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Dynamics of anemia panel in patients after sleeve gastrectomy in the long-term follow-up

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Obesity and bariatric surgery are global challenges; however, long-term postoperative patients may develop disorders of iron and vitamin metabolism that culminate in anemia. Timely laboratory surveillance is essential to detect preclinical deficiencies.

The aim of the study: to evaluate changes in anemia panel indicators in patients after sleeve gastrectomy in the long-term postoperative period.

Materials and methods. A retrospective cohort of 114 adults with morbid obesity who underwent primary sleeve gastrectomy was analyzed. Preoperative anthropometry and anemia panel were within reference limits. Laboratory follow-up included hemoglobin, ferritin, serum iron, transferrin, and vitamin B12, assessed preoperatively and at 36 months after SG (overall observation period up to 60 months). Statistics: Kolmogorov–Smirnov, Levene, Wilcoxon for paired non-normal data, Pearson correlations, and multivariate linear regression (predictors: serum iron, ferritin, transferrin, vitamin B12); significance $p < 0.05$.

Results. At 36 months, anemia was present in 23.7 % (27/114). Compared with baseline, Hb decreased from 143 [136.0–150.0] to 136.7 [127.7–142.0] g/L ($p = 0.001$), serum iron from 20.8 [17.0–23.7] to 11.6 [3.9–18.8] μmol/L ($p = 0.001$), and ferritin from 126.2 [90.7–191.0] to 10.9 [9.4–95.5] ng/mL ($p = 0.001$); vitamin B12 showed no significant change ($p = 0.053$). Overall, anemia-panel disorders were frequent: latent iron deficiency 26.3 %, iron deficiency without anemia 15.8 %, iron-deficiency anemia 15.8 %, anemia without iron deficiency (likely B12/folate) 5.3 %, and combined deficiency 2.6 % (total 65.8 % with any disorder). Hemoglobin correlated with serum iron ($r = 0.443$; $p = 0.001$) and ferritin ($r = 0.359$; $p = 0.001$). In multivariate regression ($F = 8.47$; $p < 0.001$; $R^2 = 0.237$), independent predictors of hemoglobin were serum iron ($\beta = 0.410$; $p = 0.001$) and vitamin B12 ($\beta = 0.180$; $p = 0.038$); ferritin and transferrin were not independent predictors; no critical multicollinearity (VIF < 2.2).

Conclusions. Three years after sleeve gastrectomy, nearly one quarter of patients develop anemia and two thirds exhibit anemia-panel abnormalities, predominantly iron-related. Monitoring limited to hemoglobin misses a large burden of latent deficiency. A standardized follow-up that includes ferritin, serum iron, transferrin, and vitamin B12-alongside timely nutritional correction-should be routine to prevent progression to manifest anemia and its complications.

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Динаміка анемічної панелі у пацієнтів після рукавної резекції шлунка у віддаленому післяопераційному періоді

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Ожиріння та баріатрична хірургія є глобальними викликами. У віддаленому післяопераційному періоді у пацієнтів можуть розвиватися порушення обміну заліза та вітамінів, що призводять до анемії. Своєчасний лабораторний моніторинг є важливим для виявлення доклінічних дефіцитів.

Мета роботи – оцінити зміни показників «анемічної панелі» у пацієнтів після рукавної резекції шлунка (РРШ) у віддаленому післяопераційному періоді.

Матеріали і методи. Проаналізовано ретроспективну когорту з 114 дорослих із морбідним ожирінням, яким було виконано первинну РРШ. Передопераційні антропометричні показники та «анемічна панель» перебували в межах референтних значень. Лабораторний нагляд включав гемоглобін (Hb), феритин, сироваткове залізо, трансферин і вітамін B12, що оцінювали до операції та через 36 місяців після РРШ (загальний період спостереження – до 60 місяців). Статистика: Колмогорова–Смирнова, Левена, Вілкоксона для парних даних, що не відповідають закону нормального розподілу, кореляції Пірсона та багатофакторна лінійна регресія (предиктори: сироваткове залізо, феритин, трансферин, вітамін B12); рівень значущості $p < 0,05$.

Результати. Через 36 місяців анемію виявлено у 23,7 % (27/114). Порівняно з вихідним рівнем Hb знизився з 143 [136,0–150,0] до 136,7 [127,7–142,0] г/л ($p = 0,001$), сироваткове залізо – з 20,8 [17,0–23,7] до 11,6

[3,9–18,8] мкмоль/л (p = 0,001), феритин – зі 126,2 [90,7–191,0] до 10,9 [9,4–95,5] нг/мл (p = 0,001); рівень вітаміну B12 істотно не змінився (p = 0,053). Загалом порушення показників «анемічної панелі» були частими: латентний дефіцит заліза – 26,3 %, дефіцит заліза без анемії – 15,8 %, залізодефіцитна анемія – 15,8 %, анемія без дефіциту заліза (ймовірно, B12/фолатна) – 5,3 % і поєднаний дефіцит – 2,6 % (усього 65,8 % мали будь-які порушення). Гемоглобін корелював із сироватковим залізом (r = 0,443; p = 0,001) та феритином (r = 0,359; p = 0,001). У багатофакторній регресії (F = 8,47; p < 0,001; R^2 = 0,237) незалежними предикторами Hb були сироваткове залізо (β = 0,410; p = 0,001) і вітамін B12 (β = 0,180; p = 0,038); феритин і трансферин не були незалежними предикторами; критичної мультиколінеарності не виявлено (VIF < 2,2).

Висновки. Через три роки після РРШ майже чверть пацієнтів мають анемію, а дві третини – порушення показників «анемічної панелі», переважно пов'язані з дефіцитом заліза. Моніторинг, обмежений лише гемоглобіном, пропускає значну частку латентних дефіцитів. Стандартизований нагляд, що включає феритин, сироваткове залізо, трансферин і вітамін B12, разом із своєчасною нутритивною корекцією має бути рутинним для запобігання прогресуванню до маніфестної анемії та її ускладнень.

Сучасні медичні технології. 2025. Т. 17, № 4(67). С. 239-246

Over the past decades, obesity has become a global problem and is considered one of the leading medical and social problems of our time. Its spread is associated with a complex of intersectoral factors: changes in eating habits, decreased physical activity, urbanization, and economic changes. According to numerous studies, obesity is associated with an increased risk of developing type 2 diabetes, cardiovascular disease, non-alcoholic fatty liver disease, obstructive sleep apnea, and a shorter life expectancy [1].

Numerous systematic reviews and meta-analyses have shown that bariatric surgery significantly outperforms conservative methods of treating obesity in terms of effectiveness. After surgery, there is a sustained and long-term reduction in excess body weight, as well as compensation for obesity-related comorbidities [2].

Many years ago authors proposed sleeve gastrectomy (SG) as the first stage of biliopancreatic diversion with duodenal exclusion using the Hess–Marceau technique in patients with morbid obesity in order to reduce surgical risk. It later became clear that this method not only ensures effective weight loss but also promotes remission of concomitant metabolic diseases such as type 2 diabetes mellitus (T2DM), hypertension, and non-alcoholic fatty liver disease [3]. Due to its high clinical efficacy, relative technical simplicity, and favorable safety profile, SG has gained recognition as a standalone bariatric surgery. According to the latest report from the International Federation for the Surgery of Obesity and Metabolic Disorders (IFSO), SG is the most common bariatric procedure in the world, accounting for approximately 58.4 % of all bariatric surgeries performed in 2022 [4].

SG is a restrictive bariatric surgery that doesn't mess with the anatomy of the small intestine and, unlike bypass surgeries, is usually seen as less risky for causing nutritional deficiencies. However, according to numerous publications, a high frequency of deficiencies, including changes in the anemia panel, associated with reduced intestinal absorption, has been described after Roux-en-Y gastric bypass or biliopancreatic diversion [5].

Despite the fact that SG is the most common bariatric procedure in the world, the number of researches devoted to the study of nutritional disorders after this operation remains limited. In the long term after SG, laboratory monitoring often focuses only on hemoglobin assessment, without proper analysis of other parameters of the anemia profile. This does not allow for the timely detection of latent disorders that may precede the development of clinically significant anemia with its potential complications.

Aim

To evaluate changes in anemia panel indicators in patients after sleeve gastrectomy in the long-term postoperative period.

Materials and methods

This retrospective study included 114 patients with morbid obesity who underwent sleeve gastrectomy. The postoperative observation period was 60 months.

This study was approved by the Commission on Compliance with Bioethics in conducting experimental and clinical research at the State Scientific Institution "Centre of Innovative Medical Technologies of the National Academy of Sciences of Ukraine" (protocol No. 2 dated September 3, 2025). All studies used the Declaration of Helsinki (6th edition, revised 2008, Seoul) and the Universal Declaration of Bioethics and Human Rights (2006).

Prior to the start of the study, written informed consent was obtained from all participants for voluntary participation and the processing of personal data.

The inclusion criteria were: 1) patients aged 19 to 70 years; 2) BMI between 35 and 70 kg/m^2; 3) patients after primary bariatric surgery, namely SG; 4) all patients included in this study did not follow the recommendations in the postoperative period and did not take vitamin and mineral supplements; 5) preoperative anemia profile indicators within normal limits; 6) absence of clinical or instrumental signs of acute or chronic inflammatory diseases that could affect ferritin levels or the interpretation of iron metabolism parameters; 7) written consent for the processing of personal data has been obtained.

Exclusion criteria: 1) patients after revision bariatric surgery; 2) less than 60 months after SG; 3) absence of a full range of key anemia indicators (hemoglobin, ferritin, serum iron, transferrin, and vitamin B12) after surgery; 4) patients with signs of inflammation (elevated C-reactive protein levels (>10 mg/L)) with the aim of minimizing the impact of the infectious-inflammatory component on ferritin levels.

The data evaluated (except for age and gender) included: before surgery – body weight, body mass index (BMI), and excess body weight (EBW); postoperative – body weight, BMI, percentage of excess body weight loss (%EBWL), and percentage of total body weight loss (%TBWL). Body weight and excess body

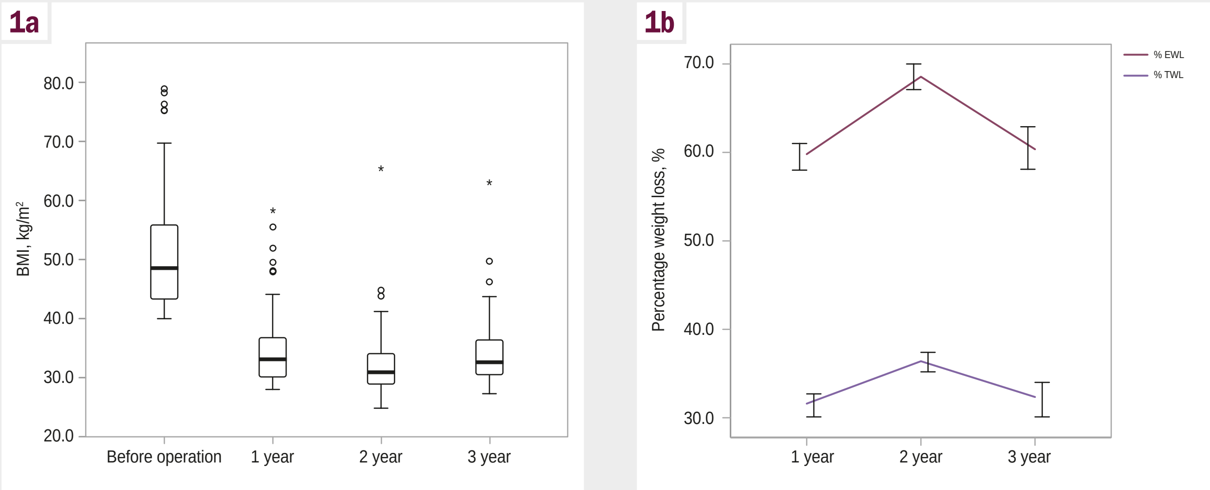

Fig. 1. Dynamics of BMI (**a**) and excess weight loss (**b**) in patients after SG.

weight in kilograms (kg), BMI in kg/m^2, %EBWL and %TBWL in percentages.

Laboratory parameters analyzed in this study: hemoglobin (Hb) (g/L), transferrin (μmol/L), ferritin (ng/mL), serum iron (μmol/L), and vitamin B12 (pg/mL).

Laboratory tests were performed on an EasyLyte Calcium biochemical analyzer (Medica, USA) and a CL-1000i chemiluminescence analyzer (Mindray, China).

The criteria approved by the World Health Organization (WHO) were used to classify anemia in patients. According to these recommendations, anemia is diagnosed when hemoglobin level is below 130 g/L in men and below 120 g/L in non-pregnant women.

Anthropometric and laboratory parameters were assessed before surgery and 3 years after sleeve gastrectomy.

Statistical data processing was performed using methods of variational and descriptive statistics with the help of the statistical analysis package SPSS Statistics: An IBM Company, version 23. Before starting the data analysis, the normality of the distribution was checked using the Kolmogorov-Smirnov criterion, and the equality of variances was checked using the Levin criterion. The study used descriptive statistical indicators: mean (M) and standard deviation (SD) (for normal distribution) or median (Me) and interquartile range (IQR) [25–75 %] (for non-normal distribution). To assess statistically significant differences in the mean values of quantitative characteristics that are not subject to the normal distribution law between two dependent samples, the nonparametric Wilcoxon criterion (W-criterion of Wilcoxon) was used. Pearson's correlation analysis was used to assess the relationship between biochemical parameters (hemoglobin, serum iron, ferritin, transferrin, and vitamin B12 levels). To identify factors affecting hemoglobin levels in the postoperative period, a multivariate linear regression analysis was performed including the variables: serum iron, ferritin, transferrin, and vitamin B12 levels. The significance of the model (F-criterion), the coefficient of determination (R^2, adjusted R^2) and individual β-regression coefficients were evaluated. The presence of multicollinearity was checked using VIF (Variance Inflation Factor) and tolerance (Tolerance); VIF values <5 were considered acceptable. Discrepancies in the results obtained were considered statistically significant at $p < 0.05$, which provides a 95 % probability level.

Results

The average age of all patients was 42.7 ± 12.4 years, ranging from 20 to 69 years. The male to female ratio was 58/56.

The average anthropometric values of patients before surgery were as follows: body weight – 150.9 ± 31.1 kg, BMI – 50.8 ± 9.5 kg/m^2, EBW – 83.3 ± 18.1 kg and %EBW – 125.6 ± 35.5 %. The distribution of patients by BMI was as follows: in 40 patients (35.1 %), BMI was in the range of 40.0–44.7 kg/m^2, in 23 patients (20.2 %) – 45.3–49.2 kg/m^2, in 32 (28.1 %) it was 50.0–59.5 kg/m^2, and in 19 patients (16.7 %) it was over 60 kg/m^2.

All patients underwent comprehensive laboratory and instrumental examinations prior to surgery in accordance with current clinical guidelines for the preoperative management of candidates for bariatric surgery. Anemia profile indicators (hemoglobin, ferritin, serum iron, and vitamin B12) were within reference values in all patients.

In the vast majority of patients (94.7 %), SG was performed via laparoscopic access, while only 5.3 % of cases used open access. The average length of postoperative hospital stay was 4.8 ± 1.5 days. No complications were recorded in the early postoperative period among the patients included in this study.

One, two, and three years after SG, the mean body weight and median BMI were 102.3 ± 18.7 kg and 33.1 [30.1–36.8] kg/m², respectively; 95.1 ± 16.5 kg and 30.9 [28.8–34.1] kg/m²; 100.9 ± 16.1 kg and 32.6 [30.5–36.5] kg/m². In general, a steady decrease in excess body weight was observed in the postoperative period. The average %EBWL after 1, 2, and 3 years 6 was 59.1 ± 8.3%, 67.6 ± 9.1%, and 59.8 ± 8.3%, respectively. At the same time, the average %TBWL at the same time points was 31.7 ± 5.1 %, 36.3 ± 6.1 %, and 32.3 ± 6.7 %, respectively. All these changes were statistically significant compared to preoperative values ($p < 0.05$) (*Fig. 1*).

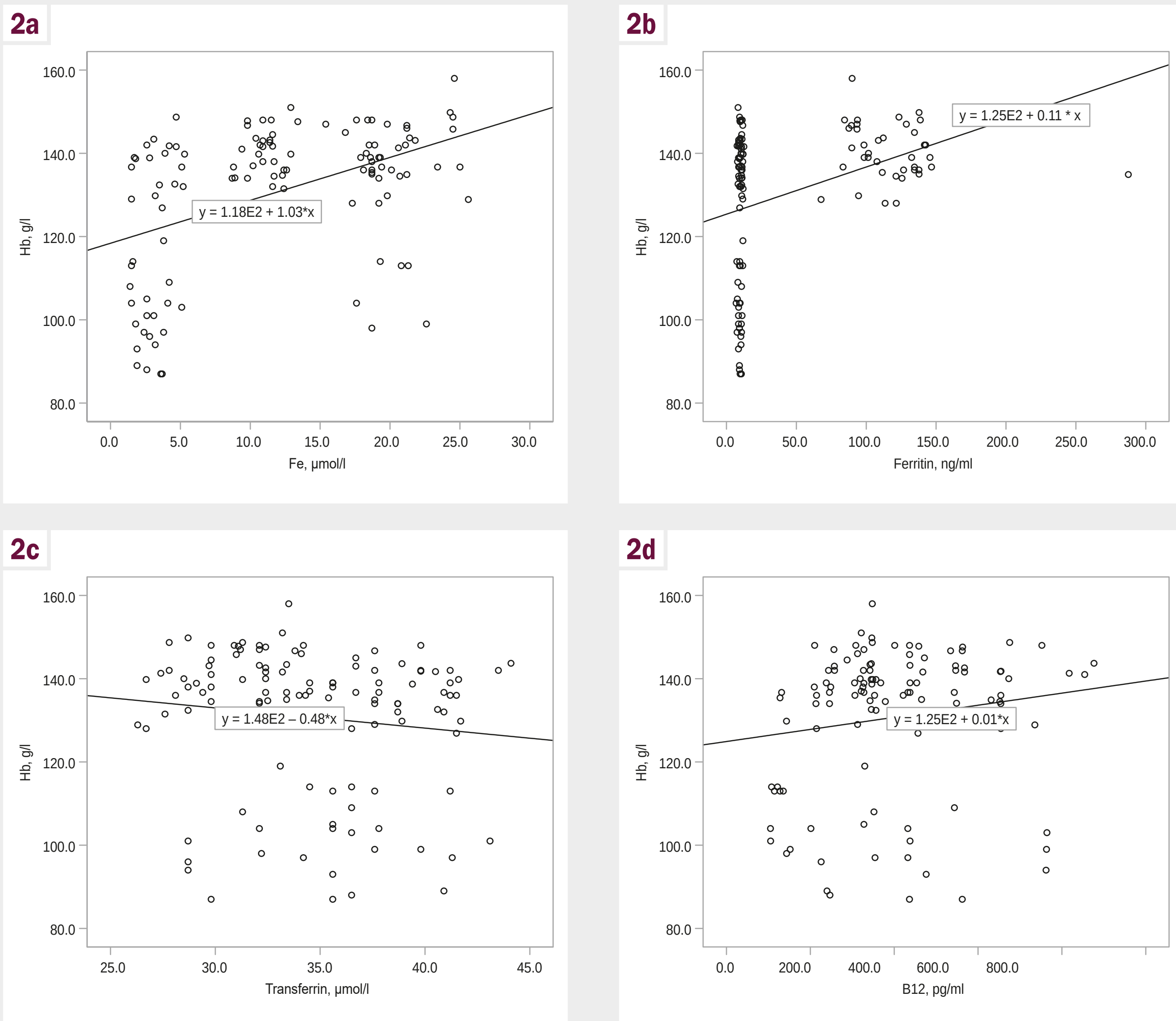

Fig. 2. Correlation between hemoglobin levels three years after SG and serum iron (**a**), ferritin (**b**), transferrin (**c**), and vitamin B12 (**d**) levels.

Three years after SG, anemia was detected in 27 patients (23.7 %). Analysis of anemia profile indicators showed a statistically significant decrease in hemoglobin levels from 143 [136.0–150.0] g/L to 136.7 [127.7–142.0] g/L (W = 5.9; p = 0.001), serum iron from 20.8 [17.0–23.7] µmol/L to 11.6 [3.9–18.8] µmol/L (W = 7.8; p = 0.001), and ferritin – from 126.2 [90.7–191.0] ng/mL to 10.9 [9.4–95.5] ng/mL (W = 8.1; p = 0.001). Vitamin B12 levels did not change significantly (W = 1.9; p = 0.053). The laboratory changes detected indicate iron metabolism disorders in a significant proportion of patients, even in the absence of clinically pronounced anemia.

Based on the biochemical indicators obtained, all examinees were classified into five clinical and laboratory groups:

• Group 1 – latent iron deficiency (n = 30; 26.3 %): decreased ferritin levels with normal or moderately decreased serum iron levels, without anemia;

• Group 2 – iron deficiency without anemia (n = 18; 15.8 %): decreased serum iron and ferritin with preserved hemoglobin levels;

• Group 3 – iron deficiency anemia (n = 18; 15.8 %): simultaneous decrease in hemoglobin, ferritin, and serum iron;

• Group 4 – anemia without iron deficiency (n = 6; 5.3 %): normal serum iron and ferritin levels with detected vitamin B12 or folic acid deficiency;

• Group 5 – anemia with combined deficiency (n = 3; 2.6 %): a combination of serum iron deficiency with simultaneous B12 or folate deficiency.

Patients in the first group (n = 30; 26.3 %) met the criteria for latent iron deficiency, a condition that precedes the development of manifest anemia. In these patients, the mean ferritin level was 10.1 ± 1.12 ng/mL, indicating iron depletion, with preserved hemoglobin levels (140.3 ± 5.4 g/L). The average serum iron level was 11.1 ± 1.3 µmol/L and remained within the reference range in some patients. This profile indicates an early phase of iron metabolism disorder, when clinical symptoms are still absent or nonspecific, but biochemical markers already signal danger. Early detection of this condition is crucial for the prevention of iron deficiency anemia.

The second group included 18 patients (15.8 %) with biochemical signs of iron deficiency in the absence of anemia. The average serum iron level was 3.5 ± 1.3 µmol/L, ferritin was 10.2 ± 1.4 ng/mL, while hemoglobin remained within the reference

Table 1. Multivariate regression analysis of hemoglobin levels after 3 years after SG

Variable	B (β)	Standard error (SE)	Standardized coefficient (Beta)	t	p	VIF
Constant	119.085	13.267	–	8.976	<0.001	–
Serum iron	0.955	0.288	0.410	3.314	0.001	2.187
Ferritin	0.019	0.039	0.061	0.496	0.621	2.143
Transferrin	-0.221	0.335	-0.056	-0.660	0.511	1.040
Vitamin B12	0.017	0.008	0.180	2.105	0.038	1.043

range (137.2 ± 5.7 g/L). This laboratory results corresponds to the compensated phase of iron deficiency: despite normal hemoglobin levels, the body is functioning against a background of depleted iron stores. This is a predictor of the potential development of manifest anemia in the event of additional stress – chronic blood loss, inflammation, or insufficient iron intake from food. Patients in this group require careful monitoring and early preventive correction of their nutritional status.

The third group consisted of 18 patients (15.8 %) with manifest iron deficiency anemia, as evidenced by a significant decrease in hemoglobin (98.9 ± 8.7 g/L), ferritin (9.6 ± 1.3 ng/mL), and serum iron (2.9 ± 1.1 μmol/L). Some patients had typical clinical manifestations of anemia syndrome: general 8 weakness, decreased exercise tolerance, and tachycardia. This type of anemia is more common for malabsorption syndrome after bypass bariatric surgery, but in our study, similar disorders were also observed after SG. The probable mechanism of anemia development in this cohort is a decrease in hydrochloric acid production (hypochlorhydria), which complicates the release and absorption of iron from food. Patients in this group require active nutritional correction and long-term monitoring with regular control of iron metabolism parameters.

The fourth group consisted of 6 patients (5.3 %) in whom anemia was accompanied by normal iron-binding profile parameters – serum iron level was 16.5 ± 1.8 μmol/L and ferritin – 85.1 ± 6.9 ng/mL, respectively. This profile indicates no iron deficiency, but the decrease in hemoglobin (112.2 ± 7.1 g/L) is likely due to a deficiency of other hematopoietic micronutrients, in particular vitamin B12 or folic acid. Patients in this group may develop megaloblastic anemia associated with impaired B12 absorption due to reduced intrinsic factor or malabsorption in the proximal small intestine. This type of anemia is potentially dangerous due to the likelihood of developing neurological complications such as paresthesia, ataxia, and cognitive impairment. Early diagnosis and administration of parenteral therapy are crucial for preventing irreversible changes.

The last group consisted of 3 patients (2.6 %) with mixed anemia, combining signs of both iron deficiency (serum iron level – 1.9 ± 0.6 μmol/L, ferritin level – 5.1 ± 1.1 ng/mL) and vitamin deficiency (vitamin B12 – 113.9 ± 8.2 pg/mL). The average hemoglobin level in this category was significantly reduced — 109.3 ± 7.2 g/L. The morphological picture of the blood showed signs of anisocytosis with a combination of normo- and macrocytic erythrocytes, indicating the multifactorial nature of erythropoiesis disorders. This combination is the result of profound nutritional imbalance after surgery, which involves several pathophysiological mechanisms: decreased gastric secretion, impaired production of intrinsic factor, and malabsorption in various parts of the small intestine. These patients require careful clinical supervision and individualized replacement therapy, taking into account all components of the deficiency.

Thus, among the 114 patients included in the study, more than half (65.8 %) had varying degrees of anemia. The most common were latent iron deficiency, compensated deficiency without anemia, and overt iron deficiency anemia. There were also cases of anemia associated with vitamin B12 deficiency and anemia of mixed origin. Only one-third of patients (34.2 %) had stable laboratory values with no signs of deficiency. The data obtained emphasize the importance of long term laboratory monitoring in patients after SG.

A correlation analysis was performed between hemoglobin levels 60 months after surgery and laboratory parameters that could potentially affect erythropoiesis. The strongest positive correlation with hemoglobin was found for serum iron ($r = 0.443$; $p = 0.001$) and ferritin ($r = 0.359$; $p = 0.001$). The correlation with vitamin B12 levels was weaker ($r = 0.149$; $p = 0.056$) and did not reach statistical significance. Transferrin had a weak negative correlation ($r = 0.123$; $p = 0.095$), which was also not significant (*Fig. 2*).To identify independent predictors of hemoglobin levels, a multivariate regression analysis was performed including the following variables: serum iron, ferritin, transferrin, and vitamin B12. The main indicators are presented in *Table 1*.

The model proved to be statistically significant ($F = 8.473$; $p = 0.001$), with an overall coefficient of determination $R^2 = 0.237$, indicating that 23.7 % of the variation in hemoglobin levels was explained by the included variables. In the model, serum ferritin ($B = 0,955$; $p = 0,001$) and vitamin B12 ($B = 0.017$; $p = 0.038$) remained independently associated with hemoglobin levels. Other indicators included in the model (ferritin, transferrin) had no statistically significant effect. Multicollinearity testing revealed no critical violations (VIF < 2.2 for all variables).

The results confirm that serum iron and vitamin B12 levels are independent factors that affect hemoglobin levels in the long term in patients after SG. This highlights the importance of monitoring these indicators when assessing the risk of developing anemia.

Discussion

Anemic conditions remain one of the most common metabolic complications after bariatric surgery, even with proper pre- and postoperative nutritional support. After sleeve gastrectomy, the incidence of anemia varies from 12 % to 43 % in the long-term postoperative period, which is due to a combination of decreased gastric secretion, reduced iron and folate intake, and impaired vitamin B12 absorption [6].

Although Roux-en-Y gastric bypass is a restrictive procedure and is not accompanied by a pronounced malabsorptive component, recent meta-analyses show that in the long term after surgery, the risk of developing iron deficiency may be comparable to that of bypass procedures. After Roux-en-Y gastric bypass, the prevalence of iron deficiency varies between 18–53 %, and after sleeve gastrectomy, it ranges from 1 to 54 %, depending on the duration of observation [7].

It is important to emphasize that anemia after bariatric surgery is multifactorial in nature, combining nutritional deficiency, changes in gastric acidity, chronic inflammation, and hormonal shifts. Studies indicate that 1 year after RYGB, hepcidin levels may increase, which inhibits iron absorption in the intestine (by reducing the expression of DMT1, the main transporter of non-heme iron) even in the absence of a chronic inflammatory component [8].

In the long term after surgery, the proportion of latent iron metabolism disorders also increases, with ferritin deficiency preceding the development of clinical anemia. A large meta-analysis of 31 studies (7,639 patients) reported that the prevalence of anemia increased from 7 % at baseline to 25 % at 36 months and 18 % at 60 months after surgery, while ferritin deficiency steadily increased to 27 % at 60 month, confirming that the drop in hemoglobin lags behind the depletion of iron stores [9]. Global research data confirm that monitoring hemoglobin levels alone is insufficient for the timely detection of iron deficiency.

In addition to restrictive bariatric interventions, the trend of anemic conditions is much more pronounced among shunting and malabsorptive techniques.

After Roux-en-Y gastric bypass surgery, the overall postoperative prevalence of diagnosed anemia is 26 %, with a clear time dependence: 15 % within ≤1 year, 27 % within >1-5 years, and 35 % within >5 years after surgery 13 [9].

Additionally, in a direct comparison of Roux-en-Y gastric bypass with a single anastomosis and sleeve gastrectomy, the incidence of anemia was statistically higher after bypass surgery: at 12-24-36 months – 28.4 % – 37.6 % – 56.5 % versus 16.2 % – 19.7 % – 24.3 % after sleeve gastrectomy [10].

The most pronounced burden of anemia has been described for malabsorptive techniques such as biliopancreatic diversion (BPD): in a 42-month follow-up series, anemia was diagnosed in 43 % of patients despite active supplementation, which is consistent with the broader physiological component of these interventions [11].

The incidence of anemia of 23.7 % at 36 months after Roux-en-Y gastric bypass surgery obtained in our study is consistent with current sources. In the largest specialized meta-analysis, the authors described a prevalence of anemia of 25 % at 36 months (from 7 % at baseline and 18 % at 60 months), which is practically consistent with our estimate for the three-year mark [6]. Similar values are demonstrated by the prospective Tehran Obesity Treatment Study cohort, where the incidence of anemia in the group of patients after Roux-en-Y gastric bypass reached 24.3 % at 36 months of follow-up [10].

Direct comparison of the frequency of anemia after RRS between individual studies is significantly complicated by differences in diagnostic approaches and observation protocols. First, different authors use different thresholds for ferritin (from < 15 to < 50–100 μg/L, sometimes in combination with TSAT < 20%), and also take into account the influence of chronic inflammation, which can "mask" iron depletion, in different ways. Some cohorts rely solely on hemoglobin and ferritin levels, while others include an expanded panel (TSAT and transferrin) [12].

Comparing the incidence of anemia after sleeve gastrectomy between studies is complicated primarily by the variability of diagnostic thresholds. Even for the basic criterion–hemoglobin–thresholds vary based on gender, pregnancy status, altitude, and smoking habits. Moreover, in 2024, the WHO introduced updated recommendations for the hemoglobin cut-off, which differ from the previous system and inevitably affect the assessment of anemia prevalence across different populations [13]. Another aspect of the problem is the interpretation of ferritin as a marker of acute phase inflammation: in "clean" conditions, values <15–30 μg/L are often cited as a sign of deficiency, but in the presence of inflammation, many authors reasonably raise the threshold to <100 μg/L or use TSAT <20 %; without determining C-reactive protein and other biochemical pro-inflammatory markers, the same population gives different indicators of iron deficiency/anemia [14].

The methodological heterogeneity of global studies is also significant. The duration of follow-up and the frequency of checkpoints vary considerably, and diagnostic losses during follow-up, especially after 12–36 months, skew prevalence estimates, making them underestimated or unstable [15].

The routine postoperative use of proton pump inhibitors is generally inconsistent: it is common in many centers and may exacerbate iron deficiency after Roux-en-Y gastric bypass surgery, creating an additional difference between cohorts with different protocols [16].

Focusing on the types of anemia profile disorders, it is important to note that after RYGB, the most common are: latent iron deficiency (low ferritin with normal hemoglobin), which often precedes manifest anemia, iron deficiency anemia (IDA), mixed forms (a combination of IDA with B12 deficiency or anemia of chronic disease), and B12 deficiency anemia itself, which is generally less common after sleeve gastrectomy than after bypass surgery, but is not an exception. Current studies agree that iron deficiency predominates in most cases, while B12 deficiency is more pronounced in Roux-en-Y gastric bypass surgery, but remains clinically significant in some patients after Roux-en-Y gastric bypass surgery, especially with insufficient postoperative supplementation [17].

The pathogenesis of these disorders after sleeve gastrectomy is multifactorial. First, hypochlorhydria after resection of the body and fundus of the stomach reduces iron recovery and the solubility of non-heme iron. In addition, long-term use of PPIs is associated with an increased risk and severity of AD in operated patients [17]. Second, hepcidin plays an important role in pathogenesis: even despite a reduction in low-grade inflammation after surgery, in prospective studies after one year, hepcidin levels may remain elevated, with a negative correlation with DMT1 in the duodenum – that is, even without intestinal bypass, hepcidin is capable of limiting enteral iron absorption and contributing to functional deficiency [8].

When forming an overall picture of anemia in the postoperative period, it is important to understand that hemoglobin reflects only the end result of prolonged iron or vitamin B12 deficiency, rather than the initial changes in metabolic status. Its level may remain within normal limits even with significant depletion of iron stores, as evidenced by a decrease in ferritin and transferrin saturation long before the onset of clinical anemia. That is why hemoglobin is considered a “late” indicator, unsuitable for early diagnosis of nutritional disorders after bariatric surgery. Studies have shown that a 30–40 % decrease in ferritin often precedes a drop in hemoglobin 6–12 months after surgery [18].

According to the recommendations of the American Society for Metabolic and Bariatric Surgery (ASMBS) and the British Obesity and Metabolic Surgery Society (BOMSS), screening for anemia after bariatric surgery should include not only hemoglobin, but also ferritin, vitamin B12, folates, and sometimes copper (Cu) and zinc (Zn) every 3–6 months during the first year and annually thereafter [19]. The European Association EASO also recommends a combined approach with the calculation of transferrin saturation and soluble transferrin receptor ratio (sTfR/log ferritin), which increases the sensitivity of iron deficiency diagnosis at the preclinical stage [17].

A detailed assessment of predictors of micronutrient deficiency, namely ferritin and vitamin B12, before the onset of clinical anemia is of unconditional prognostic value for the timely prescription of timely therapy. Patients with ferritin < 30 ng/mL and B12 < 200 pg/mL in the first 6 months after surgery have a 3.2 times higher risk of developing anemia after one year [20].

Thus, the results confirm that even with satisfactory hemoglobin levels in patients after bariatric surgery, the biochemical prerequisites for anemia syndrome develop at an early stage. Routine monitoring of hemoglobin levels alone is insufficient for adequate postoperative monitoring. In the future, it will be important to introduce the use of an expanded laboratory panel that includes ferritin, transferrin, vitamin B12, and folates, as well as early nutritional support. This approach will allow for the timely prevention of micronutrient deficiencies, improve long-term outcomes of surgical treatment, and enhance the quality of life of patients after metabolic surgery.

Conclusions

1. Three years after SG, 23.7 % of patients were diagnosed with anemia, accompanied by a significant decrease in hemoglobin, serum iron, and ferritin levels (p = 0.001), with stable vitamin B12 levels.

2. Anemia was detected in 65.8 % of patients. The most common variants were: latent iron deficiency (26.3 %), iron deficiency without anemia (15.8 %), overt iron deficiency anemia (15.8 %), isolated vitamin B12 deficiency (5.3 %), and combined forms of anemia (2.6 %).

3. According to multivariate regression analysis, the key predictors of decreased hemoglobin levels are serum iron (p = 0.001) and vitamin B12 (p = 0.038) concentrations. This highlights the need for regular monitoring of all key indicators of anemia – hemoglobin, iron, ferritin, transferrin, vitamin B12, and folate – in patients after SG, even in the absence of clinical symptoms.

Perspectives for further research. Prospective studies with standardized follow-up checkpoints are needed to validate that serum iron and vitamin B12 independently predict hemoglobin after sleeve gastrectomy and to test optimized supplementation strategies. Future protocols should extend monitoring beyond hemoglobin to include ferritin, transferrin saturation, soluble transferrin receptor, C-reactive protein, and hepcidin to enable earlier detection of latent deficiencies and clarify pathophysiology. Comparative work across bariatric procedures and attention to methodological consistency would improve generalizability and refine postoperative screening algorithms.

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