ASSOCIATION BETWEEN IRON STATUS BIOMARKERS AND METABOLIC-ENDOCRINE PARAMETERS INCLUDING INSULIN RESISTANCE, THYROID-STIMULATING HORMONE, AND VITAMIN D_3 IN YOUNG WOMEN

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Iron metabolism has emerged as a potential regulator of metabolic and endocrine pathways, particularly in female health disorders. However, its role as a biological mediator linking insulin resistance, thyroid function, and vitamin D status remains insufficiently explored. The study aimed to analyze the role of iron status as a biological mediator in the pathogenesis of metabolic and hormonal disturbances, with a focus on insulin resistance, thyroid stimulating hormone (TSH), and vitamin D_3. A cross-sectional study was conducted on 88 young, non-pregnant, fasting women aged 18–30 years with untreated iron deficiency. Iron status parameters (ferritin, serum iron, total iron-binding capacity (TIBC), and transferrin saturation) were evaluated alongside metabolic markers (insulin, glucose, HOMA-IR, QUICKI), as well as TSH, and vitamin D_3 levels. Statistical analyses included multiple linear regression, binary logistic regression, and partial correlation controlling for age using SPSS version 28. The multiple linear regression model demonstrated a strong fit ($R^2 = 0.864$, $p < 0.001$), with ferritin identified as an important independent Insulin Resistance Index (HOMA-IR) ($\beta = -0.224$, $p < 0.001$). Furthermore, ferritin showed a strong positive correlation with QUICKI ($r = +0.76$), indicating improved insulin sensitivity. Partial correlation analysis confirmed a strong independent association between ferritin and HOMA-IR ($r = -0.803$, $p < 0.001$), in addition to vitamin D_3 ($r = 0.781$, $p < 0.001$). No significant relationship was observed between iron profile and TSH ($p > 0.05$). Logistic regression achieved perfect classification but was unstable due to complete separation. Iron status, particularly ferritin, plays a central role in metabolic dysregulation and may act as a biological mediator in insulin resistance and vitamin D metabolism. These findings highlight the importance of iron homeostasis in female health disorders and suggest potential pathways for targeted intervention.

Keywords: ferritin; HOMA-IR; insulin resistance; iron status; vitamin D_3

DOI: 10.18097/PBMCE0054

INTRODUCTION

Iron is an essential trace element for oxygen transport, cellular respiration, DNA synthesis, and energy metabolism, but it can be toxic when accumulated in excess by promoting oxidative stress and ferroptosis [1]. ID remains the most prevalent nutritional disorder worldwide, affecting nearly 50% of women of reproductive age [2]. The complete iron profile includes serum ferritin, iron, TIBC, and transferrin saturation [3]. In ID, ferritin and serum iron decrease, TIBC increases, and transferrin saturation falls below 20% [4], with anemia defined as Hb < 12 g/dl and ferritin < 30 ng/ml [5].

The interplay between iron and insulin sensitivity is complex. Iron overload causes insulin resistance and type 2 diabetes via oxidative stress [6, 7], whereas emerging evidence suggests that iron deficiency may improve insulin sensitivity through the hypoxia-inducible factor (HIF) pathway, which enhances glucose uptake and glycolysis [8].

Iron is a critical cofactor for thyroid peroxidase, and iron deficiency has been linked to impaired thyroid hormone metabolism and altered TSH levels [9, 10]. However, this relationship remains incompletely characterized in young, otherwise healthy women with isolated ID [11].

Vitamin D deficiency is also common among women of the reproductive age and may influence iron metabolism via hepcidin; observational studies link low vitamin D to lower ferritin and hemoglobin [12], but randomized trials have not confirmed causality [13].

Despite these advances, research gaps still persist: most studies have focused on iron overload or severe anemia, with limited investigation

Abbreviations used: ELISA – enzyme-linked immunosorbent assay; ECLIA – electrochemiluminescence immunoassay; Hb – hemoglobin; HOMA-IR – homeostatic model assessment for insulin resistance; ID – iron deficiency; IDA – iron deficiency anemia; QUICKI – quantitative insulin sensitivity check index; TIBC – total iron-binding capacity; TSH – thyroid-stimulating hormone; UIBC – unsaturated iron-binding capacity.

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of mild-to-moderate ID on insulin resistance, TSH, and vitamin D_3 in healthy young women [14]. Moreover, no single cohort has simultaneously assessed the complete iron profile, insulin resistance indices (HOMA-IR, QUICKI), TSH, and vitamin D_3 in fasting, non-pregnant women with untreated ID.

Therefore, in this study we have to investigate correlations between iron profile markers (ferritin, iron, TIBC, transferrin saturation) and each of the insulin resistance indices, TSH, and vitamin D_3 in 88 young, non-pregnant, fasting women (18–30 years) with untreated ID or IDA, to test the hypothesis that ID paradoxically improves insulin sensitivity via adaptive hypoxia mechanisms.

This study hypothesizes that the dysregulated iron status in young women is linked to an integrated metabolic-endocrine imbalance, characterized by altered insulin resistance, thyroid function markers, and vitamin D_3 levels. We propose that ID may influence insulin sensitivity through complex metabolic pathways, although the precise direction of this relationship requires further investigation.

MATERIALS AND METHODS

Study design

This cross-sectional study included 88 Iraqi women aged 18–30 years who provided written informed consent. Participants were divided into two groups: the patient group (G1, n = 48) diagnosed with ID (serum ferritin < 30 ng/ml) or IDA (hemoglobin < 12 g/dl with serum ferritin < 30 ng/ml), and the healthy control group (G2, n = 40) with normal iron status (serum ferritin ≥ 30 ng/ml and hemoglobin ≥ 12 g/dl). The study was approved by the College of Applied Sciences, University of Fallujah. The study was designed to investigate the role of the iron status as a biological mediator in female metabolic and reproductive health disorders, with data analyzed to address the relationship between the iron status and insulin parameters (HOMA-IR, QUICKI), TSH, and vitamin D_3. None of the control and patient participants smoked, consumed alcohol, or took any medications, dietary supplements, or antioxidant vitamins.

Exclusion Criteria

Participants were excluded if they met any of the following criteria: alcohol consumption, smoking, intravenous drug use, pregnancy or lactation, recent surgery within the past 3 months, use of iron or vitamin supplements or any medications (twenty participants excluded), chronic diseases including diabetes mellitus or hypertension (fifteen participants with diabetes excluded), history of blood transfusion within the past 6 months, known hematological disorders (thalassemia, sickle cell disease, hemolytic anemia), or known malabsorption syndromes or gastrointestinal disorders affecting nutrient absorption.

Blood Sample Collection

For each participant, 8 ml of venous blood was collected after an overnight fast of 8–12 h. The blood was divided into two portions: one (2 ml) was placed into an EDTA tube for complete blood count analysis on the same day, and another one (6 ml) was placed into a gel tube for serum separation. The serum was separated by centrifugation at 3,500 rpm (centrifuge Hettich, Germany, approximately 2000 *g*) for 5 min at 4°C. Ferritin was measured immediately from fresh serum samples. The remaining serum was stored at -20°C for subsequent analysis of hormonal and insulin resistance parameters (TSH, insulin, and fasting glucose).

Demographic and Clinical Data

Information about the patients and control groups was gathered by the following measures: age, sex, and health history.

Biochemical and Hormonal Measurement

Hematological parameter. Hb concentration was measured using an automated hematology analyzer (Sysmex XN-1000, Sysmex Corporation, Canada) on the same day of collection.

Iron status markers. Serum ferritin, serum iron, and UIBC were measured using an ECLIA on a Roche Cobas e411 analyzer (Roche Diagnostics, Germany). TIBC and transferrin saturation (%) were calculated using the following standard formulas:

$$\text{TIBC } (\mu\text{mol/l}) = \text{Serum Iron} + \text{UIBC};$$

$$\text{Transferrin saturation } (\%) = (\text{Serum Iron} / \text{TIBC}) \times 100.$$

Glycemic and insulin resistance parameters. Fasting glucose was measured using the hexokinase method on a Roche Cobas c311 analyzer (Roche Diagnostics). Fasting insulin was quantified using a sandwich ELISA kit (Cat# EH0374, Fine Test, China). HOMA-IR was calculated using the following formula:

$$\text{HOMA-IR} = (\text{Fasting insulin } (\mu\text{IU/ml}) \times \text{Fasting glucose (mg/dl)}) \ / \ 405.$$

Thyroid function marker. TSH was measured using ECLIA on the Roche Cobas e411 analyzer.

Vitamin D_3. 25-Hydroxyvitamin D_3 was measured using ECLIA on the Roche Cobas e411 analyzer.

All assays were performed in duplicate within 4 h after blood collection according to the manufacturer's instructions. The intra-assay and inter-assay coefficients of variation (CVs) were < 5% and < 10%, respectively, for all parameters.

Statistical Analysis

SPSS version 28 was used to analyze the data. Multiple linear regression was used to determine independent variables of HOMA-IR, including age, ferritin, serum iron, and transferrin saturation. Binary logistic regression assessed the ability of iron markers to discriminate between normal and insulin-resistant status (HOMA-IR ≥ 2.5). Partial correlation analysis, controlling for age, examined relationships between ferritin and key variables (HOMA-IR, TSH, vitamin D_3). Bivariate Pearson's correlations were calculated between iron profile markers and metabolic-endocrine parameters (insulin, HOMA-IR, glucose, QUICKI, TSH, vitamin D_3). A p-value < 0.05 was considered statistically significant.

RESULTS

Table 1 shows that ID group had significantly lower ferritin (mean difference = -34.04 ng/ml, $p < 0.001$), serum iron (-10.98 μmol/l, $p < 0.001$), transferrin saturation (-20.85%, $p < 0.001$), and hemoglobin (-4.28 g/dl, $p < 0.001$), while TIBC was significantly higher (15.91 μmol/l, $p < 0.001$), confirming true iron deficiency.

In the context of insulin resistance, the ID group showed significantly higher insulin (21.69 mU/l, $p < 0.001$) and HOMA-IR (4.70, $p < 0.001$), and significantly lower QUICKI (-0.07, $p < 0.001$), indicating the presence of insulin resistance. Glucose levels were significantly lower (-5.33 mg/dl, $p = 0.001$), suggesting operation of early compensatory mechanisms.

Vitamin D_3 was significantly lower in the ID group (-25.57 ng/ml, $p < 0.001$), suggesting a shared pathway between iron and vitamin D metabolism.

No significant difference was noted in TSH (mean difference = 0.31 μIU/ml, $p = 0.122$), indicating that thyroid function was not affected by iron deficiency in this cohort.

To predict insulin resistance (HOMA-IR) from age and iron profile markers (ferritin, serum iron, transferrin saturation) a multiple linear regression model was constructed (Table 2). The model demonstrated excellent overall fit, explaining 86.4% of the variance in HOMA-IR ($R^2 = 0.864$, Adjusted $R^2 = 0.857$), and was highly statistically significant ($F = 131.36$, $p < 0.001$). This indicates that iron-related variables collectively contribute substantially to insulin resistance. Among individual predictors, ferritin was the only statistically significant independent predictor of HOMA-IR ($\beta = -0.224$, $p = 0.001$), showing a negative coefficient suggesting higher ferritin is associated with lower insulin resistance. Transferrin saturation showed the strongest standardized effect ($\beta = -0.455$) but did not reach statistical significance ($p = 0.080$), while serum iron ($p = 0.270$) and age ($p = 0.053$) were not significant, although age approached borderline significance.

Upon adjusting for age, partial correlation analysis demonstrated a robust negative connection between ferritin and HOMA-IR ($r = -0.803$, $p < 0.001$), affirming the independent relationship between iron storage and insulin resistance irrespective of age influences (Table 3). A robust positive connection was identified between ferritin and vitamin D_3 ($r = 0.781$, $p < 0.001$), indicating a common biological route linking iron homeostasis and vitamin D metabolism. A significant connection was not seen between ferritin and TSH ($r = -0.075$, $p = 0.492$).

Bivariate correlation analysis revealed consistent and biologically meaningful associations between all iron status markers and insulin resistance parameters (Table 4). Ferritin demonstrated strong inverse correlations, which was physiologically expected as a compensatory response to reduced iron availability. For vitamin D_3, all iron markers showed strong correlations in the expected directions: ferritin (r = +0.78), iron (r = +0.64), transferrin saturation (r = +0.69), which with HOMA-IR (r = -0.80), insulin (r = -0.79), and glucose (r = -0.65), while showing a strong positive correlation with QUICKI (r = +0.76), indicating improved insulin sensitivity with higher ferritin levels. Transferrin saturation showed a nearly identical pattern, with strong correlations with HOMA-IR (r = -0.73), insulin (r = -0.71), glucose (r = -0.60), and QUICKI (r = +0.69), reinforcing the role of bioavailable iron in metabolic regulation. TIBC exhibited the opposite pattern, with positive correlations with HOMA-IR (r = +0.52) and insulin (r = +0.55), and a negative correlation with QUICKI (r = -0.51), TIBC showed a negative correlation (r = -0.58).

The integrated summary (Table 5) demonstrates that ferritin and transferrin saturation behave similarly, showing strong positive associations with QUICKI and vitamin D_3 and strong inverse associations with HOMA-IR, reinforcing the biological role of iron storage and availability in metabolic health. TIBC consistently showed inverse relationships compared to these markers, which was expected given its physiological role as a compensatory marker for iron deficiency. All iron markers showed weak and non-significant associations with TSH, confirming that thyroid function operates independently of iron status in this sample.

Table 1. Comparison of the iron status, insulin resistance markers, vitamin D_3, and TSH between patient and control groups

Variable	Mean difference (patient – control)	t	df	*p*-value (2-tailed)	95% CI
Ferritin (ng\ml)	-34.040	-13.997	86	< 0.001	(-38.870; -29.210)
Iron (μmol\l)	-10.980	-29.106	86	< 0.001	(-11.730; -10.230)
TIBC (μmol\l)	15.910	18.764	86	< 0.001	(14.230; 17.600)
Transferrin saturation (%)	-20.850	-35.308	86	< 0.001	(-22.020; -19.670)
Hemoglobin(g\dl)	-4.280	-20.623	86	< 0.001	(-4.670; -3.880)
Insulin (mU\l)	21.690	21.852	86	< 0.001	(19.720; 23.670)
Glucose (mg\dl)	-5.330	-3.597	86	0.001	(-8.280; -2.380)
HOMA-IR	4.700	25.478	86	< 0.001	(4.330; 5.070)
QUICKI	-0.066	-29.670	86	< 0.001	(-0.070; -0.062)
Vitamin D_3 (ng\ml)	-25.570	-20.076	86	< 0.001	(-28.100; -23.030)
TSH (μlU\ml)	0.305	1.562	86	0.122	(-0.083; 0.694)

The patient group included 48 women with untreated ID; Control group contained 40 healthy women. Data are presented as mean difference (patient – control). Negative mean difference indicates lower values in the patient group. CI = confidence interval. Statistically significant *p*-values (< 0.05) are shown.

Table 2. Effect of the iron status on insulin resistance (multiple linear regression)

Variable	B	Beta	t	*p*-value	95% CI
Constant	9.179	—	17.173	< 0.001	(8.114; 10.244)
Age	-0.036	-0.081	-1.964	0.053	(-0.072; 0.001)
Ferritin	-0.027	-0.224	-3.439	0.001	(-0.043; -0.011)
Iron	-0.120	-0.276	-1.112	0.270	(-0.335; 0.095)
Transferrin saturation	-0.106	-0.455	-1.772	0.080	(-0.226; -0.013)

$R^2 = 0.864$ indicates that the model explains 86.4% of the variance in HOMA-IR. The F-value = 131.358 is statistically significant ($p < 0.001$).

Table 3. Partial correlation analysis (controlling for age)

Variable	r	*p*-value
Ferritin vs HOMA-IR	-0.803	< 0.001
Ferritin vs TSH	-0.075	0.492
Ferritin vs Vitamin D_3	0.781	< 0.001

Table 4. Correlation matrix of iron status markers with metabolic and endocrine variables

Iron marker	HOMA-IR	Insulin	Glucose	QUICKI	Vitamin D_3
Ferritin	r = -0.800	r = -0.790	r = -0.650	r = +0.760	r = +0.781
Iron	r = -0.580	r = -0.620	r = -0.540	r = +0.600	r = +0.640
TIBC	r = +0.520	r = +0.550	r = +0.490	r = -0.510	r = -0.580
Transferrin saturation	r = -0.730	r = -0.710	r = -0.600	r = +0.690	r = +0.690

All correlations are statistically significant at $p < 0.05$.

Table 5. Integrated interpretation of iron status effects

Outcome	Ferritin	Iron	TIBC	Transferrin saturation
HOMA-IR	Strong	Moderate	Inverse	Strong
QUICKI	Strong (positive)	Moderate	Inverse	Strong
TSH	Weak	Weak	Weak	Weak
Vitamin D_3	Strong	Moderate	Inverse	Strong

DISCUSSION

This study investigated the relationship between iron status biomarkers and metabolic-endocrine parameters, focusing on insulin resistance and the vitamin D status in young women with iron deficiency. The findings demonstrate a consistent inverse association between ferritin and HOMA-IR ($r = -0.803$, $\beta = -0.224$, $p = 0.001$) and a positive association with QUICKI ($r = +0.76$), indicating improved insulin sensitivity with higher ferritin levels. No significant association was observed with TSH, while a strong positive correlation was identified between ferritin and vitamin D_3 ($r = 0.781$, $p < 0.001$).

One of the most prominent findings is the strong inverse association between ferritin and HOMA-IR, which remained significant after age adjustment. This suggests that lower iron stores are associated with increased insulin resistance in this cohort. These results diverge from most of the literature data, which indicate positive associations between elevated ferritin and insulin resistance, metabolic syndrome, and an increased risk of T2DM [15, 16]. Such discrepancies likely reflect the complex, context-dependent nature of iron metabolism, differences in population characteristics, disease stage, and the dual role of ferritin as both an iron storage protein and an acute-phase reactant [17].

From a mechanistic perspective, ID induces adaptive cellular responses mediated by hypoxia-inducible factor 1α (HIF-1α), which enhances glucose uptake and promotes glycolytic metabolism by upregulation of glucose transporters [18]. Thus, reduced iron availability may shift cellular energy metabolism toward greater glucose utilization. However, given the cross-sectional design, these mechanistic interpretations remain hypothetical.

Additionally, ferritin showed a strong positive association with vitamin D_3, suggesting an interaction between iron homeostasis and vitamin D metabolism. Vitamin D modulates hepcidin expression, a key regulator of systemic iron homeostasis [19], while iron availability may influence enzymatic processes involved in vitamin D activation. A systematic review confirmed that mean hemoglobin, ferritin, and RBC counts were consistently lower in vitamin D deficiency groups [12]. Nevertheless, the observed association may also reflect shared determinants such as nutritional status, sunlight exposure, or inflammatory state, which were not fully controlled.

In contrast, no significant association was observed between iron markers and TSH. Thyroid function remains largely unaffected in young women with mild-to-moderate iron deficiency. Although iron is essential for thyroid peroxidase and thyroid hormone synthesis, its clinical impact may become evident only in more severe or chronic deficiency, or with additional autoimmune disturbances [20]. The absence of association may therefore reflect a threshold-dependent effect.

The strong correlations between iron markers and insulin resistance indices further support the involvement of iron metabolism in glucose homeostasis. However, cross-sectional design precludes causal inference, and unmeasured confounders (BMI, diet, physical activity, and inflammation) may influence both iron metabolism and insulin sensitivity.

From a statistical standpoint, logistic regression demonstrated complete separation, resulting in perfect classification of metabolic status. While this indicates high discriminative capacity of iron-related variables, it also suggests potential model instability and overfitting. Heinze and Schemper provided a solution to separation using Firth's penalized maximum likelihood estimation [21, 22], and recent studies have applied this approach in clinical settings [23].

CONCLUSIONS

This study demonstrates that iron status, particularly ferritin, is strongly and independently associated with insulin resistance and vitamin D_3 in females. The inverse ferritin-HOMA-IR relationship, though paradoxical, can be plausibly explained by a disease stage, inflammatory context, menopausal status, and the strong ferritin-vitamin D_3 axis. These findings support the hypothesis that iron homeostasis acts as a biological mediator in female metabolic health and suggest potential pathways for targeted intervention.

FUNDING

This research didn't receive any external funding.

COMPLIANCE WITH ETHICAL STANDARDS

This study was approved by the Ethics Committee of the College of Applied Sciences, University of Fallujah (approval number AS-EC-0004) on December 28, 2025. Before participating, all women signed written informed consent forms.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

REFERENCES

1. *Fehsel K.* (2023) Why is iron deficiency/anemia linked to Alzheimer's disease and its comorbidities, and how is it prevented? Biomedicines, **11**(9), 2421. DOI: 10.3390/biomedicines11092421
2. World Health Organization (WHO) (2020) Global anemia reduction efforts among women of reproductive age: impact, achievement of targets and the way forward for optimizing efforts. Geneva: WHO. (Report). Available from: https://www.who.int/publications/b/55197
3. *Camaschella C.* (2019) Iron deficiency. Blood, **133**(1), 30–39. DOI: 10.1182/blood-2018-05-815944
4. *Nemeth E., Ganz T.* (2023) Hepcidin and iron in health and disease. Annu. Rev. Med., **74**, 261–277. DOI: 10.1146/annurev-med-043021-032816
5. *Malik Z.I., Ghafoor M.U., Shah S.H.B.U., Abid J., Farooq U., Ahmad A.M.R.* (2025) Unlocking iron: nutritional origins, metabolic pathways, and systemic significance. Front. Nutr., **12**, 1637316. DOI: 10.3389/fnut.2025.1637316
6. *Dehghani F., Hajhashemy Z., Keshteli A.H., Yazdannik A., Falahi E., Saneei P., Esmaillzadeh A.* (2024) Nutrient patterns in relation to insulin resistance and endothelial dysfunction in Iranian women. Sci. Rep., **14**, 1234. DOI: 10.1038/s41598-024-53263-1
7. *Harrison A.V., Lorenzo F.R., McClain D.A.* (2023) Iron and the pathophysiology of diabetes. Annu Rev. Physiol., **85**, 339–362. DOI: 10.1146/annurev-physiol-022522-102832
8. *Mohammadi-Motlagh H.-R., Sadeghalvad M., Yavari N., Primavera R., Soltani S., Chetty S., Ganguly A., Regmi S., Fløyel T., Kaur S., Mirza A.H., Thakor A.S., Pociot F., Yarani R.* (2023) β Cell and autophagy: what do we know? Biomolecules, **13**(4), 649. DOI: 10.3390/biom13040649
9. *Gierach M., Rudewicz M., Junik R.* (2024) Iron and ferritin deficiency in women with hypothyroidism and chronic lymphocytic thyroiditis — systematic review. Endokrynol. Pol., **75**(3), 253–261. DOI: 10.5603/ep.97860
10. *Luo J., Wang X., Yuan L., Guo L.* (2021) Iron deficiency, a risk factor of thyroid disorders in reproductive-age and pregnant women: a systematic review and meta-analysis. Front. Endocrinol., **12**, 629831. DOI: 10.3389/fendo.2021.629831
11. *Lomteva S.V., Shkurat T.P., Bugrimova E.S., Zolotykh O.S., Alexandrova A.A., Karantysh G.V.* (2022) Violation of the hormonal spectrum in polycystic ovaries in combination with insulin resistance. What is the trigger: insulin resistance or polycystic ovary disease? Baghdad Science Journal, **19**(5), 990–998. DOI: 10.21123/bsj.2022.6317
12. *Alpakra M., Hamed N.F., Alfaki A., AlKabbani D.M.Z.* (2025) The correlation between vitamin D deficiency and anemia: a systematic review. Cureus, **17**(8), e89428. DOI: 10.7759/cureus.89428
13. *Lamikanra A.A., Tsang H.P., Morovat A., Hin H., Emberson J., Hill M., Clarke R., Armitage J., Roberts D.J.* (2025) Effect of supplementation with vitamin D on biochemical markers of iron status and erythropoiesis in older people: BEST-D trial. Br. J. Nutr., **134**(1), 28–34. DOI: 10.1017/S0007114525103516
14. *Li T., Zhang J., Li P.* (2024) Ferritin and iron supplements in gestational diabetes mellitus: less or more? Eur. J. Nutr., **63**(1), 67–78. DOI: 10.1007/s00394-023-03250-5
15. *Mahroum N., Alghory A., Kiyak Z., Alwani A., Seida R., Alrais M., Shoenfeld Y.* (2022) Ferritin — from iron, through inflammation and autoimmunity, to COVID-19. J. Autoimmun., **126**, 102778. DOI: 10.1016/j.jaut.2021.102778
16. *Al-Tai W.F., Mohammed I.A., Sabri M.S.* (2010) Relation between body iron store and insulin resistance in type 2 diabetes. Baghdad Science Journal, **7**(4), 1395–1399. DOI: 10.21123/bsj.2010.11934
17. *Dongiovanni P., Valenti L., Fracanzani A.L., Gatti S., Cairo G., Fargion S.* (2008) Iron depletion by deferoxamine up-regulates glucose uptake and insulin signaling in hepatoma cells and in rat liver. Am. J. Pathol., **172**(3), 738–747. DOI: 10.2353/ajpath.2008.070097
18. *Stallhofer J., Veith L., Diegelmann J., Probst P., Brand S., Schnitzler F., Olszak T., Török H., Mayerle J., Stallmach A., Beigel F.* (2022) Iron deficiency in inflammatory bowel disease is associated with low levels of vitamin D modulating serum hepcidin and intestinal ceruloplasmin expression. Clin. Transl. Gastroenterol., **13**(1), e00450. DOI: 10.14309/ctg.0000000000000450
19. *Kobayashi Y., Taniguchi R., Shirasaki E., Yoshimoto Y.S., Aoi W., Kuwahata M.* (2024) Continuous training in young athletes decreases hepcidin secretion and is positively correlated with serum 25(OH)D and ferritin. Peer J., **12**, e17566. DOI: 10.7717/peerj.17566
20. *Gupta N., Narayan A., Tonk R.S., Gupta S.K., Narayan A.* (2022) Study of relationship between iron deficiency and thyroid function in pregnant females. Cureus, **14**(12), e32411. DOI: 10.7759/cureus.32411
21. *Heinze G., Schemper M.* (2002) A solution to the problem of separation in logistic regression. Stat. Med., **21**(16), 2409–2419. DOI: 10.1002/sim.1047
22. *Jamian N.H., Ul-Saufie A.Z., Abdullah M.N.* (2025) Bibliometric analysis of research on Firth penalized logistic regression in addressing complete separation. Journal of Computing Research and Innovation, **10**(2), 266–280. DOI: 10.24191/jcrinn.v10i2.535
23. *Liu D.S., Farid A., Linden G.S., Cook D.L., Birch C.M., Hresko M.T., Hedequist D.J., Hogue G.D.* (2024) Utility of routine postoperative laboratory testing after posterior spinal fusion for adolescent idiopathic scoliosis. J. Pediatr. Orthop. Soc. North Am., **6**, 100003. DOI: 10.1016/j.jposna.2024.100003

Received: 09.05.2026.
Revised: 20.06.2026.
Accepted: 21.06.2026.

ВЗАИМОСВЯЗЬ МЕЖДУ БИОМАРКЕРАМИ СОСТОЯНИЯ ЖЕЛЕЗА И МЕТАБОЛИЧЕСКИМИ И ЭНДОКРИННЫМИ ПАРАМЕТРАМИ, ВКЛЮЧАЮЩИМИ ИНСУЛИНОРЕЗИСТЕНТНОСТЬ, ТИРЕОТРОПНЫЙ ГОРМОН, И ВИТАМИН D_3 У МОЛОДЫХ ЖЕНЩИН

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Метаболизм железа рассматривается как потенциальный регулятор метаболических и эндокринных путей, особенно при женских заболеваниях. Однако его роль в качестве биологического медиатора, связывающего инсулинорезистентность, функцию щитовидной железы и уровень витамина D, остаётся недостаточно изученной. Целью данного исследования было проанализировать роль статуса железа как биологического медиатора в патогенезе метаболических и гормональных нарушений, с акцентом на инсулинорезистентность, тиреотропный гормон (ТТГ) и витамин D_3. В поперечном исследовании приняли участие 88 молодых небеременных женщин в возрасте 18–30 лет, имевших нелеченный дефицит железа. Натощак оценивали параметры статуса железа (ферритин, сывороточное железо, общую железосвязывающую способность и насыщение трансферрина), метаболические маркеры (инсулин, глюкоза, HOMA-IR, QUICKI), уровни ТТГ и витамина D_3. Статистический анализ включал множественную линейную регрессию, бинарную логистическую регрессию и частичную корреляцию с учётом возраста с использованием SPSS версии 28. Модель множественной линейной регрессии продемонстрировала хорошее соответствие ($R^2 = 0,864$, $p < 0,001$), при этом ферритин был идентифицирован как важный независимый индекс инсулинорезистентности (HOMA-IR) ($\beta = -0,224$, $p < 0,001$). Кроме того, ферритин показал сильную положительную корреляцию с QUICKI ($r = +0,76$), что указывает на улучшение чувствительности к инсулину. Анализ частичной корреляции подтвердил сильную независимую связь между ферритином и HOMA-IR ($r = -0,803$, $p < 0,001$), а также витамином D_3 ($r = 0,781$, $p < 0,001$). Значимой связи между профилем железа и ТТГ не обнаружено ($p > 0,05$). Логистическая регрессия обеспечила идеальную классификацию, но была нестабильной из-за полного разделения. Уровень железа, особенно ферритина, играет центральную роль в нарушении метаболизма и может выступать в качестве биологического медиатора инсулинорезистентности и метаболизма витамина D. Эти результаты подчёркивают важность гомеостаза железа для здоровья женщин и указывают на потенциальные пути для целенаправленного вмешательства.

Полный текст статьи на русском языке доступен на сайте журнала (http://pbmc.ibmc.msk.ru).

Ключевые слова: ферритин; HOMA-IR; инсулинорезистентность; уровень железа; витамин D_3

Финансирование. Авторы заявляют об отсутствии внешнего финансирования.

Поступила в редакцию: 09.05.2026; после доработки: 20.06.2026; принята к печати: 21.06.2026.