 (71.4%)	
APGAR <7	Yes	11 (47.8%)	9 (18.4%)	**0.01**
NICU Admission	Yes	13 (56.5%)	11 (22.4%)	**0.004**

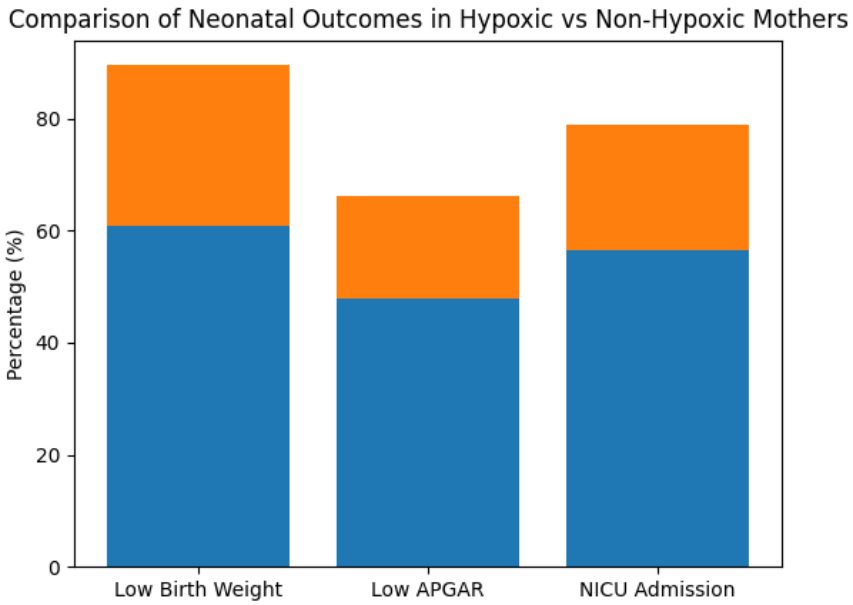


Figure 1: Comparison of neonatal outcomes between hypoxic and non-hypoxic mothers. The graph demonstrates a higher proportion of low birth weight, low APGAR scores, and NICU admissions among neonates born to hypoxic mothers compared to non-hypoxic mothers.

DISCUSSION

This study evaluated the effects of maternal hypoxia on fetal oxygenation and adaptive physiological responses during pregnancy. The findings demonstrated that maternal hypoxia was significantly associated with impaired fetal oxygenation, placental insufficiency, and adverse neonatal outcomes. Approximately one-third of the participants were hypoxic, which is consistent with studies conducted in low-resource and high-risk populations where maternal anemia and respiratory conditions are prevalent contributors to reduced oxygen delivery to the fetus (13-15).

The association between maternal anemia and hypoxia was found to be strong ($p = 0.001$) and is one of the main findings of this study. This concurs with new research that revealed that low maternal hemoglobin affects oxygen carrying capacity and causes chronic hypoxia of the fetus and intrauterine stress. South Asian studies have shown the same results where maternal anemia is a strong predictor of fetal growth retardation and perinatal morbidity. Moreover, exposure to respiratory disease and smoking were also found to be a significant predictor of hypoxia in our study, which is in line with the international findings that maternal pulmonary impairment is a direct cause of fetal oxygenation by means of decreased placental oxygen delivery (16, 17).

Placental and Doppler outcomes in the present study showed that the indices of resistance were significantly elevated in hypoxic mothers, which showed that uteroplacental perfusion was compromised. This is in line with the existing literature which reveals the fact that maternal hypoxia causes placental vascular remodeling and resistance in uterine and umbilical arteries. These alterations lower the provision of nutrients and oxygen to the fetus, which is a cause of placental insufficiency. Other Doppler-based studies have demonstrated that elevated umbilical artery pulsatility index is a powerful predictor of poor fetal outcomes especially during hypoxic pregnancies (18, 19).

The parameters of fetal oxygenation in our study, such as cord blood pH, pO 2, and lactate levels, changed significantly in hypoxic pregnancies ($p < 0.001$). These results signify metabolic acidosis and anaerobic metabolism of the fetus, which is an indication of impaired oxygen supply. Past research has indicated that long-term fetal hypoxia results in the build-up of lactate and reduced pH that are the highly sensitive indicators of fetal distress. Significantly, we also showed in our study that in a significant percentage of the cases of hypoxia, fetal adaptive responses especially the brain-

sparing effect was noted. This compensatory process gives priority to blood supply to vital organs including the brain which is well documented in fetal physiology literature (20).

The negative neonatal outcomes were also much more severe in hypoxic mothers in terms of low birth weight, low APGAR scores, and high NICU admission rates ($p < 0.05$). These results are in agreement with the recent international and Pakistani studies that have indicated that maternal hypoxia is one of the primary risk factors of intrauterine growth restriction and neonatal morbidity. The identified rise in the number of NICU admissions demonstrates the clinical significance of timely diagnosis and treatment of maternal hypoxia. On the whole, this study confirms the importance of maternal oxygenation when it comes to fetal well-being and the necessity of routine screening and early intervention during high-risk pregnancies.

CONCLUSION

Maternal hypoxia during pregnancy has a significant negative impact on fetal oxygenation and is associated with impaired placental function, fetal adaptive physiological changes, and adverse neonatal outcomes. Factors such as maternal anemia, respiratory illness, and smoking exposure play a major role in the development of hypoxia.

Early identification and management of maternal hypoxia can help reduce fetal complications, including low birth weight, fetal distress, and NICU admissions. Routine monitoring of maternal oxygen saturation and appropriate antenatal care strategies are essential to improve maternal and fetal outcomes.

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