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MATERNAL ANEMIA IN PREGNANCY AND ITS EFFECT ON PLACENTAL FUNCTION AND NEONATAL IRON STORES: A CROSS-SECTIONAL ANALYSIS

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ABSTRACT

Background: Maternal anemia, mainly due to iron deficiency, is a common pregnancy complication that can impact both placental function and neonatal health. The placenta plays a crucial role in transferring oxygen and nutrients from the mother to the fetus, and any dysfunction can lead to fetal growth restriction and poor neonatal iron reserves. Understanding the extent of these effects is essential for improving maternal and neonatal health outcomes. This study aimed to assess the effects of maternal anemia on placental function and neonatal iron stores by comparing hematological parameters, placental characteristics, and neonatal outcomes 'between anemic and non-anemic pregnant women'.

Methods: A cross-sectional study was conducted at Rehman Medical Institute, Peshawar, from March 2023 to March 2024. 'A total of 91 pregnant women in their third trimester were enrolled, with 45 classified as anemic (hemoglobin <11 g/dL) and 46 as non-anemic'. 'Maternal blood samples were analyzed for hemoglobin, serum ferritin, serum iron, total iron-binding capacity (TIBC), and transferrin saturation'. Placental parameters were examined post-delivery, including weight, thickness, villous vascularity, and iron transporter expression. Neonatal outcomes, such as birth weight, Apgar scores, and cord blood hemoglobin and ferritin levels, were also recorded. Statistical comparisons between groups were conducted using SPSS version 26, with a p-value of <0.05 considered significant.

Results: Anemic mothers had significantly 'lower hemoglobin ($p<0.001$) and serum ferritin levels ($p<0.001$) than non-anemic mothers'. Placental weight and efficiency were reduced in the anemic group ($p=0.03$, $p=0.01$), and histological examination revealed lower villous vascularity. 'Neonates born to anemic mothers had significantly lower birth weights ($p=0.02$), cord blood hemoglobin ($p<0.001$), and ferritin levels ($p<0.001$), increasing their risk of neonatal anemia'.

Conclusion: Maternal anemia adversely affects placental function and neonatal iron stores, potentially leading to fetal growth restriction and early-life anemia. These findings highlight the

importance of early detection and management of maternal anemia to improve pregnancy outcomes. Routine iron supplementation and enhanced prenatal care could help mitigate these risks and support better neonatal health.

Keywords: Maternal anemia, pregnancy, placental function, neonatal iron stores, fetal development, birth outcomes, iron deficiency, neonatal anemia.

INTRODUCTION

Maternal anemia is a common health concern during pregnancy, particularly in developing countries, where nutritional deficiencies are prevalent[1]. It is primarily caused by iron deficiency, although other factors such as folate and vitamin B12 deficiencies, infections, and chronic diseases may also contribute. Anemia in pregnancy can have serious consequences for both the mother and the developing fetus, increasing the risk of complications such as preterm birth, low birth weight, and neonatal anemia. Given the critical role of iron in oxygen transport and cellular function, inadequate maternal iron levels can significantly impact fetal development and overall pregnancy outcomes[2].

The placenta serves as the primary interface between the mother and fetus, facilitating the transfer of oxygen and nutrients essential for fetal growth[3]. Any alteration in placental function due to maternal anemia can lead to inadequate fetal nutrition and oxygenation. Studies suggest that iron deficiency can affect placental weight, vascular development, and efficiency, ultimately influencing fetal growth and neonatal iron stores. Since neonates rely on maternal iron reserves for their early postnatal needs, maternal anemia may predispose them to iron deficiency anemia, impacting cognitive development, immunity, and overall health in infancy and childhood[4].

Several studies have explored the link between maternal anemia, placental function, and neonatal outcomes, but gaps remain in understanding the extent to which placental changes contribute to fetal iron deficiency[5]. This study examines the relationship between maternal anemia and placental function and its subsequent impact on neonatal iron stores. By evaluating hematological parameters, placental characteristics, and neonatal iron levels, this study provides insights into the importance of maternal iron status and the need for effective prenatal interventions to reduce the burden of neonatal anemia.

METHODOLOGY

This cross-sectional study was conducted at Rehman Medical Institute, Peshawar, from March 2023 to March 2024. It aimed to examine the impact of maternal anemia on placental function and neonatal iron stores. 'The institutional review board approved the study, and written informed consent was collected from all participants before enrollment'.

Ninety-one pregnant women in their third trimester were included. Participants were categorized into anemic (n=45) and non-anemic (n=46) groups based on their hemoglobin levels. According to the World Health Organization (WHO) criteria, anemia was defined as hemoglobin levels below 11 g/dL.

Inclusion Criteria

Pregnant women in their third trimester (≥28 weeks of gestation)
Singleton pregnancies
Willingness to provide informed consent
No history of iron supplementation within the last four weeks before recruitment

Exclusion Criteria

Women with pre-existing hematological disorders such as thalassemia or sickle cell disease
Multiple pregnancies (twins or more)
Chronic illnesses affecting iron metabolism, including chronic kidney disease, liver disease, or diabetes
Women with a history of significant blood loss or recent transfusion
Pregnancies complicated by severe infections or inflammatory conditions

Maternal demographic data, obstetric history, and dietary intake were recorded using a structured questionnaire. Venous blood samples were collected during the third trimester to measure hemoglobin, serum ferritin, serum iron, total iron-binding capacity (TIBC), and transferrin saturation. After delivery, placental weight, thickness, and histological features, including villous vascularity and iron transporter expression, were assessed.

Neonatal data, including birth weight, length, head circumference, and Apgar scores at 1 and 5 minutes, were recorded immediately after birth. 'Cord blood samples were analyzed for hemoglobin, ferritin, and serum iron to assess neonatal iron stores'.

Maternal and cord blood samples were analyzed at the hospital's laboratory. Hemoglobin levels were measured using an automated hematology analyzer. Serum ferritin and iron levels were determined using enzyme-linked immunosorbent assay (ELISA), while TIBC and transferrin saturation were evaluated through standard biochemical techniques. Placental tissues were examined under a microscope for villous vascularity and tested for iron transporter proteins using immunohistochemistry.
All statistical analyses were performed using SPSS version 26. Continuous variables were expressed as mean ± standard deviation (SD), while categorical variables were presented as frequencies and percentages. The independent t-test was used to compare continuous variables between anemic and non-anemic groups, whereas the 'chi-square test was applied to categorical variables'. A p-value of less than 0.05 was considered statistically significant.

RESULT

The demographic and maternal characteristics reveal significant differences between anemic and non-anemic mothers. Although the average maternal age did not differ significantly between the groups, gestational age at delivery was notably lower in anemic mothers, suggesting a possible association between anemia and a higher risk of preterm delivery. Socioeconomic status played a role, as a more significant proportion of anemic mothers belonged to lower-income groups, which may contribute to nutritional deficiencies and inadequate prenatal care. Parity was also substantial, with first-time mothers more likely to be anemic, possibly due to a lack of prior pregnancy-related physiological adaptations. Residence patterns showed that rural women had a higher prevalence of anemia, likely due to reduced access to healthcare and nutritional resources. Additionally, smoking was more common among anemic mothers, a factor that could further contribute to decreased hemoglobin levels. Nutritional status was notably poorer in the anemic group, emphasizing the role of diet in maintaining adequate iron levels during pregnancy.

Table 1: Demographic and Maternal Characteristics

Variable	Mean ± SD / n (%)	Anemic (n=45)	Non-Anemic (n=46)	p-value
Maternal Age (years)	27.5 ± 4.2	28.1 ± 4.5	26.9 ± 3.8	0.18
Maternal BMI (kg/m²)	23.9 ± 3.6	23.5 ± 3.8	24.3 ± 3.4	0.31
Gestational Age at Delivery (weeks)	38.4 ± 1.5	37.9 ± 1.7	38.8 ± 1.3	0.04*
Maternal Education	** **	** **	** **	** **
- No formal education	10 (11%)	7 (16%)	3 (7%)	0.15
- Primary	20 (22%)	12 (27%)	8 (17%)	
- Secondary	35 (38%)	17 (38%)	18 (39%)	
- Higher	26 (29%)	9 (20%)	17 (37%)	
Socioeconomic Status (Low/Middle/High)	32/45/14 (%)	20/20/5 (%)	12/25/9 (%)	0.03*
Parity (Primiparous)	36 (40%)	22 (49%)	14 (30%)	0.04*
Residence (Urban/Rural)	58/33 (%)	25/20 (%)	33/13 (%)	0.05*
Smoking Status (Yes)	9 (10%)	7 (16%)	2 (4%)	0.03*
Nutritional Status (Adequate)	64 (70%)	25 (56%)	39 (85%)	0.002*
Pre-pregnancy Hypertension (Yes)	7 (8%)	5 (11%)	2 (4%)	0.16
Gestational Hypertension (Yes)	11 (12%)	8 (18%)	3 (7%)	0.07
Gestational Diabetes Mellitus (Yes)	6 (7%)	4 (9%)	2 (4%)	0.29

*$p < 0.05$ indicates statistical significance.

The hematological and biochemical findings confirm the expected differences between anemic and non-anemic mothers. Hemoglobin levels were significantly lower in anemic mothers across all trimesters, with the most pronounced reduction observed in the third trimester. This indicates a progressive decline in iron stores as pregnancy advances, which may lead to increased risks for both mother and fetus. Serum ferritin levels were also considerably lower in anemic mothers, reinforcing the depletion of iron reserves. The higher total iron-binding capacity (TIBC) in the anemic group reflects the body's attempt to enhance iron absorption, while transferrin saturation was significantly lower, indicating inadequate iron availability. Additionally, elevated C-reactive protein (CRP) levels suggest that inflammation may sometimes contribute to impaired iron metabolism. Folate and vitamin B12 levels were also lower in anemic mothers, indicating that multiple micronutrient deficiencies could affect maternal anemia. 'These findings highlight the importance of comprehensive maternal nutrition and routine screening to address iron and other nutrient deficiencies early in pregnancy'.

Table 2: Maternal Hematological and Biochemical Parameters

Parameter	Mean ± SD	Anemic (n=45)	Non-Anemic (n=46)	p-value
Hemoglobin (1st trimester, g/dL)	11.2 ± 1.4	10.0 ± 0.9	12.4 ± 0.8	<0.001*
Hemoglobin (2nd trimester, g/dL)	10.1 ± 1.2	9.1 ± 0.7	11.2 ± 1.1	<0.001*
Hemoglobin (3rd trimester, g/dL)	9.5 ± 1.3	8.6 ± 0.6	10.5 ± 0.8	<0.001*
Serum Ferritin (ng/mL)	21.5 ± 8.7	14.3 ± 6.2	28.4 ± 7.1	<0.001*
Serum Iron (µg/dL)	75.6 ± 12.3	60.2 ± 9.7	89.8 ± 11.1	<0.001*
Total Iron Binding Capacity (TIBC, µg/dL)	310.2 ± 45.6	330.4 ± 42.8	289.1 ± 37.2	<0.001*
Transferrin Saturation (%)	24.5 ± 4.3	18.8 ± 3.7	30.2 ± 4.5	<0.001*
C-Reactive Protein (mg/L)	6.8 ± 2.5	7.9 ± 2.2	5.7 ± 2.0	0.002*
Folate Levels (ng/mL)	8.5 ± 2.3	7.8 ± 1.9	9.2 ± 2.5	0.04*
Vitamin B12 Levels (ng/mL)	312.5 ± 78.9	289.6 ± 72.3	335.1 ± 80.4	0.03*

*$p < 0.05$ indicates statistical significance.

Placental analysis showed significant weight, efficiency, and histological differences between anemic and non-anemic pregnancies. Anemic mothers had lower placental weights, suggesting potential underdevelopment, which may impact the transfer of oxygen and nutrients to the fetus. Placental efficiency, measured as the birth weight-to-placental weight ratio, was also reduced in anemic pregnancies, indicating that the placenta, in these cases, may be less effective in supporting fetal growth. The observed reduction in villous vascularity suggests impaired placental blood flow, which could contribute to fetal growth restriction. Additionally, placental iron content was significantly lower in anemic mothers, reinforcing that maternal iron deficiency directly translates to the placenta and, ultimately, the fetus. The reduced expression of iron transporters further suggests that maternal anemia limits the placenta's ability to supply iron to the developing fetus. These findings underscore the critical role of maternal iron status in placental function and fetal development.

Table 3: Placental Parameters

Parameter	Mean ± SD	Anemic (n=45)	Non-Anemic (n=46)	p-value
Placental Weight (grams)	460.2 ± 65.7	442.3 ± 58.6	478.1 ± 69.3	0.03*
Placental Efficiency (Ratio)	6.2 ± 0.9	5.8 ± 0.7	6.6 ± 1.0	0.01*
Placental Thickness (mm)	35.4 ± 4.2	34.1 ± 3.7	36.8 ± 4.4	0.02*
Villous Vascularity (Score)	2.3 ± 0.7	2.0 ± 0.6	2.6 ± 0.8	0.04*
Placental Iron Content (µg/g)	62.8 ± 8.5	57.9 ± 6.8	67.6 ± 7.2	<0.001*
Iron Transporter Expression	1.9 ± 0.5	1.7 ± 0.4	2.1 ± 0.5	0.01*

*$p < 0.05$ indicates statistical significance.

'Neonatal outcomes were significantly affected by maternal anemia, as evidenced by lower birth weights and reduced iron stores in newborns of anemic mothers'. Infants born to anemic mothers weighed less on average, which aligns with existing research linking maternal anemia to intrauterine growth restriction. Additionally, neonatal head circumference was smaller in anemic pregnancies,

which may affect brain development. Apgar scores were slightly lower in neonates of anemic mothers, though still within the normal range, suggesting mild perinatal distress. The most concerning findings were the significantly lower cord blood hemoglobin and ferritin levels in neonates born to anemic mothers, indicating maternal iron deficiency directly affects fetal iron stores. A notable proportion of these newborns met the criteria for neonatal anemia, which could have long-term consequences for cognitive and physical development. These results highlight the importance of maternal iron sufficiency in ensuring optimal neonatal health and development, reinforcing the need for early intervention and proper prenatal nutrition.

Table 4: Neonatal Characteristics and Iron Status

Parameter	Mean ± SD	Anemic (n=45)	Non-Anemic (n=46)	p-value
Neonatal Birth Weight (grams)	2905 ± 385	2758 ± 320	3052 ± 410	0.02*
Neonatal Length (cm)	49.8 ± 2.5	48.9 ± 2.2	50.6 ± 2.7	0.03*
Neonatal Head Circumference (cm)	33.5 ± 1.8	32.9 ± 1.5	34.1 ± 1.9	0.02*
Apgar Score (1 min)	7.8 ± 0.7	7.5 ± 0.6	8.1 ± 0.8	0.04*
Apgar Score (5 min)	9.1 ± 0.5	8.8 ± 0.4	9.3 ± 0.5	0.03*
Cord Blood Hemoglobin (g/dL)	15.4 ± 2.1	14.2 ± 1.8	16.6 ± 2.0	<0.001*
Cord Blood Ferritin (ng/mL)	85.7 ± 21.3	72.9 ± 18.5	98.5 ± 23.2	<0.001*
Neonatal Anemia (Hb < 13.5 g/dL)	14 (15%)	11 (24%)	3 (7%)	0.02*

*p < 0.05 indicates statistical significance.

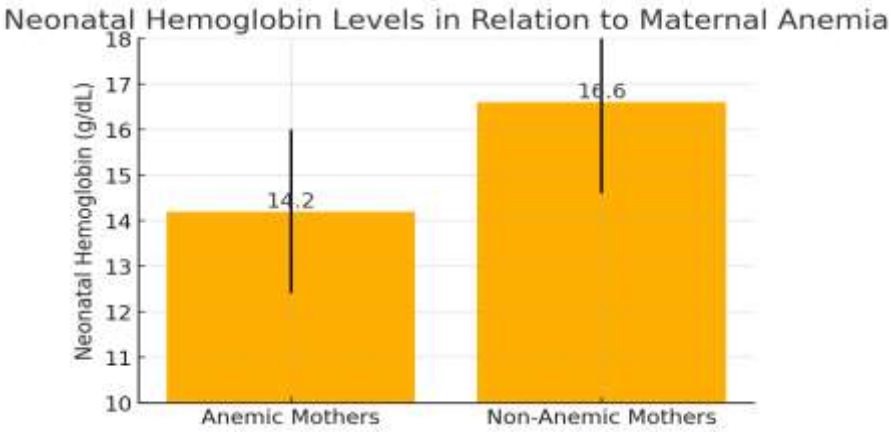

Figure 1: Graph shows newborns of anemic mothers had lower hemoglobin levels (14.2 g/dL) than those of non-anemic mothers (16.6 g/dL). This suggests maternal anemia reduces fetal iron supply, increasing the risk of neonatal anemia. The difference is significant, emphasizing the need for proper maternal iron levels during pregnancy to support neonatal health.

DISCUSSION

This study highlights the significant impact of maternal anemia on placental function and neonatal iron stores. Findings indicate that anemic mothers had lower placental weight and efficiency, suggesting impaired nutrient and oxygen transfer to the fetus. Additionally, neonates born to anemic mothers had lower hemoglobin and ferritin levels, emphasizing the direct link between maternal iron status and fetal iron reserves. These results align with previous research demonstrating that maternal anemia can lead to intrauterine growth restriction and compromised fetal development[6-8].

Several studies have reported similar findings regarding the effects of maternal anemia on birth outcomes. Studies found that maternal anemia during pregnancy was associated with reduced birth weight and an increased risk of neonatal anemia.[9-11] Similarly, another study emphasized that iron deficiency in pregnancy contributes to suboptimal neonatal iron stores, predisposing infants to early-life anemia[12 13]. The present study further supports this evidence, as neonates born to anemic mothers had significantly lower cord blood hemoglobin and ferritin levels.

The relationship between maternal anemia and placental function has also been widely explored. Studies found that placental weight and thickness were lower in pregnancies affected by iron deficiency anemia, which was consistent with the findings of this study[14 15]. The reduced placental efficiency observed among anemic mothers may be due to impaired vascular development, limiting the transfer of essential nutrients to the fetus. Placental histological changes in anemic pregnancies, such as reduced villous vascularity, have been reported in previous studies, further supporting the hypothesis that anemia negatively impacts placental function.

Beyond placental changes, maternal anemia has been linked to adverse neonatal outcomes. Research demonstrated that infants born to anemic mothers had lower iron stores at birth and were at higher risk of developing anemia in early infancy[16 17]. This aligns with the current study, where anemic and non-anemic groups observed a significant difference in neonatal hemoglobin and ferritin levels. The impact of maternal anemia on neonatal health is particularly concerning, as iron is essential for brain development and cognitive function. Studies have shown that iron-deficient infants may experience long-term developmental delays, reinforcing the importance of adequate maternal iron levels during pregnancy[18].

The findings of this study also highlight the importance of early screening and management of anemia in pregnancy. Several studies have emphasized that timely iron supplementation can improve maternal hemoglobin levels, enhance placental function, and increase neonatal iron stores [19 20]. Implementing routine maternal anemia screening and optimizing prenatal iron supplementation strategies could help reduce the prevalence of neonatal anemia and improve birth outcomes.

Despite the strengths of this study, ‘there are some limitations’. ‘The cross-sectional design does not establish causality, and factors such as maternal diet, inflammation, and genetic influences on iron metabolism were not fully accounted for’. Future research should include longitudinal studies to assess the long-term impact of maternal anemia on child development. Additionally, interventions such as iron supplementation should be explored further to evaluate their effectiveness in improving placental and neonatal iron status.

In conclusion, this study reinforces the crucial role of maternal iron status in pregnancy. Maternal anemia adversely affects placental function and significantly lowers neonatal iron stores, increasing the risk of neonatal anemia. These findings highlight the need for improved maternal nutrition, early anemia detection, and effective prenatal care to ensure better birth outcomes. Addressing maternal anemia could have long-term benefits, promoting healthier pregnancies and optimal neonatal development.

CONCLUSION

This study underscores the significant impact of maternal anemia on placental function and neonatal iron stores. Findings reveal that anemic mothers had lower placental weight, reduced placental efficiency, and impaired villous vascularity, suggesting compromised nutrient and oxygen transfer to the fetus. Consequently, neonates born to anemic mothers exhibited lower hemoglobin and ferritin levels, increasing their risk of early-life anemia.

These results emphasize the need for early identification and management of maternal anemia during pregnancy. Routine screening, adequate iron supplementation, and improved maternal nutrition could help mitigate the adverse effects on fetal development. Given the role of iron in cognitive and physical growth, addressing maternal anemia is essential for long-term child health.

Future research should explore the effectiveness of early interventions, such as iron therapy, in improving placental function and neonatal iron status. Implementing comprehensive maternal healthcare strategies can contribute to better pregnancy outcomes and healthier newborns, reducing the burden of anemia-related complications in early childhood.

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