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Association of Maternal Iron Status with Labor Induction Outcomes and Neonatal Adaptation: A Prospective Cohort Study

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Abstract *Objective.* To evaluate the association between maternal iron status and labor induction outcomes, obstetric complications, and early neonatal outcomes. *Methods.* This prospective cohort study included 225 pregnant women undergoing labor induction between May 2023 and June 2025 at a tertiary obstetric care center. Participants were stratified by gestational age (37-41 weeks and ≥41 weeks) and further subdivided according to serum ferritin and hemoglobin levels into normal iron status, latent iron deficiency, and manifest iron deficiency anemia. A comparison group of 40 women with spontaneous labor and normal ferritin levels was included. Induction efficacy, mode of delivery, intrapartum and postpartum complications, and neonatal outcomes (Apgar score and NICU admission) were analyzed using χ^2 tests and ANOVA/Kruskal-Wallis tests as appropriate. *Results.* Reduced serum ferritin levels (<30 ng/mL) were significantly associated with lower labor induction efficiency, prolonged induction-to-delivery interval, and increased resistance to prostaglandin-based induction methods ($p < 0.05$). Vaginal delivery rates decreased progressively with worsening iron deficiency, while cesarean section rates due to failed induction increased, reaching 32.5% at 37-41 weeks and 42.8% in post-term pregnancies among women with manifest anemia ($p < 0.05$). Iron-deficient women demonstrated higher rates of uterine inertia, atonic postpartum hemorrhage, and postpartum anemia. Neonatal outcomes were adversely affected by maternal iron deficiency, with lower Apgar scores and higher NICU admission rates observed exclusively among newborns of women with manifest iron deficiency. *Conclusion.* Maternal iron deficiency, including latent iron deficiency with normal hemoglobin, is associated with poorer labor induction outcomes, increased obstetric complications, and impaired early neonatal adaptation. Routine assessment of serum ferritin prior to labor induction may improve risk stratification, optimize clinical decision-making, and enhance maternal and neonatal outcomes.

Keywords Labor induction, Iron deficiency, Serum ferritin, Pregnancy outcomes, Uterine contractility, Neonatal outcomes

1. Introduction

The increasing use of labor induction (LI) has become a key issue in modern obstetrics because it directly affects maternal and perinatal outcomes. The World Health Organization reports that induced deliveries account for ~9.6% of births globally and may reach up to 25% of term births in high-income countries, reflecting a growing reliance on planned delivery in complicated pregnancies [1,3,5]. However, LI effectiveness remains variable and depends on cervical readiness, uterine contractility, hormonal factors, and maternal metabolic status [2,4,9]. Iron deficiency is one of the most common nutritional disorders in women of reproductive age and is increasingly linked to LI outcomes. UNICEF (2023) estimates that ~40% of women of childbearing age have iron deficiency and ~20% have anemia; in pregnancy, iron deficiency anemia may reach 40-50% (WHO) [3]. Evidence suggests that anemia and even latent iron deficiency (low ferritin with normal hemoglobin) are associated with induction failure, prolonged labor, and higher operative delivery rates. Low serum ferritin indicates depleted iron stores and may reflect impaired myometrial energy metabolism and reduced responsiveness to prostaglandins and oxytocin, increasing risks of labor dystocia, uterine atony, and postpartum hemorrhage, with potentially unfavorable neonatal outcomes [6,8,10]. Despite these concerns, there is no unified international standard for incorporating ferritin into LI planning. Integrating biochemical biomarkers into individualized induction strategies may improve risk stratification, optimize management, and enhance maternal-neonatal outcomes.

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2. Materials and Methods

The study protocol was approved by the Local Ethics Committee, and the study was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants.

This study was conducted from May 2023 to June 2025 at a tertiary obstetric care center. Pregnant women aged 19-42 years with medical indications for labor induction were enrolled based on predefined clinical and laboratory criteria. Participants were stratified according to gestational age into two main groups. The first group included women at 37-41 weeks of gestation undergoing planned labor induction, while the second group consisted of women at ≥41 weeks of gestation undergoing post-term induction. Each main group was further subdivided based on serum ferritin and hemoglobin (Hb) levels into three subgroups:

(a) women with normal iron status (serum ferritin >30 ng/mL and Hb ≥110 g/L; n=40);
(b) women with latent iron deficiency (serum ferritin <30 ng/mL and Hb ≥110 g/L; n=40);
(c) women with manifest iron deficiency anemia (serum ferritin <30 ng/mL and Hb <110 g/L; n=40).

Women in the ≥41-week group were similarly subdivided according to ferritin and hemoglobin levels, with 35 participants in each subgroup. A control group of 40 pregnant women with normal ferritin levels and spontaneous onset of labor was also included. Diagnostic assessment comprised obstetric and gynecological history, clinical examination, laboratory investigations, and ultrasound evaluation. During labor induction, all participants underwent comprehensive clinical and laboratory monitoring. Induction efficacy was assessed by labor progression parameters, mode of delivery, and intrapartum complications, while neonatal outcomes were evaluated using standard clinical indicators, including Apgar scores.

Statistical analysis was performed using SPSS software (version 26.0). Normality was assessed using the Shapiro-Wilk test. A p-value < 0.05 was considered statistically significant. Categorical variables were compared using the χ^2 test (Fisher’s exact test when appropriate); continuous variables were analyzed using ANOVA (Kruskal-Wallis for non-normal data).

3. Results

Overall, 225 women undergoing labor induction and 40 women with spontaneous labor were analyzed. The groups were comparable in baseline characteristics.

Indications for labor induction

Hypertensive disorders were the leading indication for labor induction at 37-41 weeks of gestation, accounting for 47.5%, 55.0%, and 60.0% of cases in groups 1A, 1B, and 1C, respectively. In contrast, post-term pregnancy was the predominant indication at ≥41 weeks, observed in 77.1% of group 2A, 88.6% of group 2B, and 71.4% of group 2C.

Table 1. Indications for labor induction across study groups

Indication for labor induction	1A (n=40)	1B (n=40)	1C (n=40)	2A (n=35)	2B (n=35)	2C (n=35)
	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)
Hypertensive disorders	19 (47.5)	22 (55.0)	24 (60.0)	-	-	-
Fetal macrosomia	7 (17.5)	4 (10.0)	7 (17.5)	13 (37.1)	4 (11.4)	10 (28.6)
Post-term pregnancy	-	-	-	27 (77.1)	31 (88.6)	25 (71.4)
Somatic diseases	7 (17.5)	6 (15.0)	6 (15.0)	-	-	-
Oligohydramnios	2 (5.0)	4 (10.0)	1 (2.5)	-	-	-
Polyhydramnios	2 (5.0)	-	2 (5.0)	-	-	-
Impaired uteroplacental-fetoplacental circulation	3 (7.5)	4 (10.0)	-	-	-	-

Note: “-” indicates that the indication/method was not applicable or not used in the corresponding group.

Table 2. Iron metabolism parameters in pregnant women undergoing labor induction

Parameter	Control (n=40)	1A (n=40)	1B (n=40)	1C (n=40)	2A (n=35)	2B (n=35)	2C (n=35)	p^1	p^2	p^3
Ferritin (ng/mL)	51.3 ± 2.4	43.3 ± 0.64	18.5 ± 0.33	10.3 ± 0.62	41.5 ± 0.33	15.3 ± 0.65	9.6 ± 0.10	<0.001	<0.001	<0.05
Transferrin (g/L)	2.8 ± 0.08	3.9 ± 0.14	6.9 ± 0.21	8.1 ± 0.44	3.5 ± 0.12	7.3 ± 0.15	8.9 ± 0.07	<0.001	<0.001	>0.05
Serum iron (µmol/L)	22.6 ± 0.72	10.4 ± 0.32	7.3 ± 0.67	6.3 ± 0.76	9.3 ± 0.64	6.8 ± 0.20	5.6 ± 0.35	<0.001	<0.001	>0.05
Total iron-binding capacity (µmol/L)	57.3 ± 1.2	54.3 ± 1.3	74.1 ± 0.7	79.2 ± 1.5	52.7 ± 1.8	77.3 ± 1.5	83.5 ± 0.78	<0.001	<0.001	>0.05

p^1- comparison between control group and 37-41-week groups;
p^2- comparison between control group and ≥41-week groups;
p^3- comparison between corresponding 37-41-week and ≥41-week ferritin-based subgroups. Data are presented as mean ± standard error (SE).

Fetal macrosomia was more frequent in post-term pregnancies, particularly among women with iron deficiency. Indications for labor induction differed significantly according to gestational age and iron status (χ^2 test, $p < 0.05$) (Table 1).

Iron metabolism parameters

Significant differences in iron metabolism parameters were observed between the study groups.

Serum ferritin levels decreased progressively from normal iron status to latent and manifest iron deficiency in both gestational-age cohorts ($p < 0.001$), with the lowest values recorded in women with manifest anemia, particularly in post-term pregnancies. In contrast, transferrin, serum iron, and total iron-binding capacity differed significantly according to iron status ($p < 0.001$) but showed no significant differences between corresponding gestational-age groups ($p > 0.05$). Ferritin levels remained significantly lower in post-term pregnancies compared with 37-41 weeks ($p < 0.05$), indicating greater depletion of iron stores with advancing gestation (Table 2).

Types of labor induction

Analysis of labor induction methods revealed significant differences across gestational-age and ferritin-based subgroups. Prostaglandin E2 alone was more commonly used at 37-41 weeks, whereas post-term pregnancies more often required combined induction strategies.

Women with latent and manifest iron deficiency showed an increased need for repeated prostaglandin dosing, indicating reduced responsiveness to pharmacological induction. In post-term pregnancies, prostaglandin E2 combined with amniotomy predominated, reflecting a greater need for mechanical augmentation. Overall, reduced ferritin levels were associated with more complex induction approaches and lower induction efficiency (Table 3).

Mode of delivery

Analysis of delivery mode showed significant differences according to iron status and gestational age. At 37-41 weeks, vaginal delivery rates decreased from 85.0% in women with normal ferritin to 67.5% in those with manifest iron deficiency ($\chi^2 = 3.5$, $p < 0.05$). In post-term pregnancies, all women with normal ferritin delivered vaginally, whereas rates declined to 65.7% and 57.1% in latent and manifest iron deficiency, respectively ($\chi^2 = 4.6$, $p < 0.05$).

Differences between corresponding ferritin-based subgroups across gestational ages were also significant ($\chi^2 = 3.2$, $p < 0.05$). Overall, reduced ferritin levels were associated with a lower likelihood of vaginal delivery and increased cesarean section rates following labor induction (Table 4).

Indications for cesarean section

Analysis of cesarean section indications showed that failed labor induction was the predominant reason for operative delivery in women with reduced ferritin levels. This indication was absent in women with normal iron status but increased progressively in latent and manifest iron deficiency, reaching 17.5% at 37-41 weeks and 34.3% in post-term pregnancies.

Table 3. Types of labor induction used in the studied groups

Type of labor induction	Dose	1A (n=40)	1B (n=40)	1C (n=40)	2A (n=35)	2B (n=35)	2C (n=35)
		n (%)	n (%)	n (%)	n (%)	n (%)	n (%)
Prostaglandin E2 only (gel/tablet)	1 dose	11 (27.5)	13 (32.5)	7 (17.5)	-	-	12 (34.3)
	2 doses	9 (22.5)	18 (45.0)	18 (45.0)	-	23 (65.7)	8 (22.8)
	3 doses	-	9 (22.5)	10 (25.0)	-	-	3 (8.6)
PGE2 + amniotomy	1 dose	6 (15.0)	-	5 (12.5)	27 (77.1)	-	-
	2 doses	4 (10.0)	-	-	18 (51.4)	12 (34.3)	6 (17.1)
	3 doses	-	-	-	-	-	-
Induction + PROM	1 dose	4 (10.0)	-	-	-	-	-
	2 doses	6 (15.0)	-	-	-	-	6 (17.1)
	3 doses	-	-	-	-	-	-

Notes: PGE2 - prostaglandin E2; PROM - premature rupture of membranes. Data are presented as number of cases, n (%).

Table 4. Mode of delivery in women undergoing labor induction

Mode of delivery	Control (n=40)	1A (n=40)	1B (n=40)	1C (n=40)	χ^2	P_{c-1}	2A (n=35)	2B (n=35)	2C (n=35)	χ^2	P_{c-2}	χ^2	P_{1-2}
	n (%)	n (%)	n (%)	n (%)			n (%)	n (%)	n (%)				
Vaginal delivery	40 (100)	34 (85.0)	31 (77.5)	27 (67.5)	3.5	<0.05	35 (100)	23 (65.7)	20 (57.1)	4.6	<0.05	3.2	<0.05
Cesarean section	-	6 (15.0)	9 (22.5)	12 (32.5)	-	-	-	12 (34.3)	15 (42.8)	-	-	-	-

Note: '-' indicates zero/not observed/not applicable. p_{c-1} - comparison between control group and 37-41-week groups; p_{c-2} - comparison between control group and ≥41-week groups; p_{1-2} - comparison between corresponding 37-41-week and ≥41-week ferritin-based subgroups. Data are presented as n (%).

Table 5. Main indications for cesarean section in women undergoing labor induction

Indication for cesarean section	1A (n=40)	1B (n=40)	1C (n=40)	2A (n=35)	2B (n=35)	2C (n=35)
	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)
Malpresentation of the fetus	4 (10.0)	-	5 (12.5)	-	4 (11.4)	-
Cephalopelvic disproportion	2 (5.0)	2 (5.0)	-	-	-	3 (8.6)
Failed labor induction	-	7 (17.5)	7 (17.5)	-	8 (22.8)	12 (34.3)

Note: '-' indicates zero/not observed/not applicable.

Table 6. Labor complications in women undergoing labor induction

Labor complications	1A (n=40)	1B (n=40)	1C (n=40)	2A (n=35)	2B (n=35)	2C (n=35)
	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)
Prolonged labor / uterine inertia	3 (7.5)	9 (22.5)	15 (37.5)	-	7 (20.0)	15 (42.8)
Atonic postpartum hemorrhage	-	4 (10.0)	5 (12.5)	-	3 (8.6)	5 (14.3)
Retained placenta	2 (5.0)	3 (7.5)	2 (5.0)	-	4 (11.4)	5 (14.3)
Postpartum anemia	13 (32.5)	40 (100)	40 (100)	8 (22.8)	35 (100)	35 (100)
Need for blood transfusion	-	4 (10.0)	5 (12.5)	-	3 (8.6)	5 (14.3)

Note: '-' indicates zero/not observed/not applicable.

Table 7. Birth weight of newborns in the studied groups

Birth weight (g)	Control (n=40)	1A (n=40)	1B (n=40)	1C (n=40)	2A (n=35)	2B (n=35)	2C (n=35)
	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)
<2500	1 (2.5)	2 (5.0)	4 (10.0)	7 (17.5)	-	1 (2.8)	-
2500-2999	12 (30.0)	6 (15.0)	18 (45.0)	15 (37.5)	4 (11.4)	4 (11.4)	3 (8.6)
3000-3499	19 (47.5)	21 (52.5)	18 (45.0)	13 (32.5)	9 (25.7)	6 (17.1)	11 (31.4)
≥3500	8 (20.0)	11 (27.5)	-	5 (12.5)	22 (62.8)	24 (68.6)	21 (60.0)

Notes: Data are presented as n (%).

Malpresentation and cephalopelvic disproportion were infrequent and showed no consistent association with gestational age. Overall, impaired iron status was strongly associated with an increased likelihood of cesarean section due to induction failure (Table 5).

Labor complications

Labor complications were more common in women with reduced ferritin levels. The frequency of prolonged labor due to uterine inertia increased progressively with worsening iron deficiency, reaching 37.5% in group 1C and 42.8% in group 2C. Atonic postpartum hemorrhage and retained placenta were mainly observed in iron-deficient women, particularly in post-term pregnancies with manifest anemia.

Postpartum anemia occurred in almost all women with latent and manifest iron deficiency, whereas blood transfusion was required predominantly in women with severe iron depletion.

Overall, impaired iron metabolism was associated with a higher risk of intrapartum and postpartum complications following labor induction (Table 6).

Birth weight of newborn

Neonatal birth weight differed according to maternal ferritin status and gestational age. Low birth weight (<2500 g) occurred more frequently in newborns of women with latent and manifest iron deficiency, particularly at 37-41 weeks, reaching 17.5% in group 1C, while it was rare or absent in women with normal iron status.

Iron-deficient groups showed a predominance of birth weight 2500-2999 g, whereas post-term pregnancies were characterized by a higher proportion of newborns weighing ≥3500 g, exceeding 60% across groups 2A-2C. Overall, worsening maternal iron deficiency was associated with a shift toward lower neonatal birth weight, while post-term gestation was linked to higher birth weight irrespective of iron status (Table 7).

Neonatal outcomes assessed by Apgar score

Comparative analysis using the χ^2 test demonstrated statistically significant differences in Apgar score distribution among the study groups ($p < 0.05$). Lower Apgar scores (6-7 points) were observed exclusively in women with latent and manifest iron deficiency, whereas high Apgar scores (8-9 points) predominated in the control group.

A progressive shift toward lower Apgar categories was noted with worsening maternal iron deficiency across both gestational-age cohorts, indicating an association between impaired iron metabolism and reduced early neonatal adaptation following labor induction (Table 8).

Table 8. Neonatal outcomes assessed by Apgar score

Apgar score	Control (n=40)	1A (n=40)	1B (n=40)	1C (n=40)	2A (n=35)	2B (n=35)	2C (n=35)	χ^2 (overall)	p
	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)		
6-7	-	-	-	4 (10.0)	-	-	5 (14.3)		
7-8	-	23 (57.5)	31 (77.5)	25 (62.5)	17 (48.6)	29 (82.8)	26 (74.3)	χ^2 test	<0.05
8-9	40 (100)	17 (42.5)	9 (22.5)	11 (27.5)	18 (51.4)	6 (17.2)	4 (11.4)		

Notes: '-' indicates zero/not observed/not applicable; data are presented as n (%). Differences were assessed using the χ^2 test; $p < 0.05$ was considered statistically significant.

Table 9. Proportion of newborns transferred to the neonatal intensive care unit (NICU)

Time of NICU transfer	1A (n=40)	1B (n=40)	1C (n=40)	2A (n=35)	2B (n=35)	2C (n=35)
	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)
Immediately after birth	-	-	1 (2.5)	-	-	3 (8.6)
≥1 hour after birth	-	-	2 (5.0)	-	-	2 (5.7)
Total NICU admissions	-	-	3 (7.5)	-	-	5 (14.3)

Notes: '-' indicates zero/not observed/not applicable; data are presented as n (%).

Proportion of newborns transferred to the neonatal intensive care unit

NICU admission was observed exclusively among newborns of women with manifest iron deficiency. In the 37-41-week cohort, 7.5% of neonates required NICU care, increasing to 14.3% in post-term pregnancies, with immediate admission more common in post-term deliveries.

Overall, NICU admission was associated with severe maternal iron deficiency and was more pronounced in post-term births, indicating impaired neonatal adaptation following labor induction (Table 9).

4. Discussion

Labor induction outcomes were closely associated with maternal iron status. Progressive iron deficiency was linked to higher rates of induction-related complications, particularly prolonged labor, uterine inertia, postpartum hemorrhage, and operative delivery, with more pronounced effects in post-term pregnancies and women with manifest anemia. Lower ferritin levels were consistently associated with poorer neonatal outcomes, including reduced Apgar scores, lower birth weight, and increased NICU admission. Importantly, even latent iron deficiency was associated with less favorable outcomes compared with normal iron status. These findings underscore the clinical relevance of ferritin assessment and support the incorporation of iron status evaluation into pre-induction risk stratification to improve maternal and neonatal outcomes.

5. Conclusions

This study confirms that labor induction outcomes are closely related to maternal iron status. Reduced ferritin levels were associated with increased induction-related complications and poorer neonatal outcomes, including lower Apgar scores, reduced birth weight, and higher NICU admission rates. Even latent iron deficiency was linked to less favorable outcomes compared with normal iron status. These findings identify ferritin as a clinically relevant biomarker for pre-induction risk assessment. Incorporating iron status evaluation into labor induction planning may improve maternal and neonatal outcomes and enhance obstetric safety.

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