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Original Article

Hematological Parameters and Iron Status in Pregnant Women in Conflict-Affected Taiz, Yemen

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ABSTRACT

Background: Iron deficiency anemia persists as a serious public health concern in conflict-affected settings, with Yemen exhibiting among the highest global prevalence rates. This cross-sectional study evaluates trimester-specific hematological changes and iron levels among pregnant women in Taiz, Yemen—a region devastated by persistent humanitarian crises.

Methods: A cross-sectional study was conducted from January to March 2022. A total of 165 pregnant women (15–40 years) were systematically enrolled from antenatal clinics. Complete blood count and serum iron were analyzed. Statistical analyses included analysis of variance (ANOVA) and multivariable regression.

Results: Stratification by trimester revealed significant progressive declines in hemoglobin, serum iron, and red blood cell indices from the first to the third trimester (all $p < 0.01$). Overall, 41.8% of participants exhibited anemia (hemoglobin < 11.0 g/dL), with the prevalence escalating to 57.8% in the third trimester. Iron deficiency (serum iron < 60 µg/dL) was found in 28.5% of the women. Multivariable analysis identified illiteracy (adjusted β = −1.2 [95% CI, −2.2 to −0.2]; $p = 0.02$) and grand multiparity (adjusted β = −1.1 [95% CI, −1.9 to −0.3]; $p = 0.007$) as independent predictors of lower hemoglobin levels.

Conclusions: Trimester-dependent declines in hemoglobin and red blood cell parameters are common during pregnancy. However, in conflict-affected regions, these changes are often more severe, likely due to iron deficiency and limited access to proper screening and care.

Key words: Hematological parameters, serum iron, pregnancy, anemia, Yemen, Taiz

INTRODUCTION

Pregnancy induces significant hematological changes, including plasma volume expansion (up to 50%) and increased iron requirement, which alter standard hematological reference ranges. [1] These expected changes frequently result in gestational anemia, defined by the World Health Organization (WHO) as hemoglobin (Hb) levels < 11.0 g/dL during pregnancy. [2] In conflict-affected regions like Yemen, where 71% of pregnant women experience anemia due to malnutrition and limited healthcare access, [3] these extra challenges increase the risk of severe anemia.

Iron deficiency anemia (IDA) accounts for 50% of global anemia cases and is particularly prevalent in pregnancy, increasing risks of preterm birth and maternal mortality. [4]

Hematological parameters, including red cell indices (mean corpuscular volume [MCV], mean corpuscular hemoglobin [MCH], MCHC) and serum iron, serve as critical biomarkers for IDA. However, current clinical guidelines are based on Western standards, which may not reflect normal blood values in populations facing chronic malnutrition or frequent illnesses. [5]

In Taiz, Yemen, the ongoing conflict has damaged healthcare infrastructure and increased hunger and poor nutrition, with over 20% of women of childbearing age exhibiting iron deficiency. [6] Despite this, Yemen lacks locally derived, pregnancy-specific hematological reference intervals, which may cause the misclassification of normal physiological adaptations or pathological anemia. [7] This study aimed to assess blood and serum iron levels in pregnant women at different stages of pregnancy residing in Taiz, while establishing preliminary reference ranges that reflect normal pregnancy changes in this population. Our primary hypothesis was that sociodemographic factors, such as education and parity, would be associated with hematological abnormalities.

MATERIALS AND METHODS

Study design and setting

A hospital-based cross-sectional study was conducted from January to March 2022 at antenatal clinics across Taiz City, Yemen. The study received ethical clearance from Taiz University (approval no.: MED-2022-011) and adhered to the Declaration of Helsinki. Participants were recruited from three major hospitals across Taiz Governorate (Al-Thawra, Al-Mudhaffar, and Al-Jumhouri) to ensure geographical representation.

Participants

A total of 165 pregnant women aged 15 to 40 years were randomly enrolled after providing written informed consent.

Inclusion criteria

1. Yemeni nationality.
2. Gestational age confirmed by last menstrual period or ultrasound.
3. Residence in Taiz city.

Exclusion criteria

1. Non-Yemeni nationals.
2. Chronic illnesses (renal/cardiac disease, HIV, malignancy).
3. Blood transfusion within 3 months before enrollment.

Sample size calculation

The sample size was calculated using the formula for cross-sectional studies [8]

$$N = \frac{z^2\, p(1-P)}{b^2} = \frac{1.96^2 \times 16.2\%\ (1-16.2\%)}{(3\%)^2} = 105$$

where z = 1.96 (95% confidence level), p = 16.2%, p = 16.2% (anemia prevalence from a prior Yemeni study, Noman Ahmed et al., [9] and b = 3%, b = 3% (margin of error).

This yielded n = 374. However, due to resource constraints in the conflict-affected setting and strict adherence to inclusion/exclusion criteria, A total of 165 pregnant women aged 15 to 40 years were enrolled using a systematic random sampling approach (every third patient attending the antenatal clinic during the study period) after providing written informed consent. This sample size provides 80% power to detect a 0.8 g/dL Hb difference between trimesters (SD = 1.0, α = 0.05).

A post-hoc power analysis was performed using G*Power software (version 3.1.9.7), confirming that the final sample size of 165 provides over 80% power to detect a 0.8 g/dL Hb difference between trimesters (effect size d = 0.8, α = 0.05, using a one-way ANOVA test).

Data and sample collection

1. Sociodemographic data: Age, education, occupation, parity, and trimester were recorded via structured questionnaires.
2. Blood sampling:
   - 4 mL of venous blood was collected by trained phlebotomists.
   - 2 mL in K_2EDTA tubes for complete blood count (CBC) analysis.
   - 2 mL in plain serum tubes for iron quantification.
   - Serum samples were centrifuged at 3,000 rpm for 10 minutes within 2 hours of collection.

Laboratory analysis

1. CBC:
   - Analyzed using Sysmex XP-300™ (Sysmex Corporation, Japan) hematology analyzer.
   - Parameters: hemoglobin (Hb), red blood cells (RBC), hematocrit (HCT), mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), mean corpuscular hemoglobin concentration (MCHC), white blood cells (WBC), and platelets.
   - Calibration and quality control were performed daily according to the manufacturer's protocol.
   - Principle: Electrical impedance (Coulter principle) for cell counting and sizing. [10]
2. Serum iron:
   - Quantified via spectrophotometry (BioSystems S.A., Spain) using the FerroZine® method. [11]
   - Wavelength: 560 nm.
   - Reagent: Iron/UIBC Kit (REF: 11505; Linear range: 10–500 µg/dL).

Additional data collection

- Data on malaria infection (confirmed by rapid diagnostic test during routine antenatal screening) were extracted from medical records for 158 participants (95.8%).

- Dietary iron intake was assessed via a simplified 7-day food frequency questionnaire focused on iron-rich foods (red meat, poultry, legumes, dark leafy greens). Intake was categorized as "low" (<3 servings/week) or "adequate" (≥3 servings/week) based on FAO/WHO thresholds.

This tool provided a rapid assessment of iron-rich food consumption suitable for the low-resource setting, though it was not a comprehensive, validated nutrient analysis.

Statistical analysis

Data were analyzed using SPSS v.28.0 and R v.4.2.1.

- Group comparisons: Analysis of covariance (ANCOVA) with Bonferroni post-hoc tests (adjusting for age, parity).
- Iron deficiency predictors: Multivariable logistic regression (outcome: serum iron < 60 µg/dL).
- Optimal Hb thresholds: ROC analysis against ferritin-defined iron deficiency.
- Significance: $p < 0.05$ (two-tailed).

Quality control

- Internal QC: Commercial controls (Bio-Rad Liquichek™) run daily.
- Instrument calibration: Weekly per manufacturer protocols.
- Duplicate testing: 10% of samples randomly re-analyzed.

Ethical approval

This study received ethical clearance from the Institutional Review Board (IRB) of Taiz University, Yemen (approval reference: MED-2022-011; Date: December 15, 2021). All procedures adhered to the Declaration of Helsinki (2013) and Taiz University's Ethical Guidelines for Biomedical Research.

RESULTS

Participant characteristics

The cohort comprised 165 pregnant women aged 15 to 40 years (mean age: 26.4 ± 5.8), predominantly housewives (95.8%, *n* = 158). Educational distribution included: illiterate (15.2%, *n* = 25), primary (23.0%, *n* = 38), secondary (36.4%, *n* = 60), and graduates (25.5%, *n* = 42). Most were in their third trimester (54.5%, *n* = 90), with multiparous women (≥3 children) representing 38.2% (*n* = 63) of participants.

Hematological parameters and serum iron levels

Our analysis revealed significant trimester-dependent alterations in hematological indices. The key results are summarized in **Table 1**. There were significant progressive reductions in Hb, HCT, MCV, and MCH across the trimesters ($p < 0.01$). Serum iron levels also declined significantly from the first to the third trimester.

Significant trimester-dependent reductions were observed in Hb, serum iron, and red cell indices (**Table 1**; **Figure 1**).

Key findings

The main outcomes of this study are summarized based on the analyzed data:

1. **Anemia prevalence:** The overall prevalence of anemia (Hb < 11.0 g/dL) was 41.8% (69/165). This prevalence was highest in the third trimester (57.8%) compared to the first trimester (17.1%, $p < 0.001$).
2. **Iron deficiency:** Based on serum iron levels (<60 µg/dL), 28.5% (47/165) of the participants were iron deficient.
3. **Sociodemographic correlations:** Lower hemoglobin levels were significantly associated with illiteracy (adjusted $\beta = -1.2$ [95% CI, −2.2 to −0.2]; $p = 0.02$) and grand multiparity (≥3 children: 10.9 ± 1.0 g/dL vs. primigravida: 12.0 ± 0.8 g/dL; $p = 0.007$). Consequently, anemia prevalence was three times higher among illiterate women compared to graduates (62% vs. 20%) and 3.4 times higher in grand multiparous women compared to primigravidae (68% vs. 20%).

DISCUSSION

This cross-sectional study provides the first comprehensive analysis of hematological parameters and serum iron levels among pregnant women in conflict-affected Taiz, Yemen. Our main findings reveal a high burden of anemia that worsens with pregnancy trimester and is strongly influenced by socio-demographic factors like education and parity.

The progressive decline in Hb (12.1–11.0 g/dL), HCT, and red cell indices (MCV, MCH) across trimesters ($p < 0.01$) aligns with physiological plasma expansion in pregnancy. [1] However,

Table 1: Hematological profile of pregnant women (mean ± SD).

Parameter	All (*n* = 165)	First trimester (*n* = 35)	Second trimester (*n* = 40)	Third trimester (*n* = 90)	*p*-value
Hemoglobin (g/dL)	11.5 ± 1.1	12.1 ± 0.9	11.7 ± 1.0	11.0 ± 1.0	<0.001
Serum iron (µg/dL)	89.6 ± 34.8	102.3 ± 28.1	92.5 ± 30.4	82.1 ± 35.2	0.003
Hematocrit (%)	33.9 ± 4.8	35.8 ± 3.2	34.2 ± 4.1	32.8 ± 5.1	<0.001
Mean corpuscular volume (fL)	78.9 ± 8.1	82.4 ± 6.3	80.1 ± 7.2	76.8 ± 8.3	<0.001
Mean corpuscular hemoglobin (pg)	27.1 ± 3.4	28.3 ± 2.8	27.6 ± 2.9	26.3 ± 3.5	0.002
Platelets (×10^3/µL)	277.2 ± 76.5	291.4 ± 70.1	285.3 ± 72.8	265.8 ± 78.3	0.052
WBCs (×10^3/µL)	6.7 ± 2.1	6.4 ± 1.8	6.6 ± 1.9	6.9 ± 2.3	0.41

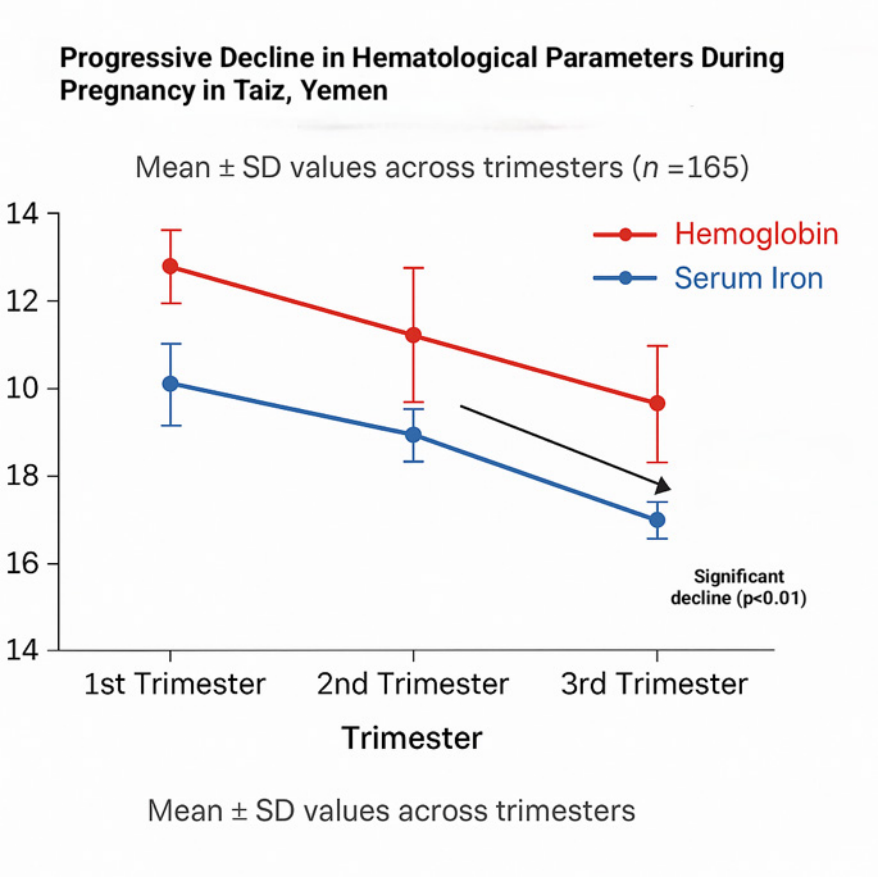

Figure 1: Trimester-specific trends in hemoglobin and serum iron levels. Red line: hemoglobin (g/dL); blue line: serum iron (µg/dL) showed a decrease with trimesters.

the 41.8% anemia prevalence (Hb < 11.0 g/dL)—peaking at 57.8% in the third trimester—far exceeds global rates (WHO: 38.2%) and reflects pathological drivers:

- Iron deficiency: 28.5% had serum iron <60 µg/dL, compounded by low dietary intake. [12]
- Multiparity: Women with ≥ 3 children had significantly lower Hb (10.9 vs. 12.0 g/dL; p = 0.007), indicating cumulative nutritional depletion. [13]

Hemodilution alone cannot explain Hb levels below physiological thresholds in resource-limited settings. [7]

The 41.8% anemia prevalence in Taiz reflects an intermediate burden between war-torn Sana'a and stable Riyadh (**Figure 2**).

Illiteracy strongly predicted anemia (illiterate: 10.7 g/dL vs. graduates: 11.9 g/dL; p = 0.02), mirroring findings from Aden, Yemen. [14] This highlights:

- Limited health literacy, leading to delayed antenatal care.
- Food insecurity: 72% of Taiz households face severe food shortages, [15] which restricts access to iron-rich foods.

The observed near-normal serum iron (89.6 µg/dL) alongside high anemia prevalence suggests a multifactorial etiology:

- Inflammation-mediated iron sequestration: The observed near-normal mean serum iron level alongside high anemia prevalence suggests a multifactorial etiology. This paradox could be explained by inflammation-mediated iron sequestration due to high rates of infections like malaria, although this remains speculative as C-reactive protein (CRP) and ferritin were not measured in this study. [4,16]
- Non-iron deficiencies: Folate/B12 deficiencies (unmeasured due to reagent constraints) may explain macrocytic anemia in 18% of anemic women (MCV > 90fL).
- Dietary inadequacy: 68.5% reported low iron intake, consistent with WFP reports of 72% household food insecurity in Taiz. [14]

This highlights that IDA diagnosis requires ferritin measurement (unavailable here) in high-infection settings per WHO guidelines. [2]

Anemia prevalence in Taiz (41.8%) was intermediate between conflict-affected Sana'a (48.1% [13]) and stable Riyadh (28.3% [17]). Similarly, mean Hb (11.5 g/dL) and iron deficiency rates (28.5%) reflected this gradient of healthcare access across settings.

This gradient of anemia burden is consistent with trends observed in other resource-limited and conflict-affected settings in the region. [18,19]

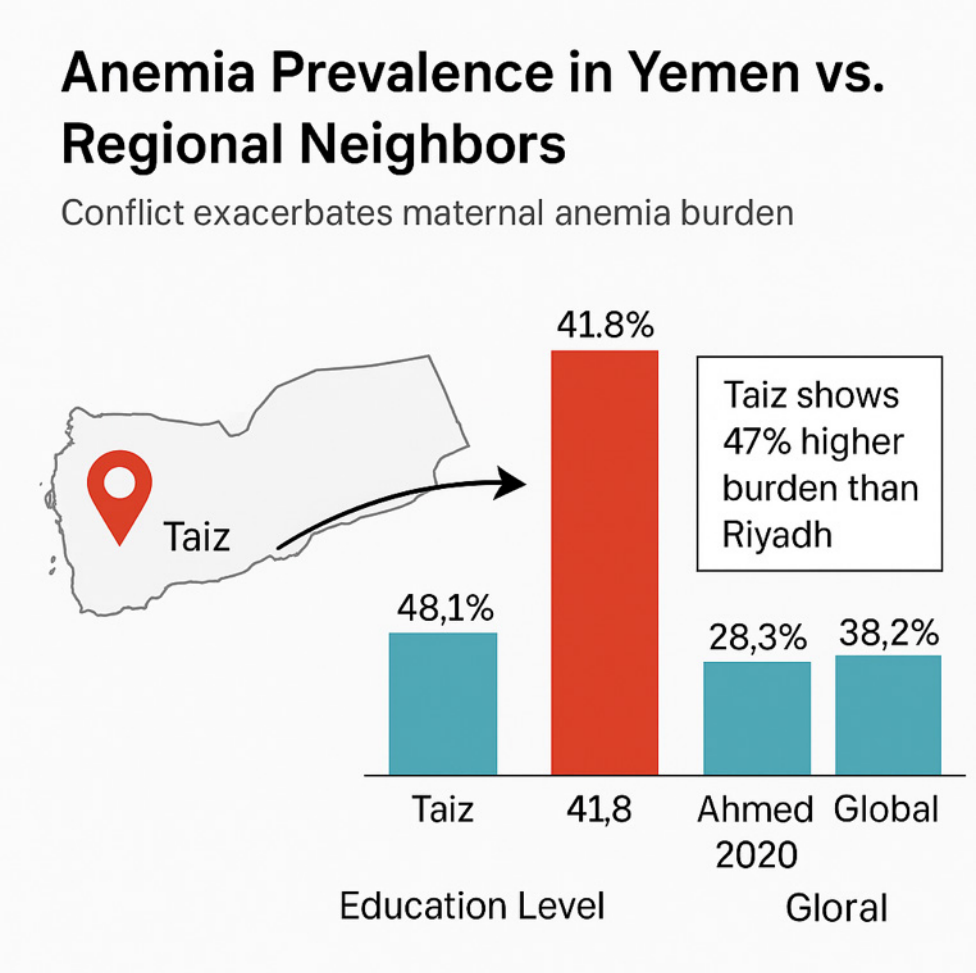

Figure 2: Regional comparison of anemia burden in conflict versus non-conflict settings: Taiz (current study) and Sana'a. [13,17]

Taiz shows moderate improvement over Sana'a but lags behind Saudi Arabia, reflecting the gradient of healthcare access.

Recommendations for practice

1. Trimester-specific protocols:
   - Universal iron supplementation from the first trimester (60 mg/day) + folate. [2]
2. Community interventions:
   - Nutrition education targeting illiterate women (e.g., pictorial dietary guides).
3. Conflict-sensitive monitoring:
   - Point-of-care hemoglobinometers in mobile clinics. [20]
   - Integrated testing: Deploy point-of-care ferritin/CRP devices (e.g., VitaCheck®) in mobile clinics to distinguish true IDA from anemia of inflammation.
   - Food aid integration: Partner with WFP to co-distribute iron supplements with fortified wheat flour (e.g., 60 mg elemental iron sachets).

Study limitations

1. Single-region sampling limits nationwide generalizability, though our tri-hospital approach enhances Taiz's representativeness.
2. Ferritin and CRP were not measured due to reagent shortages during the conflict period, restricting inflammation-adjusted iron status assessment.
3. Cross-sectional design precludes causal inferences about anemia progression.
4. Parasitic infection data beyond malaria were unavailable due to disrupted laboratory services.

CONCLUSIONS

This study reveals a high prevalence of anemia and iron deficiency among pregnant women in Taiz, Yemen, that worsens significantly across trimesters and is strongly predicted by illiteracy and high parity. These findings underscore that the anemia crisis in this conflict-affected region is a multifactorial problem driven by nutritional, socio-economic, and healthcare access issues.

AUTHORS' CONTRIBUTIONS

Each author has made a substantial contribution to the present work in one or more areas, including conception, study design,

conduct, data collection, analysis, and interpretation. All authors have given final approval of the version to be published, agreed on the journal to which the article has been submitted, and agreed to be accountable for all aspects of the work.

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CONFLICT OF INTEREST

None.

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