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Longitudinal Hematologic Dynamics and Obstetric Outcomes in Central India: A Prospective Cohort Study

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Abstract

Background: Pregnancy induces substantial physiological hematologic adaptations, including plasma-volume expansion and changes in hemoglobin, leukocyte, and platelet indices. In Central India, nutritional deficiencies and prevalent hemoglobin disorders may compound these changes and influence obstetric risk.

Objective: To characterize longitudinal trajectories of maternal hematologic indices across gestation and evaluate their associations with major obstetric complications in a Central Indian tertiary-care cohort.

Methods: This prospective observational cohort study enrolled 1,000 pregnant women at a tertiary-care teaching hospital in Chhattisgarh over a 12-month recruitment period. Serial complete blood counts were obtained at 8–12, 20–24, and 32–36 weeks. Primary outcomes were hypertensive disorders of pregnancy (HDP) and postpartum hemorrhage (PPH); secondary outcomes included preterm delivery, low birth weight, intrauterine growth restriction, and neonatal-unit admission. Group-based trajectory modeling identified hemoglobin trajectories, and multivariable logistic regression estimated adjusted associations with obstetric outcomes.

Results: Baseline anemia (Hb <11.0 g/dL) was present in 53.6% of participants. Three hemoglobin trajectories were identified: decline-stable (n=312; 31.2%), physiological dip-rise (n=498; 49.8%), and failure of hemodilution/elevated hemoglobin (n=190; 19.0%). Within the decline-stable group, women with third-trimester Hb <9.0 g/dL had higher PPH risk (14.2% vs. 3.8%; adjusted OR 3.87, 95% CI 2.14–6.99; p<0.001). Failure of hemodilution (second-trimester HCT >36%) was associated with preeclampsia (adjusted OR 2.41, 95% CI 1.52–3.82; p<0.001). Progressive thrombocytopenia was associated with severe HDP and greater operative blood loss.

Conclusion: Longitudinal hematologic monitoring during pregnancy may provide clinically useful prognostic information for identifying women at increased risk of obstetric complications. External validation is required before trajectory-based risk classification is adopted for routine clinical use.

Keywords: Maternal anemia; Hemoglobin trajectory; Postpartum hemorrhage; Preeclampsia; Thrombocytopenia; Central India

1. Introduction

Normal pregnancy is accompanied by extensive maternal physiological adaptation. Plasma volume expands by approximately 40%–50%, exceeding the corresponding increase in red-cell mass and producing physiological hemodilution that reduces blood viscosity and supports uteroplacental perfusion [1,2].

In Central India, pre-gestational iron-deficiency anemia, nutritional deficiencies, and hemoglobinopathies may coexist with these normal adaptations and can mask or exacerbate pathological hematologic states [3]. Abnormal hematologic patterns, including failure of hemodilution, accelerated hemoglobin decline, and thrombocytopenia, have been associated with adverse maternal and neonatal outcomes [1,4].

Single-trimester measurements provide only a snapshot of maternal hematologic status. Longitudinal analyses may better capture clinically relevant change across gestation, and recent studies have evaluated hemoglobin trajectories and broader complete-blood-count dynamics in relation to pregnancy complications [2,5,8]. Evidence from Central Indian populations remains limited.

The objectives of this study were to characterize longitudinal maternal hematologic trajectories across all three trimesters, evaluate their associations with major obstetric complications, and assess the potential prognostic utility of serial complete blood count monitoring in a Central Indian tertiary-care setting.

2. Materials and Methods

2.1 Study Design and Setting

This prospective observational cohort study was conducted at Pt. Jawaharlal Nehru Memorial Medical College, Raipur, a tertiary-care teaching hospital serving urban and rural populations in Chhattisgarh, Central India. Recruitment was conducted over a 12-month period, with follow-up through delivery and neonatal discharge. The authors report that the study was approved by the Institutional Ethics Committee of Pt. Jawaharlal Nehru Memorial Medical College and that written informed consent was obtained from all participants before enrollment. Reporting was guided by the STROBE recommendations for cohort studies [6].

2.2 Participant Selection

Pregnant women presenting for routine prenatal care in the first trimester (8–12 weeks) were consecutively screened. Inclusion criteria were singleton pregnancy, gestational age confirmed by early ultrasonography, maternal age 18–45 years, and willingness to complete prenatal follow-up through delivery. Exclusion criteria were pre-existing chronic renal disease, pre-pregnancy hypertension, active oncologic disease, baseline autoimmune bleeding disorders, known hemoglobinopathy requiring specialized care, and multiple pregnancy.

2.3 Data Collection and Laboratory Analysis

Serial blood samples were obtained at three predefined gestational windows: 8–12 weeks, 20–24 weeks, and 32–36 weeks. Complete blood counts were performed using a Sysmex XN-1000 automated hematology analyzer (Sysmex Corporation, Kobe, Japan) in the institutional laboratory, which was reported to be accredited by the National Accreditation Board for Testing and Calibration Laboratories (NABL). Quality-control procedures followed manufacturer specifications and institutional protocols.

Recorded parameters included hemoglobin (Hb), hematocrit (HCT), red blood cell count (RBC), mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), mean corpuscular hemoglobin concentration (MCHC), white blood cell count (WBC), and platelet count (PLT). Microcytic anemia was defined as MCV <80 fL and hypochromic anemia as MCH <27 pg.

2.4 Outcome Definitions

Primary outcomes. Hypertensive disorders of pregnancy included gestational hypertension, preeclampsia, and eclampsia, defined using the study criteria based on ACOG Practice Bulletin No. 222 [7]. For this study, postpartum hemorrhage was defined as measured blood loss ≥500 mL after vaginal delivery or ≥1,000 mL after cesarean delivery, assessed using calibrated collection drapes and weighed swabs.

Secondary outcomes. Preterm delivery was defined as birth before 37 completed weeks; low birth weight as birth weight <2,500 g; intrauterine growth restriction as estimated fetal weight below the 10th percentile for gestational age; and neonatal-unit admission as admission to either neonatal intensive care or a special-care unit.

2.5 Statistical Analysis

Sample size: Enrollment of 1,000 participants was based on the feasibility of consecutive recruitment over 12 months and was reported to provide 80% power to detect an odds ratio of 1.5 for the primary outcomes, assuming a 15% event rate and a two-sided alpha of 0.05.

Trajectory modeling: Group-based trajectory modeling was performed using the traj plugin in Stata version 17 (StataCorp, College Station, TX, USA). Models containing two to five groups were fitted using a censored normal distribution. Model selection considered the Bayesian Information Criterion (BIC), average posterior probability of assignment (>0.70), and clinical interpretability. The three-group model was selected (BIC = -8234.5; entropy = 0.78).

Outcome analysis: Multivariable logistic regression was used to estimate adjusted odds ratios (aORs) with 95% confidence intervals. Prespecified covariates were maternal age, parity, baseline hemoglobin, body mass index, iron supplementation, and mode of delivery. Missing data were analyzed by complete-case analysis, with sensitivity analyses using multiple imputation. Statistical significance was defined as two-sided $p<0.05$. All analyses were performed in Stata version 17.

3. Results

3.1 Participant Flow and Baseline Characteristics

Of 1,247 women screened, 1,000 met the eligibility criteria and were enrolled. Follow-up data were available for 942 participants (94.2%) in the second trimester, 898 (89.8%) in the third trimester, and 891 (89.1%) through delivery. Reported reasons for loss to follow-up were relocation (n=52), transfer to another facility (n=38), and withdrawal (n=19).

Mean maternal age was 24.9 ± 4.2 years. Primigravidae comprised 43.7% (n=437) and multigravidae 56.3% (n=563). Baseline anemia (Hb <11.0 g/dL) was present in 536 women (53.6%); among women with anemia, 41.5% were classified as mild, 51.2% as moderate, and 7.3% as severe.

Table 1. Selected baseline characteristics by gravidity

Parameter	Primigravida (n = 437)	Multigravida (n = 563)	Total (N = 1,000)
Mean age (years)	22.4 ± 3.1	26.8 ± 3.8	24.9 ± 4.2
Mean first-trimester Hb (g/dL)	10.8 ± 1.2	10.2 ± 1.4	10.5 ± 1.3
Mean third-trimester Hb (g/dL)	9.8 ± 1.4	9.1 ± 1.5	9.4 ± 1.5

3.2 Hemoglobin Trajectories

Three distinct hemoglobin trajectories were identified. The curves represent model-estimated group means at each gestational window and do not represent diagnostic thresholds or the full range of individual values within each group.

1. Decline-stable (n=312; 31.2%): Mean Hb declined from approximately 11.3 g/dL at 8–12 weeks to 10.6 g/dL at 20–24 weeks and plateaued at approximately 10.5 g/dL at 32–36 weeks. Although the group mean remained above 10.0 g/dL, some women in this class had Hb <10.0 g/dL, including a higher-risk subgroup with third-trimester Hb <9.0 g/dL.

2. Physiological dip-rise (n=498; 49.8%): Mean Hb showed a second-trimester dip followed by recovery to approximately 12.0 g/dL at 32–36 weeks.

3. Failure of hemodilution/elevated hemoglobin (n=190; 19.0%): Mean Hb remained persistently elevated at approximately 13.2-13.6 g/dL, with HCT >36% through the second and third trimesters.

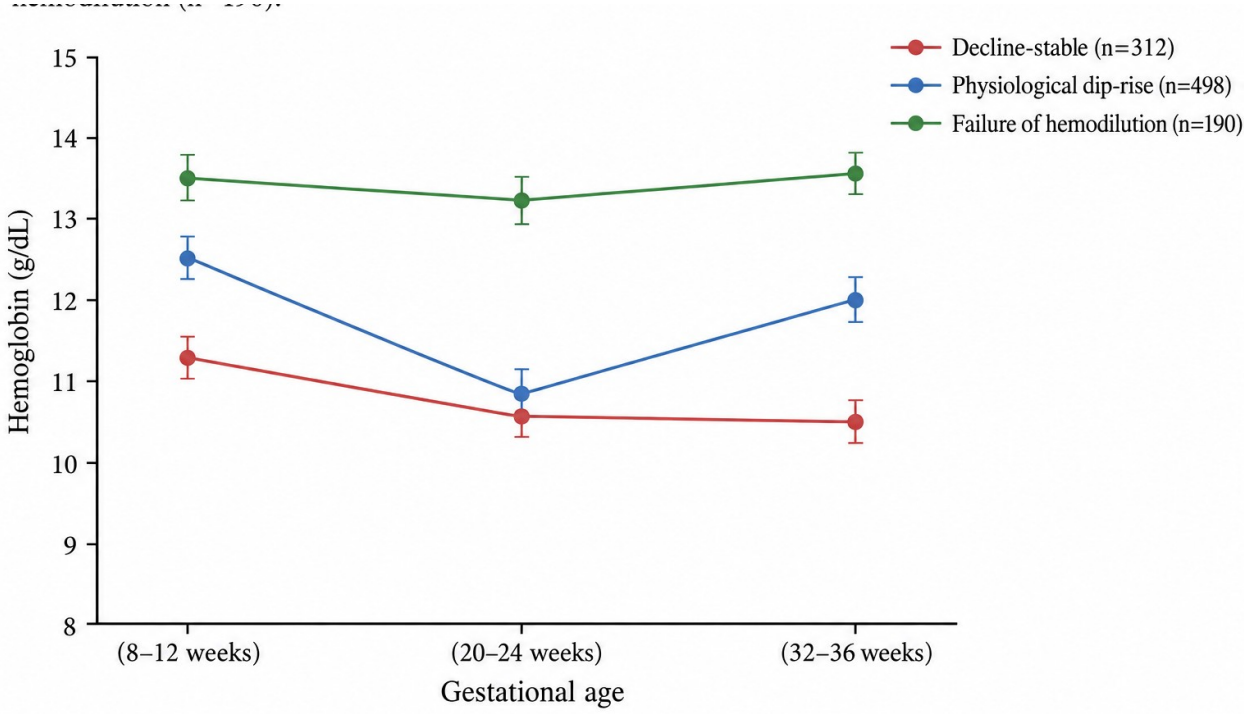


Figure 1. Hemoglobin trajectories across pregnancy. Group-based trajectory modeling identified decline-stable (n=312), physiological dip-rise (n=498), and failure of hemodilution (n=190) trajectories. Points represent model-estimated means at 8–12, 20–24, and 32–36 weeks. The approximately 12.0 g/dL third-trimester value is the mean of the physiological dip-rise group; the <10.0 and <9.0 g/dL values in the text refer to individual women within the decline-stable group rather than group-mean cutoffs.

3.3 Primary Outcomes

Women in the failure-of-hemodilution trajectory had higher odds of preeclampsia than women with physiological hemodilution (22.1% vs. 9.4%; aOR 2.41, 95% CI 1.52–3.82; p<0.001). A platelet count <150,000/µL in the late second trimester was associated with progression to severe preeclampsia or HELLP syndrome (aOR 3.12, 95% CI 1.68–5.79; p<0.001).

Within the decline-stable trajectory, women entering the third trimester with Hb <9.0 g/dL had higher primary PPH rates than the comparison group (14.2% vs. 3.8%; aOR 3.87, 95% CI 2.14–6.99; p<0.001). Uterine atony was reported as the primary cause in 68% of PPH cases among anemic mothers.

3.4 Secondary Outcomes

Preterm delivery occurred in 12.4% of women in the decline-stable trajectory compared with 7.1% in the physiological dip-rise group (aOR 1.82, 95% CI 1.18–2.81; p=0.007). Low birth weight occurred in 18.6% versus 11.2%, respectively (aOR 1.79, 95% CI 1.24–2.58; p=0.002).

Table 2. Selected adjusted associations between hematologic patterns and obstetric outcomes

Outcome / predictor	Reported event rates	Adjusted OR (95% CI)	p value
Preeclampsia: failure of hemodilution vs. physiological hemodilution	22.1% vs. 9.4%	2.41 (1.52–3.82)	<0.001
Severe preeclampsia / HELLP: platelets <150,000/µL	Not reported	3.12 (1.68–5.79)	<0.001
PPH: decline-stable subgroup with third-trimester Hb <9.0 g/dL	14.2% vs. 3.8%	3.87 (2.14–6.99)	<0.001
Preterm delivery: decline-stable vs. physiological dip-rise	12.4% vs. 7.1%	1.82 (1.18–2.81)	0.007
Low birth weight: decline-stable vs. physiological dip-rise	18.6% vs. 11.2%	1.79 (1.24–2.58)	0.002

4. Discussion

This prospective cohort study characterized longitudinal hematologic patterns in 1,000 pregnant women in Central India and reported associations between abnormal hemoglobin trajectories and obstetric complications. Both failure of physiological hemodilution and marked hemoglobin decline were associated with adverse outcomes, particularly hypertensive disorders and postpartum hemorrhage.

Iron deficiency remains a major contributor to anemia during pregnancy, particularly in resource-constrained settings [1,3]. Low hemoglobin reserves may reduce tolerance to peripartum blood loss, while abnormal longitudinal hemoglobin patterns may provide information that is not captured by isolated trimester-specific measurements [1,2]. The observed association between the decline-stable trajectory and PPH is directionally consistent with recent trajectory-based research [5].

Conversely, failure to achieve expected hemodilution may reflect inadequate plasma-volume expansion and has been linked to hypertensive pregnancy complications [2,8]. Serial CBC monitoring is widely available and inexpensive, which makes longitudinal interpretation potentially attractive in settings with limited access to specialized testing. Nevertheless, the associations observed in this study do not establish a validated prediction rule and should not be used as diagnostic thresholds without external validation.

4.1 Limitations

- The single-center design may limit generalizability to other populations and healthcare settings.
- Loss to follow-up (10.9% through delivery) may have introduced selection bias.
- Residual confounding from unmeasured factors, including dietary intake and socioeconomic status, cannot be excluded.
- Iron supplementation was not randomized and may have influenced observed hematologic trajectories.
- Blood-loss measurement in PPH is subject to measurement error despite use of calibrated drapes and weighed swabs.
- The prognostic utility of the trajectory groups requires validation in independent cohorts and should not be considered diagnostic without development and validation of a formal prediction model.

5. Conclusion

Serial monitoring of hematologic indices throughout pregnancy may assist in identifying women at elevated risk for obstetric complications in Central India. In this cohort, uncompensated anemia within a decline-stable hemoglobin trajectory was associated with postpartum hemorrhage, whereas failure of hemodilution was associated with hypertensive disorders of pregnancy. These findings require confirmation in independent prospective cohorts before clinical implementation.

Declarations

Ethics approval and consent to participate: The authors report that the study was approved by the Institutional Ethics Committee of Pt. Jawaharlal Nehru Memorial Medical College, Raipur, Chhattisgarh, India, and that written informed consent was obtained from all participants before enrollment.

Consent for publication: Not applicable.

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Author contributions: VB conceptualized and designed the study, collected data, performed statistical analysis, and drafted the manuscript. RS contributed to study design, data collection, and critical revision of the manuscript. Both authors approved the final version.

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