

Serum Ferritin and Iron Levels in Bariatric Surgery Candidates: A Cross-sectional Study

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Abstract. *Aim.* Iron deficiency and altered ferritin levels elevate perioperative risks and postoperative outcomes in individuals with extreme obesity, particularly in patients undergoing bariatric surgery. *The aim of the study.* The current study is aimed to evaluate ferritin levels and iron deficiency in candidates for bariatric surgery (BS), categorized by age, gender, and co-morbid conditions. *Materials and methods.* A cross-sectional study with 221 BS applicants measured height, weight, blood pressure, ferritin, and iron levels. Relationships between biomarkers and comorbidities were analyzed using chi-square tests and Pearson's correlation, following stratification of participants by age and gender. *Results and discussion.* The preoperative BMI was 43.8 kg/m², indicating extreme obesity, and the mean age was 36.5 years, as per the study. Male applicants exhibited 15.7% abnormalities in ferritin and 39.2% in serum iron, in contrast to female applicants. Ferritin levels below 30 ng/mL were correlated with iron deficiency in 40% of women and 19.7% of men. Gender had a greater impact on ferritin levels than age. The limited positive correlation of ferritin with blood iron ($r = 0.202$, $p = 0.014$) indicates that it may not serve as a dependable measure of iron status in individuals with overweight. Diabetes and hypertension exhibited no correlation with biomarker abnormalities. *Conclusion.* In BS candidates, gender influences biomarker status more significantly than age or comorbidities, with a prevalent deficiency in iron and ferritin. This underscores the advantages of personalized nutritional therapy prior to surgery and ongoing assessment thereafter.

Keywords: bariatric surgery, ferritin, serum iron, body mass index, obese, gender differences.

Introduction

Obesity is a rapidly escalating global health challenge, affecting approximately 13% of the world's adult population as of 2025, with a prevalence of more than doubling since 1990 [1]. Current projections indicate that by 2030, over 1 billion adults worldwide will live with obesity, representing nearly 12% of the global population [2]. This alarming increase is coupled with a disproportionate rise in severe obesity (BMI ≥ 35 kg/m²), which is associated with a high risk of comorbidities, such as type 2 diabetes, hypertension, cardiovascular diseases, and certain cancers, leading to substantial mortality and high healthcare costs [3]. Specifically, obesity-related non-communicable diseases cause approximately 1.6 million premature deaths annually, exceeding fatalities from road traffic accidents [4]. Bariatric surgery (BS) has emerged as a highly effective intervention for sustainable weight loss and improvement of obesity-associated diseases such as type 2 diabetes, hypertension, and dyslipidemia [5]. However, BS is not without complications; nutritional deficiencies, especially iron deficiency and altered ferritin status, are common both preoperatively and in the long-term postoperative period [5, 6].

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Iron is an essential micronutrient involved in critical physiological processes, including oxygen transport, energy metabolism, and cellular function [7]. Ferritin, the principal intracellular iron storage protein, provides a readily accessible reserve in states of increased demand or physiological stress [8]. Both iron and ferritin status are regulated by complex systems, including dietary absorption, recycling of iron in erythrocytes, and hormonal control mediated by hepcidin, a peptide hormone elevated in obesity and chronic inflammation [9]. Obesity is associated with low-grade chronic inflammation, leading to increased hepcidin levels, impaired intestinal iron absorption, and redistribution of iron away from circulation (hypoferremia) [5]. Evidence supports the association between obesity and iron deficiency, with a higher risk observed in certain patient groups, notably women, adolescents, and individuals with central adiposity [10]. For example, it has been shown that overweight and obese women are more likely to have elevated hepcidin, higher inflammatory markers, and lower iron absorption compared to their normal-weight counterparts [11]. Routine markers, such as serum ferritin and hemoglobin, provide important information but may be confounded by inflammation and require careful interpretation in obese populations [10]. In adults, iron stores are considered depleted if ferritin levels drop below 15 g/L [12]. Iron deficiency is often measured using this cutoff in clinical settings and research, despite gender-specific and higher cutoffs being more appropriate [13].

Within BS candidates, the incidence of iron deficiency and ferritin abnormalities is substantial, with reports ranging from 10 to 40% preoperatively and higher rates postoperatively, especially following malabsorptive procedures such as the Roux-en-Y gastric bypass [14]. In bariatric cohorts, iron deficiency can worsen perioperative risk, increase complications such as infection and poor wound healing, and negatively affect quality of life [15]. Postoperatively, altered gastrointestinal anatomy, reduced tolerance to iron-rich foods, and persistent inflammation contribute to sustained iron depletion and the potential for developing anemia [6].

Patients seeking BS frequently exhibit heightened susceptibility to iron deficiency and iron deficiency anemia due to multiple contributing factors, including obesity-related complications, systemic inflammation, nutritional patterns, and particularly menstrual blood loss in premenopausal females [16]. The incidence of post-BS anemia fluctuates between 10% and 40%, representing a predominant nutritional complication [17]. Preoperative nutritional assessments consistently demonstrate iron deficiency in approximately 35% of these individuals, with 24% exhibiting decreased serum ferritin levels. This phenomenon disproportionately affects female patients, who demonstrate increased susceptibility to iron and ferritin depletion due to menstrual cycles and inherently lower iron reserves [12, 18].

A surveillance study encompassing 619 females aged 20–49 years demonstrated iron deficiency prevalence of 23.5%, 41.9%, and 45.6% among normal weight, overweight, and obese participants, respectively [19]. Elevated hepcidin concentrations and chronic inflammatory states are considered fundamental in the obesity-hypoferremia correlation [20]. While obesity has emerged as a significant risk factor for iron deficiency, the mechanistic pathways remain unclear [10]. Recent intervention studies have demonstrated that aggressive preoperative iron supplementation with targeted ferritin thresholds is associated with improved postoperative iron and ferritin levels, reduced incidence of iron deficiency and anemia, and optimized recovery. However, even with supplementation, the risk persists owing to ongoing metabolic and absorptive challenges, necessitating continued monitoring and individualized nutritional support [5, 6, 15].

The aim

The current study investigated the iron and ferritin status among BS candidates, assessing associations with age, gender, and relevant comorbidities such as diabetes and hypertension.

Materials and methods

Study characteristics. This prospective cross-sectional study was conducted at Dr. Sulaiman Al Habib Hospital-Olaya Branch, a tertiary referral center for bariatric surgery, over a 12-month period from June 2024 to June 2025. The study population comprised all patients (aged ≥ 15 years) diagnosed with morbid obesity who were scheduled to undergo bariatric surgery, specifically laparoscopic sleeve gastrectomy or Roux-en-Y gastric bypass, as their primary surgical intervention.

Inclusion and exclusion criteria. The inclusion criteria were based on the standard indications for bariatric surgery, including a body mass index (BMI) ≥ 40 kg/m² or ≥ 35 kg/m² with at least one obesity-related comorbidity, such as type 2 diabetes mellitus, hypertension, or obstructive sleep apnea. Patients must be able to provide informed consent, either directly or through their guardians. Patients were excluded if they had undergone any prior bariatric surgical procedure or any abdominal surgery that could potentially alter gastrointestinal anatomy in a manner affecting iron absorption, such as previous bowel resection or small intestine bypass, patients known for inflammatory bowel disease, chronic liver disease, renal failure, or malabsorption disorders, or patients who are taking iron supplementation or multivitamins within the past 3 months, also excluded any patients with known history of hematological disorder or active infection, or patients who are required to be placed on a preoperative bariatric diet like Very Low Calorie Diet (VLCD) or high protein low calories diet.

Surgery. Before surgical scheduling, all participants underwent a comprehensive preoperative workup, which included a detailed physiological assessment (covering cardiovascular, respiratory, gastrointestinal, and metabolic systems) and a psychiatric evaluation to identify any psychological or behavioral conditions that could influence postoperative outcomes. These assessments were performed by a multidisciplinary team (MDT) comprising bariatric surgeons, anesthesiologists, psychiatrists, dietitians, and specialized bariatric nurses. Only patients who were deemed suitable candidates for surgery after the MDT evaluation were included in the study.

Following approval for surgical intervention, each patient was informed of the study protocol and provided written informed consent. Subsequently, fasting venous blood samples were collected to measure serum iron and ferritin levels. Blood sampling was conducted within one week before hospital admission for surgery to ensure that the results reflected the preoperative nutritional status. Samples were collected in serum separator (SST) tubes. The samples were separated by centrifugation and stored according to laboratory policy until analysis. Serum ferritin was measured CMIA (Chemiluminescent Microparticle Immunoassay) by Abbott ALINITY i machine.

The normal ferritin range was set as 4.63–204 for females and 11–171 ng/mL for males. There is no widely accepted ferritin cutoff value for diagnosing iron deficiency, as ferritin is an acute-phase reactant that can be normal even if iron stores are low in inflammatory states [6]. Similarly, we reanalyzed our data using a ferritin cutoff of 30 ng/mL based on the findings of a systematic review that showed that the positive likelihood ratio for iron deficiency does not decrease until a ferritin level of 40 ng/mL is reached in an unselected population [21]. All biochemical analyses were performed in the hospital's central laboratory using standardized spectrophotometric techniques with quality-control measures to ensure accuracy and

reproducibility. The study protocol was approved by the Institutional Review Board (IRB). All participants provided written informed consent prior to enrolment.

Statistical analysis. Statistical analyses were performed using IBM SPSS version 26. Continuous data are expressed as mean values $\pm$ standard deviation, and frequencies are reported as percentages. ANOVA and chi-square tests were used to compare means and percentages. Correlations among variables were measured using the Pearson correlation coefficient, and a general multivariate regression model was used to analyze the effects of comorbidities on serum vitamin and zinc levels. All p-values were considered significant at <0.05 .

The results

Baseline characteristics of the study population. A total of 221 BS candidates were included in the analysis (Table 1A). The mean age of the participants was 36.52 ± 11.05 years (range: 15–66 years). The average weight was 116.70 ± 23.24 kg, with values ranging from 39 kg to 196 kg, and the mean height was 163.64 ± 9.28 cm (range: 145–187 cm). The mean preoperative body mass index (BMI) was 43.78 ± 6.32 kg/m², with a minimum of 33.05 and a maximum of 84.00 kg/m², reflecting the severe obesity of the cohort. The mean hemoglobin concentration was 13.72 ± 1.44 g/dL (range: 10.20–17.90 g/dL). With respect to iron indices, the mean serum iron level was 12.47 ± 6.13 μ mol/L (range: 2.00–42.00) and the mean ferritin concentration was 97.45 ± 119.82 ng/mL (range: 4.77–768.00). Notably, both serum iron and ferritin showed positive skewness, particularly ferritin (skewness 2.52 ± 0.17), indicating that while most patients had lower to moderate values, a subset presented with disproportionately high values.

Table 1A. Descriptive statistics of the study population

Characteristics	N	Minimum	Maximum	Mean $\pm$ SD	Skewness $\pm$ SE
Age (years)	221	15.00	66.00	36.52 ± 11.05	0.27 ± 0.16
Weight (kg)	217	39.00	196.00	116.70 ± 23.24	0.54 ± 0.17
Height	217	145.00	187.00	163.64 ± 9.28	0.31 ± 0.17
BMI before	217	33.05	84.00	43.78 ± 6.32	1.70 ± 0.17
Hemoglobin (g/dL)	217	10.20	17.90	13.72 ± 1.44	0.16 ± 0.17
Iron	217	2.00	42.00	12.47 ± 6.13	1.49 ± 0.17
Ferritin	217	4.77	768.00	97.45 ± 119.82	2.52 ± 0.17

SD – standard deviation; SE – standard error.

When stratified by gender, significant differences were observed across most anthropometric and hematological parameters (Table 1B). Female participants ($n = 136$) were significantly older than males ($n = 81$), with mean ages of 38.32 ± 11.43 years and 33.51 ± 9.91 years, respectively ($p = 0.002$). Male participants had considerably higher mean body weight (136.94 ± 20.40 kg vs. 104.65 ± 15.02 kg, $p < 0.001$) and greater mean height (172.19 ± 7.16 cm vs. 158.55 ± 6.13 cm, $p < 0.001$) than female participants. Although preoperative BMI was higher in males (46.26 ± 6.04 kg/m²) than in females (42.31 ± 6.03 kg/m²), this difference was not statistically significant ($p = 0.248$). Regarding hematological parameters, males exhibited significantly higher mean hemoglobin levels than females (14.89 ± 1.22 g/dL vs. 13.02 ± 1.06 g/dL, $p < 0.001$). Similarly, ferritin concentrations were markedly higher in males (151.30 ± 143.19 ng/mL)

than in females (65.37 ± 89.69 ng/mL, $p < 0.001$). Serum iron levels were also significantly higher in males (14.08 ± 7.07 μ mol/L) than in females (11.51 ± 5.30 μ mol/L, $p = 0.003$). These findings indicate that while women constituted the majority of BS candidates, men tended to present with greater body size and higher hematological indices, including ferritin and serum iron levels.

Table 1B. Antropometric and medical characteristic of participants based on their gender

Character	Gender	N	Minimum	Maximum	Mean $\pm$ SD	P value	95% CI	
							Lower band	Upper band
Age	M	81	15	62	33.51 $\pm$ 9.91	0.002*	31.31	35.70
	F	136	16	66	38.32 $\pm$ 11.43		36.38	40.25
Weight	M	81	83	196	136.94 $\pm$ 20.40	0.000*	132.43	141.45
	F	136	39	153	104.65 $\pm$ 15.02		102.10	107.19
Height	M	81	152	187	172.19 $\pm$ 7.16	0.000*	170.60	173.77
	F	136	145	177	158.55 $\pm$ 6.13		157.51	159.59
BMI before	M	81	34.94	68.08	46.26 $\pm$ 6.04	0.248	44.92	47.25
	F	136	33.05	84.00	42.31 $\pm$ 6.03		41.29	43.34
HB	M	81	12.00	17.90	14.89 $\pm$ 1.22	0.000*	14.62	15.15
	F	136	10.20	15.10	13.02 $\pm$ 1.06		12.84	13.20
Ferritin	M	81	12.47	645.0	151.30 $\pm$ 143.19	0.000*	119.64	182.97
	F	136	4.77	768.00	65.37 $\pm$ 89.69		50.16	80.58
Iron	M	81	5.00	39.10	14.08 $\pm$ 7.07	0.003*	12.52	15.65
	F	136	2.00	42.00	11.51 $\pm$ 5.30		10.62	12.41

The p-value is the asymptotic significance or detection of difference in both positive and negative associations, which was analyzed using the Pearson chi-square test.

Characteristics of participants by age group. Participants were stratified into six age groups to assess differences in anthropometric and hematological parameters (Table 2). Body weight showed a gradual decline across age groups, with the highest mean observed among younger adults (123.06 $\pm$ 23.25 kg in group 1 and 122.51 $\pm$ 26.35 kg in group 2) and the lowest mean among the oldest participants (99.17 $\pm$ 7.76 kg in group 6). Similarly, the mean height decreased with advancing age, from 165.82 $\pm$ 9.00 cm in group 2 to 155.00 $\pm$ 2.97 cm in group 6. Preoperative BMI values remained generally comparable across groups, ranging from 41.30 $\pm$ 3.26 kg/m² in the oldest group to 47.15 $\pm$ 11.98 kg/m² in group 5, without a clear age-related trend.

Hemoglobin concentrations were relatively consistent across age categories, with means ranging from 13.12 $\pm$ 0.59 g/dL in the oldest group to 14.11 $\pm$ 1.50 g/dL in group 2. Ferritin levels demonstrated wide variability, with the highest mean values noted in middle-aged participants (108.29 $\pm$ 128.89 ng/mL in group 3 and 105.97 $\pm$ 144.17 ng/mL in group 4), while lower means were observed in the youngest (51.61 $\pm$ 40.98 ng/mL) and older age groups (66.88 $\pm$ 62.10 ng/mL in group 5 and 80.52 $\pm$ 96.27 ng/mL in group 6). Serum iron concentrations fluctuated across groups, with peak levels recorded in groups 2 (13.75 $\pm$ 7.28 μ mol/L) and 3 (12.82 $\pm$ 5.98 μ mol/L), whereas lower means were observed in groups 4–6

(ranging from $11.31 \pm 5.50 \mu\text{mol/L}$ to $11.40 \pm 4.57 \mu\text{mol/L}$). Overall, while weight and height showed a downward trend with increasing age, the hematological indices, particularly ferritin and serum iron, demonstrated variability without a consistent age-dependent pattern.

Table 2. Characteristics of participants based on their age

Categories	Age group	N	Mean	Std. deviation	95% confidence interval for mean		Minimum	Maximum
					Lower bound	Upper bound		
Weight	1	16	123.06	23.25	110.67	135.45	87.00	162.00
	2	51	122.51	26.35	115.10	129.92	79.00	196.00
	3	74	116.68	24.68	110.96	122.39	39.00	172.00
	4	55	112.64	19.06	107.48	117.79	77.00	158.00
	5	15	112.20	17.04	102.76	121.64	86.00	141.00
	6	6	99.17	7.76	91.03	107.31	93.00	113.00
Height	1	16	164.38	7.81	160.21	168.54	152.00	177.00
	2	51	165.82	9.00	163.29	168.35	148.00	185.00
	3	74	164.53	10.13	162.18	166.87	145.00	187.00
	4	55	162.02	8.93	159.60	164.43	146.00	182.00
	5	15	160.47	7.32	156.41	164.52	149.00	170.00
	6	6	155.00	2.97	151.89	158.11	151.00	158.00
Before BMI	1	16	45.27	5.42	42.38	48.16	34.81	54.13
	2	51	44.06	6.80	42.15	45.98	34.06	68.08
	3	74	43.29	5.18	42.09	44.49	33.05	55.53
	4	55	43.11	5.36	41.66	44.56	34.08	54.84
	5	15	47.15	11.98	40.52	53.79	33.37	84.00
	6	6	41.30	3.26	37.88	44.72	37.27	45.20
Hemoglobin	1	16	13.77	1.76	12.83	14.70	10.90	16.20
	2	51	14.11	1.50	13.69	14.53	10.90	17.90
	3	74	13.74	1.35	13.43	14.05	10.20	17.60
	4	55	13.36	1.47	12.97	13.76	10.40	16.80
	5	15	13.74	1.17	13.09	14.39	11.60	15.20
	6	6	13.12	0.59	12.50	13.73	12.40	13.80
Ferritin	1	16	51.61	40.98	29.77	73.45	4.77	166.60
	2	51	97.89	107.56	67.64	128.14	9.00	448.50
	3	74	108.29	128.89	78.43	138.15	6.46	645.00
	4	55	105.97	144.17	66.99	144.94	5.00	768.00
	5	15	66.88	62.10	32.49	101.27	7.98	217.20
	6	6	80.52	96.27	-20.51	181.55	12.36	265.90

Categories	Age group	N	Mean	Std. deviation	95% confidence interval for mean		Minimum	Maximum
					Lower bound	Upper bound		
Iron	1	16	11.83	5.58	8.85	14.80	2.00	24.60
	2	51	13.75	7.28	11.70	15.80	4.90	42.00
	3	74	12.82	5.98	11.43	14.20	4.80	39.10
	4	55	11.31	5.50	9.82	12.79	2.80	25.00
	5	15	11.85	5.82	8.63	15.07	4.30	23.70
	6	6	11.40	4.57	6.60	16.20	6.00	18.00

Correlation between ferritin and iron level. Pearson's correlation analysis was conducted to evaluate the relationship between ferritin and serum iron levels among BS candidates (Table 3). The results demonstrated a statistically significant but weak positive correlation between ferritin and serum iron levels ($r = 0.202$, $p = 0.014$). This indicates that while higher ferritin concentrations were modestly associated with higher serum iron levels, the weak strength of the correlation suggests that ferritin may not reliably reflect serum iron status in this cohort and could be influenced by other factors, such as inflammation or metabolic changes related to obesity.

Table 3. Correlation between ferritin and iron level

		Ferritin	Iron
Ferritin	Pearson correlation	1	0.202*
	Sig. (2-tailed)		0.014
	N	188	147
Iron	Pearson correlation	0.202*	1
	Sig. (2-tailed)	0.014	
	N	147	150

Prevalence of ferritin deficiency by age and gender. The prevalence of abnormal ferritin levels was examined across age and gender groups (Table 4). Among different age categories, no statistically significant association was observed between age and ferritin status ($\chi^2 = 5.540$, $df = 5$, $p = 0.354$). Across age groups, most participants had ferritin values within the normal range, with abnormal values observed most frequently in the 21–30 (21.6%) and 41–50 (18.2 %) years groups, while the lowest prevalence was noted in the 51–60 years group (6.7%). In contrast, a significant association was observed between sex and ferritin status ($\chi^2 = 30.523$, $df = 1$, $p < 0.001$). Men demonstrated a markedly higher prevalence of abnormal ferritin levels (33.3%) than women (5.1%). While deficiency is set to be below 4.63 by lab rules and definitions, we considered 30 ng/mL as a cutoff. In our data, there were 16 males out of 81 (19.7%) and 55 out of 136 (40%) females below 30 ng/mL. Overall, 15.7% of the study population had abnormal ferritin levels, with the majority of these cases occurring in male participants. These findings indicate that gender, rather than age, plays a more prominent role in determining ferritin status among BS candidates.

Prevalence of iron deficiency by age and gender. The prevalence of iron deficiency was assessed across age and gender groups (Table 4). Overall, 39.2% of the participants were iron deficient, 59.4% had normal

iron levels, and 1.4% had elevated iron levels. No statistically significant association was observed between age and iron status across age categories ($\chi^2 = 5.282$, $df = 10$, $p = 0.872$). The prevalence of deficiency was relatively consistent among the younger and middle-aged groups, ranging from 36.5% in the 31–40 years group to 47.3% in the 41–50 years group, while lower rates were noted in the 51–60 years group (26.7%). The oldest participants (61–70 years) demonstrated the highest relative prevalence (50%), although the sample size was small ($n = 6$). When analyzed by gender, males showed a slightly higher prevalence of iron deficiency than females (44.4% vs. 36.0%), whereas normal iron levels were more common among females (63.2% vs. 53.1%). Elevated iron levels were rare in both genders (2.5% in men and 0.7% in women). However, these gender-based differences did not reach statistical significance ($\chi^2 = 2.901$, $df = 2$, $p = 0.230$). Taken together, these findings indicate that iron deficiency was common across all age and gender groups among BS candidates, with no significant associations detected, highlighting the widespread risk of iron depletion in this population.

Table 4. Prevalence of ferritin deficiency among age and gender group

Categories	Ferritin/Iron/Hemoglobin (n, %)				Pearson chi-square (r, df, p-value)
	Deficient	Normal	Over	Total	
Ferritin deficiency					
Age group (n = 217)					
1 (15–20 yrs)	NA	16 (100.0)	0 (0.0)	16 (100.0)	r = 5.540; df = 5; p = 0.354
2 (21–30 yrs)	NA	40 (78.4)	11 (21.6)	51 (100.0)	
3 (31–40 yrs)	NA	63 (85.1)	11 (14.9)	74 (100.0)	
4 (41–50 yrs)	NA	45 (81.8)	10 (18.2)	55 (100.0)	
5 (51–60 yrs)	NA	14 (93.3)	1 (6.7)	15 (100.0)	
6 (61–70 yrs)	NA	5 (83.3)	1 (16.7)	6 (100.0)	
Total	NA	183 (84.3)	34 (15.7)	217 (100.0)	
Gender group (n = 217)					
Male	NA	54 (66.7)	27 (33.3)	81 (100.0)	r = 30.523; df = 1; p = 0.00
Female	NA	129 (94.9)	7 (5.1)	136 (100.0)	
Total	NA	183 (84.3)	34 (15.7)	217 (100.0)	
Iron deficiency					
Age group (n = 217)					
1 (15–20 yrs)	6 (37.5)	10 (62.5)	0 (0.0)	16 (100.0)	r = 5.282; df = 10; p = 0.872
2 (21–30 yrs)	19 (37.3)	31 (60.8)	1 (2.0)	51 (100.0)	
3 (31–40 yrs)	27 (36.5)	45 (60.8)	2 (2.7)	74 (100.0)	
4 (41–50 yrs)	26 (47.3)	29 (52.7)	0 (0.0)	55 (100.0)	
5 (51–60 yrs)	4 (26.7)	11 (73.3)	0 (0.0)	15 (100.0)	
6 (61–70 yrs)	3 (50.0)	3 (50.0)	0 (0.0)	6 (100.0)	
Total	85 (39.2)	129 (59.4)	3 (1.4)	217 (100.0)	

Categories	Ferritin/Iron/Hemoglobin (n, %)				Pearson chi-square (r, df, p-value)
	Deficient	Normal	Over	Total	
Gender group (n = 217)					
Male	36 (44.4)	43 (53.1)	2 (2.5)	81 (100.0)	r = 2.901; df = 2; p = 0.23
Female	49 (36.0)	86 (63.2)	1 (0.7)	136 (100.0)	
Gender	85 (39.2)	129 (59.4)	3 (1.4)	217 (100.0)	
Hemoglobin (Hb) deficiency					
Age group (n = 217)					
1 (15–20 yrs)	3 (18.8)	12 (75.0)	1 (6.3)	16 (100.0)	r = 10.200; df = 10; p = 0.423
2 (21–30 yrs)	3 (5.9)	46 (90.2)	2 (3.9)	51 (100.0)	
3 (31–40 yrs)	7 (9.5)	66 (89.2)	1 (1.4)	74 (100.0)	
4 (41–50 yrs)	11 (20.0)	41 (74.5)	3 (5.5)	55 (100.0)	
5 (51–60 yrs)	1 (6.7)	14 (93.3)	0 (0.0)	15 (100.0)	
6 (61–70 yrs)	1 (16.7)	5 (83.3)	0 (0.0)	6 (100.0)	
Total	26 (12.0)	184 (84.8)	7 (3.2)	217 (100.0)	
Gender group (n = 217)					
Male	6 (7.4)	72 (88.9)	3 (3.7)	81 (100.0)	r = 2.604; df = 2; p = 0.272
Female	20 (14.7)	112 (82.4)	4 (2.9)	136 (100.0)	
Gender	26 (12.0)	184 (84.8)	7 (3.2)	217 (100.0)	

NA – not applicable.

Ferritin level: Female <4.63 deficient; 4.63–204 normal; >204 over;

Male <11 deficient; 11–171 normal; >171 over.

Iron level: Female <9 deficient; 9–30.4 normal; >30.4 over;

Male <11 deficient; 11–31 normal; >31 over.

Hemoglobin level: Female <11.8 deficient; 11.8–14.8 normal; >14.8 over;

Male <13 deficient; 13–17.4 normal; >17.4 over.

Prevalence of hemoglobin deficiency by age and gender. The overall prevalence of hemoglobin (Hb) deficiency among BS candidates was 12.0%, while 84.8% of participants had normal Hb levels and 3.2% presented with values above the normal range (Table 4). No statistically significant association was observed between age and Hb status across age categories ($\chi^2 = 10.200$, $df = 10$, $p = 0.423$). The highest prevalence of Hb deficiency was observed in the 41–50 years age group (20.0%), followed by the youngest participants aged 15–20 years (18.8%) and those aged 61–70 years (16.7%). In contrast, deficiency was least frequent in the 21–30 (5.9%) and 51–60 (6.7%) age groups.

When stratified by gender, Hb deficiency was more prevalent among females (14.7%) than among males (7.4%), whereas normal Hb levels were more frequent in males (88.9% vs. 82.4% in females). Elevated Hb levels were uncommon in both genders (3.7% in men and 2.9% in women). However, the association between gender and Hb status did not reach statistical significance ($\chi^2 = 2.604$, $df = 2$, $p = 0.272$). Overall, hemoglobin deficiency was present in a minority of patients, with a slightly higher prevalence among females and certain age subgroups, although these differences were not statistically significant.

Association of ferritin, iron, and hemoglobin levels with comorbidities. The relationship between ferritin, iron, and Hb levels and the presence of comorbidities was examined (Table 5). Among participants stratified by ferritin levels ($n = 43$), hypertension was the most common comorbidity, with 86.2% of patients classified as deficient and 13.8% within the normal range of ferritin levels. All individuals with diabetes ($n = 9$) were ferritin-deficient, while those with both diabetes and hypertension showed a predominance of deficiency (80.0%), with a minority in the normal range (20.0%). However, no statistically significant association was observed between ferritin status and the type of comorbidity ($\chi^2 = 1.658$, $df = 2$, $p = 0.437$).

Table 5. Comparison of comorbidity by ferritin, iron and hemoglobin level

Categories	Deficient (n, %)	Normal (n, %)	Over (n, %)	Total (n, %)	Pearson chi-square (r, df, p-value)
Ferritin group (n = 43)					
Hypertension (HT)	9 (100.0)	0 (0.0)	9 (100.0)	9 (100.0)	r = 1.658; df = 2; p = 0.437
Diabetes	25 (86.2)	4 (13.8)	29 (100.0)	25 (86.2)	
Diabetes + HT	4 (80.0)	1 (20.0)	5 (100.0)	4 (80.0)	
Total	38 (88.4)	5 (11.6)	43 (100.0)	38 (88.4)	
Iron group (n = 52)					
Hypertension (HT)	2 (22.2)	7 (77.8)	0 (0.0)	9 (100.0)	r = 3.783; df = 6; p = 0.706
Diabetes	11 (37.9)	17 (58.6)	1 (3.4)	29 (100.0)	
Diabetes + HT	1 (20.0)	4 (80.0)	0 (0.0)	5 (100.0)	
Total	14 (32.6)	28 (65.1)	1 (2.3)	43 (100.0)	
Hemoglobin group (n = 43)					
Hypertension (HT)	0 (0.0)	9 (100.0)	0 (0.0)	9 (100.0)	r = 2.162; df = 4; p = 0.706
Diabetes	3 (10.3)	25 (86.2)	1 (3.4)	29 (100.0)	
Diabetes + HT	1 (20.0)	4 (80.0)	0 (0.0)	5 (100.0)	
Total	4 (9.3)	38 (88.4)	1 (2.3)	43 (100.0)	

In the iron group ($n = 52$), 37.9% of patients with hypertension were iron-deficient, 58.6% had normal iron levels, and 3.4% had elevated iron levels. Among participants with both diabetes and hypertension, 20.0% were deficient and 80.0% were normal. Patients with diabetes alone predominantly showed normal iron levels (77.8%). The association between iron status and comorbidities was not statistically significant ($\chi^2 = 3.783$, $df = 6$, $p = 0.706$). Similarly, Hb status was not significantly associated with comorbidities ($\chi^2 = 2.162$, $df = 4$, $p = 0.706$). All patients with diabetes had normal Hb levels, whereas among those with hypertension, 86.2% had normal Hb levels, 10.3% had low Hb levels, and 3.4% had elevated Hb levels. Among participants with both diabetes and hypertension, 80.0% had normal Hb levels and 20.0% were deficient. Overall, abnormalities in ferritin, iron, or Hb levels were not significantly associated with the presence of diabetes, hypertension, or both in this BS cohort.

Discussion of the research results

The cross-sectional analysis of iron and ferritin levels among BS candidates revealed several key findings with important implications for clinical practice, research, and patient outcomes. The data show significant gender differences in iron metabolism; male participants presented with higher body weight, BMI, ferritin, and serum iron values than their female counterparts, paralleling established literature on gender-based differences in iron dynamics among obese populations. Elevated ferritin and iron levels in males may reflect differences in lean mass, erythropoietic activity, and hormone regulation, such as testosterone, while the higher prevalence of iron deficiency among females likely arises from menstrual loss, increased iron requirements, and lower muscle mass [10].

Stratification by age demonstrated wide variability in hematological and iron markers without a clear age-dependent trend, although specific groups (e.g., middle-aged and youngest) exhibited higher rates of deficiency. The results correspond with international registry findings, confirming that bariatric interventions predominantly occur during early- to mid-adulthood when obesity-associated comorbidities manifest [1]. Importantly, abnormal ferritin concentrations were most frequently observed in certain age categories, yet did not reach statistical significance, underscoring the complexity of iron metabolism in the obese state and suggesting a more prominent role for gender than age in ferritin regulation. Nevertheless, research has demonstrated that candidates for BS may present with subclinical iron deficiency despite normal hemoglobin levels, particularly in women of reproductive age [22]. Preoperative anemia has been consistently associated with an elevated risk of postoperative anemia and prolonged recovery periods, validating the implementation of standardized iron status assessment protocols before surgical intervention [23].

It is reasonable to assume that the serum ferritin (SF) level represents the total amount of iron stored in the body at a steady state. In a healthy adult, 1 ng/mL of SF indicates 8–10 mg of storage iron, whereas 200–250 mg increases hemoglobin (Hb) concentration by one g/dL [13]. In a study by Obinwanne et al. [24] among 959 patients who underwent Laparoscopic Roux-en-Y gastric bypass (LRYGB), 40.9% had iron deficiency, with a ferritin level <30 ng/mL. Iron therapy is suggested for patients undergoing BS. However, in our study, 40% of female patients showed <30 ng/mL as the cutoff for serum ferritin and might become iron deficient after BS. In another study of anemic patients who underwent bone marrow biopsy, those levels of 30 ng/mL showed good sensitivity and specificity [25].

The prevalence of iron deficiency and anemia in the cohort mirrors global findings in bariatric populations, with rates of 39% and 12%, respectively, and greater vulnerability noted among females and particular age brackets [26, 27]. These rates are consistent with robust studies reporting cumulative incidences of deficiency and anemia as high as 40–60% in follow-up periods of 3–5 years after malabsorptive procedures [6]. Iron deficiency in obese individuals and bariatric populations is driven by multiple overlapping mechanisms: impaired absorption due to reduced gastric acid and bypass of the duodenum, ongoing inflammation with hepcidin-mediated blockade of ferroportin, and suboptimal intake or tolerance of iron-rich foods post-surgery [5, 6, 10].

In obese individuals, elevated ferritin levels frequently reflect chronic, low-grade inflammatory processes rather than iron surplus, primarily mediated through cytokine-induced hepcidin upregulation, which subsequently impairs iron absorption and mobilization [10]. Alternatively, individuals with diminished ferritin concentrations are clearly susceptible to iron deficiency. The simultaneous occurrence of markedly elevated and reduced ferritin values exemplifies the diagnostic complexities inherent to this population, necessitating the concurrent evaluation of supplementary iron parameters, including transferrin saturation and C-reactive protein levels, for the precise interpretation of iron status [28, 29]. Regarding ferritin

concentrations, despite males exhibiting higher mean values, statistical significance was not attained, potentially due to the substantial variability in ferritin measurements across both genders. While males typically demonstrate higher ferritin levels due to enhanced iron reserves and the absence of menstrual depletion, obesity-associated inflammation-induced hepcidin upregulation can artificially elevate ferritin levels independent of iron status, potentially diminishing observable statistical gender differences [30, 31]. Similarly, serum iron concentrations were marginally higher in men than in women; however, the difference was not statistically significant. This pattern reflects the intricate interplay between gender-specific biological variations, potential dietary differences, and the complex modulatory effects of obesity-associated inflammation on iron metabolism parameters [32, 33].

Hemoglobin concentrations remained consistent across age groups, ranging from 13.12 g/dL in elderly participants to 14.11 g/dL in group 2 participants. This uniformity indicates that age does not independently constitute a major determinant of hemoglobin concentration among BS candidates during preoperative assessment. However, considering that bariatric procedures, particularly those incorporating malabsorptive components, frequently result in progressive deterioration of hemoglobin levels and iron reserves postoperatively, this baseline homogeneity emphasizes the necessity for equivalent monitoring vigilance across all age groups when assessing postoperative anemia risk [27, 34]. Ferritin concentrations exhibited substantial heterogeneity, with the youngest cohort demonstrating the lowest mean values and middle-aged patients (Group 4) presenting the highest levels. Although these variations were not statistically significant, this distribution pattern potentially reflects multiple intersecting physiological factors. Younger patients, especially premenopausal women, exhibit increased susceptibility to iron depletion due to menstrual blood loss, elevated iron requirements during reproductive years, and potentially reduced medical surveillance before surgical intervention [35, 36].

Regarding comorbidity associations, the analysis did not demonstrate statistically significant links between iron indices and diabetes or hypertension status in the cohort. This finding is partially supported by the literature, indicating that while iron deficiency is common in obesity-associated comorbidities, the relationship may be multifactorial, involving overlapping metabolic and inflammatory pathways. Nonetheless, patients with diabetes, hypertension, or both conditions exhibit frequent iron and ferritin deficiencies, highlighting the importance of routine screening in these high-risk groups [10, 37]. Recent literature emphasizes the importance of individualized nutritional interventions, with studies demonstrating that preoperative iron supplementation to achieve ferritin targets significantly improves postoperative iron and ferritin levels, thereby reducing anemia and optimizing functional outcomes [23, 36]. The implementation of such protocols should become standard practice, and continued monitoring is required, given the progressive and delayed nature of post-surgery deficiencies [38]. Malabsorptive bariatric procedures pose the highest risk, with nearly 60% of patients developing iron deficiency five years post-operation [6, 10].

While ferritin primarily functions as an iron storage indicator, serum iron reflects instantaneous transferrin-bound circulating iron concentrations. In subjects with normalized iron homeostasis, these parameters typically demonstrate moderate correlation, and enhanced iron stores generally support elevated circulating iron levels [39]. However, in candidates for BS, this relationship is confounded by obesity-associated inflammation and other physiological factors [40]. As obesity is characterized by persistent low-grade inflammatory processes, elevated ferritin levels may not accurately indicate iron sufficiency but rather reflect an inflammatory response, primarily mediated through increased hepcidin expression, which inhibits iron release from macrophages and reduces intestinal absorption [5]. This attenuating effect may explain the weak linear correlation between ferritin and serum iron levels in this population.

Overall, the present study reinforces the notion that iron metabolism in obesity and BS is highly dynamic and is influenced by intersecting biological, demographic, and clinical factors. Future research should focus on the prospective, longitudinal assessment of iron, ferritin, and emerging biomarkers such as hepcidin, with robust adjustments for inflammatory status, dietary patterns, and gender differences. The development of standardized protocols for supplementation, laboratory assessment, and long-term management is vital for improving health outcomes in this vulnerable population.

Numerous limitations must be recognized while assessing the conclusions of this study. The cross-sectional approach solely assessed associations at a singular time point, hence complicating the establishment of causation between iron and ferritin levels and clinical features. Longitudinal studies are crucial to comprehend variations in iron metabolism before and after BS. Secondly, the research was performed at a single institution, perhaps constraining its generalizability to populations with diverse demographics or clinical characteristics. Dietary intake, supplement compliance, inflammatory markers, and socioeconomic variables were not thoroughly evaluated, whereas demographic and clinical information was collected. The absence of comprehensive data may have influenced the found correlations due to unaccounted iron metabolism variables in the study. Third, inflammation associated with obesity might elevate blood ferritin levels independent of iron storage, thereby complicating the assessment of iron status. The absence of supporting biomarkers (e.g., hepcidin, soluble transferrin receptor, CRP) complicates the differentiation between genuine iron deficiency and inflammation-induced alterations. Ultimately, the clinical outcomes of iron shortage, such as postoperative complications and symptoms of anemia, were not assessed, hence constraining the therapeutic significance of the biochemical data. To enhance the identification and management of iron deficiency in candidates for bariatric surgery, it is essential to investigate biomarker panels, dietary and supplemental information, and patient-centered outcomes across many sites.

Conclusions

This cross-sectional study confirmed a high prevalence of iron and ferritin deficiencies among BS candidates, with significant gender-based disparities and a modest association between serum iron and ferritin levels. While age did not exert a marked influence on biochemical parameters, males were at greater risk for abnormal ferritin concentrations and females for iron deficiency, reflecting complex hormonal and physiological interactions within obesity. Using a ferritin cutoff of 30 ng/mL, 40% of females and 19.7% of males were below this threshold for iron deficiency. Age-related variability was observed, but gender was a stronger determinant of ferritin status. A weak positive correlation between ferritin and serum iron was found ($r = 0.202$, $p = 0.014$), suggesting ferritin's limited reliability as a sole indicator of iron status in obese candidates. No statistically significant association was found between biomarker abnormalities and the presence of diabetes or hypertension. The findings highlight the high prevalence of iron and ferritin deficiencies among BS candidates, with gender exerting a stronger influence than age or comorbidities. Individualized preoperative nutritional interventions and continuous postoperative monitoring are needed to optimize patient outcomes.

Ethical approval and consent to participate

This study received approval from Dr. Sulaiman Al Habib Medical Group (Ethical approval No. RC25.12.129), and written informed consent was obtained from all legal guardians after they were fully informed of the study details.

Data availability

The data will be available on request from the corresponding author.

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Authors' contributions

The corresponding author confirms having conceived the study, designed the methodology, collected and analyzed the data, interpreted the results, drafted and revised the manuscript, and approved the final version.

References

1. Ahmed SK, Mohammed RA. Obesity: Prevalence, causes, consequences, management, preventive strategies and future research directions. *Metabol Open* 2025; 27: 100375. DOI: 10.1016/j.metop.2025.100375.
2. Review for “Overweight, obesity and incident atrial fibrillation: Real-world evidence from 400 000 patients in Germany”. 2025. DOI: 10.1111/dom.16637/v1/review3.
3. Jobe M, Mactaggart I, Bell S, Kim MJ, Hydera A, Bascaran C, Njai M, Badjie O, Perel P, Prentice AM, Burton MJ. Prevalence of hypertension, diabetes, obesity, multimorbidity, and related risk factors among adult Gambians: A cross-sectional nationwide study. *Lancet Glob Health* 2024; 12(1): e55–65. DOI: 10.1016/s2214-109x(23)00508-9.
4. Parums DV. Editorial: Global obesity rates continue to rise with challenges for new drug treatments including GLP-1 receptor agonists. *Medical Science Monitor* 2025; 31. DOI: 10.12659/msm.950816.
5. Tarancon-Diez L, Iriarte-Gahete M, Sanchez-Mingo P, Muñoz-Fernandez MÁ, Navarro-Gomez ML, Pacheco YM, Leal M. Impact of obesity on iron metabolism and the effect of intravenous iron supplementation in obese patients with absolute iron deficiency. *Sci Rep* 2025; 15. DOI: 10.1038/s41598-024-84498-7.
6. Gowanlock Z, Lezhanska A, Conroy M, Crowther M, Tiboni M, Mbuagbaw L, Siegal DM. Iron deficiency following bariatric surgery: A retrospective cohort study. *Blood Adv* 2020; 4: 3639–3647. DOI: 10.1182/bloodadvances.2020001880.
7. Obeagu EI. Iron homeostasis and health: Understanding its role beyond blood health – a narrative review. *Ann Med Surg (Lond)* 2025; 87: 3362–3371. DOI: 10.1097/ms9.0000000000003100.
8. Arosio P, Cairo G, Bou-Abdallah F. A brief history of ferritin, an ancient and versatile protein. *Int J Mol Sci* 2024; 26: 206. DOI: 10.3390/ijms26010206.
9. Catapano A, Cimmino F, Petrella L, Pizzella A, D’Angelo M, Ambrosio K, Marino F, Sabbatini A, Petrelli M, Paolini B, Lucchin L, Cavaliere G, Cristino L, Crispino M, Trinchese G, Mollica MP. Iron metabolism and ferroptosis in health and diseases: The crucial role of mitochondria in metabolically active tissues. *J Nutr Biochem* 2025; 140: 109888. DOI: 10.1016/j.jnutbio.2025.109888.
10. Alshwaiyat N, Ahmad A, Wan Hassan WMR, AlJamal H. Association between obesity and iron deficiency (Review). *Exp Ther Med* 2021; 22. DOI: 10.3892/etm.2021.10703.
11. Rachmah Q, Mondal P, Phung H, Ahmed F. Association between overweight/obesity and iron deficiency anaemia among women of reproductive age: A systematic review. *Public Health Nutr* 2024; 27. DOI: 10.1017/s1368980024001794.

12. Sandvik J, Bjerkan KK, Græslie H, Hoff DAL, Johnsen G, Klöckner C, Mårvik R, Nymo S, Hyldmo ÅA, Kulseng BE. Iron deficiency and anemia 10 years after Roux-en-Y gastric bypass for severe obesity. *Front Endocrinol (Lausanne)* 2021; 12. DOI: 10.3389/fendo.2021.679066.
13. Cancado RD, Leite LAC, Muñoz M. Defining global thresholds for serum ferritin: A challenging mission in establishing the iron deficiency diagnosis in this era of striving for health equity. *Diagnostics* 2025; 15: 289. DOI: 10.3390/diagnostics15030289.
14. Soheilipour F, Nematollahi S, Mottaghi A, Ordooei M, Shahrzad MK, Alaei M, Bahoush G, Ebrahimian M, Eskandari D. The prevalence of vitamin B12, hemoglobin, and ferritin deficiency in patients with morbid obesity and changes in their blood levels after bariatric surgery. *Int J Prev Med* 2025; 16. DOI: 10.4103/ijpvm.ijpvm_34_23.
15. Lowry B, Hardy K, Vergis A. Iron deficiency in bariatric surgery patients: A single-centre experience over 5 years. *Can J Surg* 2020; 63: E365–269. DOI: 10.1503/cjs.001818.
16. Schweiger C, Weiss R, Berry E, Keidar A. Nutritional deficiencies in bariatric surgery candidates. *Obes Surg* 2009; 20: 193–197. DOI: 10.1007/s11695-009-0008-3.
17. Nie Y, Tian Z, Wang P, Liu B, Zhang N, Zhou B, Wang S, Hei X, Meng H. Prevalence of anemia and related nutrient deficiencies after sleeve gastrectomy: A systematic review and meta-analysis. *Obesity Reviews* 2022; 24. DOI: 10.1111/obr.13516.
18. Kamal FA, Fernet LY, Rodriguez M, Kamal F, Da Silva NK, Kamal OA, Ayala Aguilar A, Arruarana VS, Martinez Ramirez M. Nutritional deficiencies before and after bariatric surgery in low- and high-income countries: Prevention and treatment. *Cureus* 2024. DOI: 10.7759/cureus.55062.
19. Kaner G, Pekcan G, Pamuk G, Pamuk BÖ. Could obesity be a risk factor for iron deficiency? Review. *Turkiye Klinikleri J Health Sci* 2016; 1: 208–212. DOI: 10.5336/healthsci.2015-45726.
20. D'Angelo G. Role of hepcidin in the pathophysiology and diagnosis of anemia. *Blood Res* 2013; 48: 10. DOI: 10.5045/br.2013.48.1.10.
21. Guyatt GH, Oxman AD, Ali M, Willan A, McIlroy W, Patterson C. Laboratory diagnosis of iron-deficiency anemia. *J Gen Intern Med* 1992; 7: 145–153. DOI: 10.1007/bf02598003.
22. Björklund G, Peana M, Pivina L, Dosa A, Aaseth J, Semenova Y, Chirumbolo S, Medici S, Dadar M, Costea DO. Iron deficiency in obesity and after bariatric surgery. *Biomolecules* 2021; 11: 613. DOI: 10.3390/biom11050613.
23. Ng O, Keeler BD, Mishra A, Simpson JA, Neal K, Al-Hassi HO, Brookes MJ, Acheson AG. Iron therapy for preoperative anaemia. *Cochrane Database Syst Rev* 2019; 2019. DOI: 10.1002/14651858.cd011588.pub3.
24. Obinwanne KM, Fredrickson KA, Mathiason MA, Kallies KJ, Farnen JP, Kothari SN. Incidence, treatment, and outcomes of iron deficiency after laparoscopic Roux-en-Y gastric bypass: A 10-year analysis. *J Am Coll Surg* 2014; 218: 246–252. DOI: 10.1016/j.jamcollsurg.2013.10.023.
25. Mast AE, Blinder MA, Lu Q, Flax S, Dietzen DJ. Clinical utility of the reticulocyte hemoglobin content in the diagnosis of iron deficiency. *Blood* 2002; 99: 1489–1491. DOI: 10.1182/blood.v99.4.1489.
26. Salgado W, Modotti C, Nonino CB, Ceneviva R. Anemia and iron deficiency before and after bariatric surgery. *Surg Obes Relat Dis* 2014; 10: 49–54. DOI: 10.1016/j.soard.2013.06.012.
27. Kędzierska K, Dymkowski M, Niegowska W, Humięcka M, Sawicka A, Walczak I, Jędral ZM, Wąsowski M, Bogółowska-Stieblach A, Binda A, Jaworski P, Tarnowski W, Jankowski P. Iron deficiency anemia following bariatric surgery: A 10-year prospective observational study. *Nutrients* 2025; 17(2): 339. DOI: 10.3390/nu17020339.
28. Dignass A, Farrag K, Stein J. Limitations of serum ferritin in diagnosing iron deficiency in inflammatory conditions. *Int J Chronic Dis* 2018; 2018: 1–11. DOI: 10.1155/2018/9394060.
29. Al-Naseem A, Sallam A, Choudhury S, Thachil J. Iron deficiency without anaemia: A diagnosis that matters. *Clinical Medicine* 2021; 21: 107–113. DOI: 10.7861/clinmed.2020-0582.
30. Ru Q, Li Y, Chen L, Wu Y, Min J, Wang F. Iron homeostasis and ferroptosis in human diseases: Mechanisms and therapeutic prospects. *Signal Transduct Target Ther* 2024; 9. DOI: 10.1038/s41392-024-01969-z.
31. Kolarš B, Mijatović Jovin V, Živanović N, Minaković I, Gvozdenović N, Dickov Kokeza I, Lesjak M. Iron deficiency and iron deficiency anemia: A comprehensive overview of established and emerging concepts. *Pharmaceuticals* 2025; 18: 1104. DOI: 10.3390/ph18081104.

32. Han K, Jung JH, Jeong SM, Kim MK. Epidemiology and trends of obesity and bariatric surgery in Korea. *Endocrinol Metab* 2024; 39: 678–685. DOI: 10.3803/enm.2024.2056.
33. Zhao L, Zhang X, Shen Y, Fang X, Wang Y, Wang F. Obesity and iron deficiency: A quantitative meta-analysis. *Obesity Reviews* 2015; 16: 1081–1093. DOI: 10.1111/obr.12323.
34. Ajeed AM, Naif NH, Farag AH, Mohsein OA. Assessing the impact of sleeve gastrectomy on micronutrient levels and inflammatory markers – a case-control study. *Eur J Clin Exp Med* 2025; 23: 369–377. DOI: 10.15584/ejcem.2025.2.13.
35. Cappellini MD, Santini V, Braxs C, Shander A. Iron metabolism and iron deficiency anemia in women. *Fertil Steril* 2022; 118: 607–614. DOI: 10.1016/j.fertnstert.2022.08.014.
36. Hisham A, Bukhari ME, Alkhamis WH, Albadawi IA, Shukri MA, Angioni S, Chahine RH, Vannuccini S, Chapron C. Iron deficiency anemia and uterine disorders: Impact on surgical management. *J Endometr Uterine Disord* 2025; 10: 100112. DOI: 10.1016/j.jeud.2025.100112.
37. Benotti PN, Wood GC, Dove JT, Kaberi-Otarod J, Still CD, Gerhard GS, Bistrrian BR. Iron deficiency is highly prevalent among candidates for metabolic surgery and may affect perioperative outcomes. *Surg Obes Relat Dis* 2021; 17: 1692–1699. DOI: 10.1016/j.soard.2021.05.034.
38. Lewis CA, Osland EJ, de Jersey S, Hopkins G, Seymour M, Webb L, Chatfield MD, Hickman IJ. Monitoring for micronutrient deficiency after bariatric surgery – what is the risk? *Eur J Clin Nutr* 2023; 77: 1071–1083. DOI: 10.1038/s41430-023-01318-3.
39. Fonseca Ó, Ramos AS, Gomes LTS, Gomes MS, Moreira AC. New perspectives on circulating ferritin: Its role in health and disease. *Molecules* 2023; 28: 7707. DOI: 10.3390/molecules28237707.
40. Savulescu-Fiedler I, Mihalcea R, Dragosloveanu S, Scheau C, Baz RO, Caruntu A, Scheau AE, Caruntu C, Be-neana SN. The interplay between obesity and inflammation. *Life (Basel)* 2024; 14(7): 856. DOI: 10.3390/life14070856.