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Enhancing nutritional health and patient satisfaction five years after metabolic bariatric surgery with targeted supplementation

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Abstract

Background This study analyzes the long-term outcomes of metabolic bariatric surgery (MBS), focusing on weight loss, nutritional deficiencies, and patient satisfaction. We evaluate different surgical techniques to identify their impact on these outcomes.

Methods A five-year retrospective analysis was conducted on 249 patients who underwent MBS at a specialized center. Baseline characteristics included an average age of 38.5 years, weight of 118.5 kg, and BMI of 43.2 kg/m^2. Weight loss outcomes were assessed using mean excess weight loss (%EWL) at 60 months. Surgical techniques included laparoscopic sleeve gastrectomy (LSG), one anastomosis gastric bypass (OAGB), and Roux-en-Y gastric bypass (RYGB). Nutritional deficiencies and patient-reported quality of life were also evaluated.

Results The mean %EWL at 60 months was 92.1% ± 25.8% ($p=0.013$). While LSG and OAGB showed similar weight loss patterns, RYGB resulted in further weight reduction from the third year onwards. Patients revised from LSG to RYGB had significantly greater weight loss (102.1%) compared to those revised to mini-gastric bypass (MGB) (84.6%, $p<0.05$). Nutritional deficiencies were prevalent, with 41.2% of revised LSG patients experiencing iron deficiency and 14.3% developing new vitamin D deficiencies ($p<0.05$). Most patients (85%) reported improvements in quality of life, and 85% expressed a willingness to undergo surgery again ($p=0.0028$).

Conclusions MBS resulted in substantial and sustained weight loss, particularly in RYGB patients. Surgical revisions, especially from LSG to RYGB, were associated with greater weight loss but also increased nutritional risks. Persistent iron and vitamin D deficiencies highlight the necessity of individualized supplementation and long-term monitoring. Type-targeted supplementation represents an innovative approach to optimizing long-term nutritional support in

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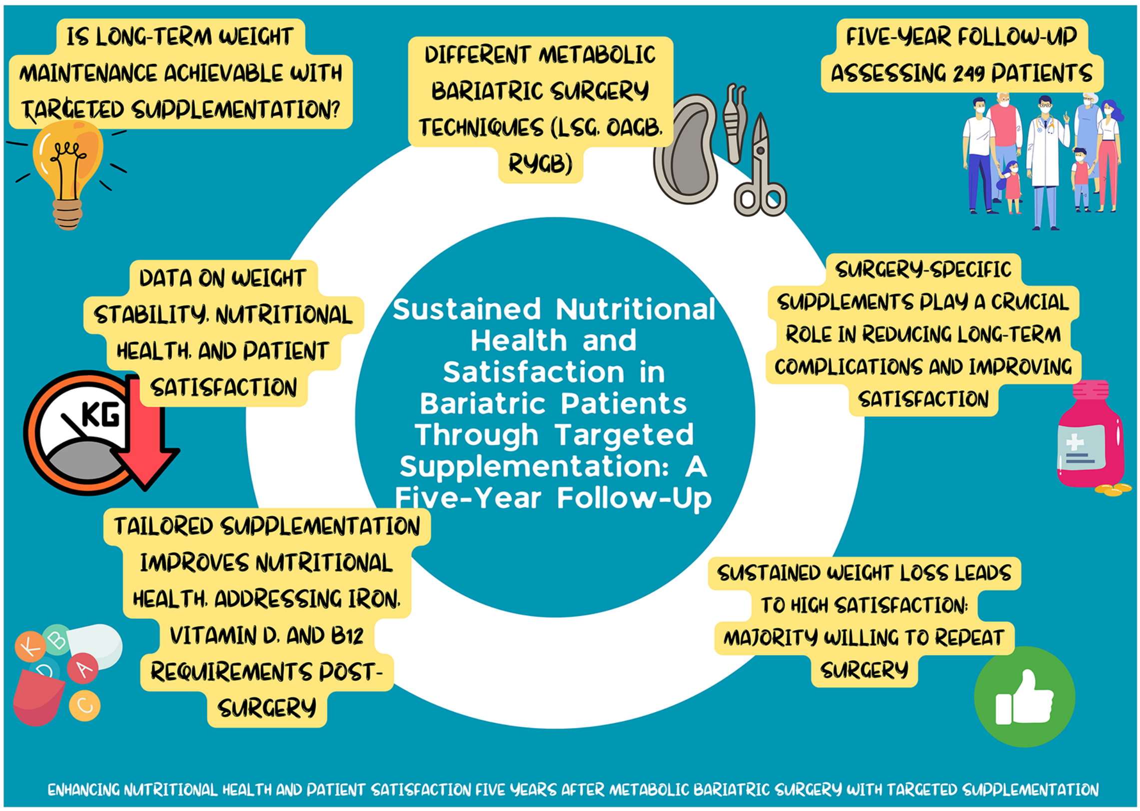
bariatric patients. Future studies with larger cohorts and validated tools are needed to confirm these findings and strengthen clinical guidelines.

Trial registration This study is registered at ClinicalTrials.gov (NCT06664580).

Graphical abstract



Keywords Metabolic bariatric surgery, Nutritional health, Targeted supplementation, Long-term weight maintenance, Patient satisfaction, Roux-en-Y gastric bypass, Sleeve gastrectomy, Personalized nutrition, Postoperative outcomes, Bariatric supplementation

Introduction

Metabolic bariatric surgery (MBS) is considered one of the most effective therapy for the treatment of subjects with a (Body Mass Index) BMI over 40 kg/m^2 or with a BMI between 35 and 40 kg/m^2 with obesity-related comorbidities [1, 2]. Long-term follow-up studies [3, 4] demonstrated a substantial mortality reduction in patients who previously underwent MBS, as well as a reduction in the risk of developing new comorbidities with related healthcare costs.

According to the IFSO/ASBMS 2022 guidelines [3], MBS is recommended for patients with a BMI ≥ 35 kg/m^2, regardless of the presence or severity of comorbidities. For individuals with a BMI between 30 and 34.9 kg/m^2, MBS is indicated when metabolic diseases, such as type 2 diabetes, are present and non-surgical treatments have failed to achieve adequate control. These guidelines also suggest that BMI thresholds should be adjusted to different populations, particularly for the Asian population, where the threshold for clinical obesity is set at a BMI ≥ 25 kg/m^2 due to the higher metabolic risk. Furthermore, the guidelines emphasise that age should not be considered an absolute contraindication for surgery, provided that frailty and comorbidities are carefully assessed.

Surgical techniques include laparoscopic adjustable gastric banding (AGB), laparoscopic sleeve gastrectomy (SG), also referred to simply as sleeve gastrectomy, to avoid confusion with vertical banded gastroplasty (VBG), laparoscopic Roux-en-Y gastric bypass (RYGB), one anastomosis gastric bypass (OAGB) and biliopancreatic diversion with duodenal switch (BPD/DS). AGB is largely abandoned in current clinical practice due to suboptimal long-term outcomes. When used, it is typically employed in combination with banded sleeve gastrectomy or banded gastric bypass. SG involves the removal of a large portion of the stomach, reducing its capacity and hunger hormone production [4]. Although less prone to severe malnutrition, patients may develop iron, B12 and vitamin D deficiencies. RYGB and OAGB combine restrictive and malabsorptive components, with the exclusion of part of the small intestine, which increases the risk of deficiencies of vitamins, calcium, iron and B12 [5]. BPD/DS also combines restriction through a SG and malabsorption by bypassing a significant portion of the small intestine, resulting in substantial weight loss but also a higher risk of severe nutritional deficiencies, especially of fat-soluble vitamins, protein, iron, calcium and B12 [6]. According to the IFSO Worldwide Survey 2020–2021 (Angrisani et al., 2024), the most commonly performed bariatric procedures are SG and RYGB, while LAGB has seen a significant decline in use [7].

Among the major drawbacks of all types of MBS is the regain of initially lost weight [8]. In addition, the nutritional needs of bariatric patients are often not met, despite the widespread use of vitamin and mineral supplements [9]. A recent systematic review has emphasised that there is still a lack of long-term follow-up data suggesting how long nutritional deficiencies might persist after MBS, especially for RYGB and SG [10]. The risks of nutritional deficiencies are greater in patients who have undergone RYGB [11], but previous studies have shown that, despite the extensive use of supplements, nutritional deficiencies can occur several years post-operatively even in patients who have undergone SG [12, 13]. Recent research further highlights the role of individualized supplementation strategies in mitigating these deficiencies. For example, Basolo et al. [14] analyzed the long-term effects of a tailored micronutrient supplementation regimen, showing that patients receiving targeted formulations exhibited a significantly lower incidence of vitamin D and iron deficiencies compared to those following generic multivitamin protocols. The study also emphasized the importance of adherence to supplementation, noting that poor compliance was a key predictor of persistent deficiencies. These findings reinforce the need for personalized approaches and continuous biochemical monitoring to optimize post-MBS nutritional outcomes.

The study explores the effects after five years of MBS, focusing on nutritional health, weight maintenance and patient satisfaction, with a focus on the use of targeted supplements according to the type of intervention.

Research design and methods

Study design and participants

We retrospectively analyzed the medical records of 249 patients who underwent MBS at the outpatient service of the "Obesity Center" of the Policlinico Tor Vergata University Hospital Rome, Italy between 2012 and 2017. The cohort consisted predominantly of females (95.6%, $n = 238$), with only 4.4% ($n = 11$) of participants being male. This imbalance reflects the well-documented higher prevalence of MBS among women in clinical settings. However, this gender disparity limits our ability to conduct meaningful gender-specific analyses. While our findings primarily represent outcomes in female patients, the extent to which results might differ in males remains uncertain. Future studies should consider targeted recruitment strategies to ensure a more balanced gender representation, allowing for a deeper exploration of potential sex-specific metabolic and nutritional outcomes post-MBS. We included only subjects with available follow-up data for at least five years post-surgery. Exclusion criteria were as follows: age < 18 or > 65 years, personal history of alcoholism, significant social anxiety or difficulty participating in group activities related to post-operative care (referred to as social discomfort), recent diagnosis (after MBS) of neoplastic diseases, neurocognitive disorders or other systemic diseases (both chronic and acute) potentially leading to disability and impacting quality of life. We initially examined 260 medical records of patients who underwent surgery. After applying the exclusion criteria, 11 patients were excluded for the following reasons: one patient had a personal history of alcoholism, one patient reported significant social anxiety affecting post-operative care participation, one patient had a recent diagnosis of neoplastic diseases, and 8 patients had incomplete data. The remaining 249 patients met the inclusion criteria and were retrospectively analyzed. The patients had previously agreed to have their data entered into a prospective database, and a waiver was obtained from the ethics committee to allow for the retrospective review of this data. The different MBS procedures included: AGB, LSG, RYGB, BPD/DS, and OAGB. In RYGB, the alimentary limb length ranged between 100 cm and 150 cm, and the biliopancreatic limb length between 50 cm and 100 cm. For OAGB, the biliopancreatic limb length ranged between 180 cm and 220 cm. All subjects were adult white Europeans and gave their own written informed consent to be included in the analysis. The study protocol conformed to the ethical guidelines of the 1975 Declaration of Helsinki and was approved by the Lazio Area 5 Territorial Ethics Committee (100/SR/24). This paper has been registered to ClinicalTrial.gov (NCT06664580).

Data collection and outcomes

Data were extracted using the electronic clinical records regularly provided by the "Obesity Center" outpatient service. The following clinical data collected prior to MBS and at 3, 6, 12, 24, 36, 48 and 60 months after surgery were included: age, gender, weight, height, body mass index (BMI), routine biochemical examinations, and use of nutritional supplements. Anthropometric data were measured at baseline and at each follow-up visit. Following overnight fasting, weight and height were collected while the subjects were wearing only underwear. To calculate the percentage of excess weight loss (%EWL), a BMI of 25 kg/m² was used as a target to define the ideal body weight (IBW). This is standard practice in MBS, as a BMI of 25 marks the upper limit of the World Health Organisation classification for normal weight. The formula for %EWL is: %EWL = [(Initial weight - Postoperative weight) / (Initial weight - Ideal weight)] × 100, where ideal weight corresponds to a BMI of 25. This parameter is widely adopted in the literature on MBS to assess postoperative weight loss outcome [16].

According to the self-reported use of nutritional supplements, patients were defined as "adherent" if they reported consistent use for a minimum of five days per week. Different types of supplements have been studied, including surgery-specific supplements formulated to meet the nutritional needs of each surgical procedure, such as iron supplements for RYGB or vitamin B12 for SG, to reduce the risk of deficiencies: (a) bariatric multivitamin supplements generally formulated for patients undergoing MBS without specific adjustments according to the type of surgical intervention; (b) bariatric specific supplements specifically designed to meet the nutritional needs specific to the type of MBS performed; (c) complete nutritional support: This category encompasses patients who require comprehensive supplementation, typically including a multivitamin combined with additional nutrients to address individual deficiencies; (d) generic multivitamin supplements: This group includes all forms of multivitamin supplements, whether standalone or combined with proteins or other components; (e) other supplements: Supplements used to target specific diagnosed deficiencies are categorized here, such as symbiotics, zinc, calcium and Vitamin D, iron supplements, Vitamin C, Omega 3, and folic acid.

Nutritional deficiencies were categorized into short-term and long-term based on the duration of the deficiency post-surgery. Short-term deficiencies were defined as those identified within the first 12 months following surgery, while long-term deficiencies were those persisting or appearing after 12 months.

At the time of analysis, patients completed a customized survey assessing key post-surgical outcomes, including weight loss, supplement adherence, and patient satisfaction. Although this approach allowed us to capture specific aspects relevant to our cohort, we acknowledge that the use of a validated instrument, such as the BAROS, would enhance comparability with existing literature. Future studies should consider incorporating validated tools to improve methodological robustness and facilitate cross-study comparisons. In future studies, we will consider using validated instruments like BAROS for broader comparability. The survey aimed to assess the impact of surgery on patients' quality of life, particularly in the context of obesity-related health problems. It was designed in a simple manner to facilitate understanding and response by the participants. The survey included the following two key questions: (a) Post-intervention improvement: "Has the quality of life and/or obesity-associated diseases improved after the intervention?" This question seeks to collect subjective data on the personal health benefits the patient perceives after surgical treatment, including both physical and psychological aspects. (b) Willingness to repeat surgery: "Would you undergo the same surgery again?". This question aims to assess the patient's satisfaction with the outcome of the surgery and whether his or her experience was positive enough to justify repeating the surgery under similar circumstances.

Statistical analysis

Statistical analysis was performed with the SPSS 25.0 software (SPSS, Chicago, IL, USA). Means ± SD or absolute and percent values were used as descriptive statistics for quantitative and categorical variables, respectively. As this is a retrospective study, no formal protocol for outlier detection was established. Data were collected and analyzed without predefined criteria for outliers. All quantitative variables were tested for normality distribution using the Kolmogorov–Smirnov test and continuous parameters with non-normal distribution were logarithmically transformed before being used in the subsequent parametric procedures. Differences in continuous variables between groups were assessed using analysis of variance (ANOVA) test for multiple comparisons, with the Bonferroni test as post-hoc analysis. Differences in proportions of discrete traits were assessed using the chi-square test. Within-groups differences in continuous variables between baseline and follow-up values were assessed using the t-test for paired data. In addition, the Kruskal-Wallis test was utilized to determine if there were statistically significant differences in the median percentage of excess weight loss (%EWL) among different groups. The Mann-Whitney U test was applied to compare mean %EWL at 60 months between patients who underwent revision surgery and those who did not, across each type of surgical intervention. To account for baseline heterogeneity in age, preoperative BMI, and the type of procedure performed, a multivariable regression analysis was conducted. The model was adjusted for key variables including age, preoperative BMI, and type of bariatric procedure to assess their impact on weight at 60 months post-surgery. For all of these analyses, a p-value < 0.05, based on a two-sided test, was considered statistically significant.

Results

The entire sample had a mean age of 38.5 years, a mean weight of 118.5 kg and a BMI of 43.2 kg/m² (Table 1). Although the initial differences in BMI between the different intervention types were not statistically significant ($p = 0.060$), the patients undergoing BPD had the highest mean weight. In contrast, there was significant variation in age ($p = 0.0000045$), with patients undergoing OAGB being older on average. Follow-up rates were 98.8% at 3 months, 96.8% at 6 months, 93.5% at 12 months, 90.2% at 24 months, 87.4% at 36 months, 94.1% at 48 months and 91.0% at 60 months.

To consider the initial heterogeneity between the groups, we conducted a multivariate regression analysis to assess the impact of age, preoperative BMI and type of bariatric procedure on weight at 60 months postoperatively. The regression model included these variables as independent predictors, with weight at 60 months as the dependent variable. The analysis revealed that the type of intervention significantly influenced weight at 60 months. Specifically, patients who underwent RYGB gastric bypass had a statistically significant weight reduction at 60 months ($p = 0.015$), with a mean weight difference of 24.9 kg compared to other procedures. In contrast, other types of intervention such as SG, BPD and OAGB showed no statistically significant effect on long-term outcomes.

The mean %EWL at 60 months varied significantly between the groups, with an overall mean of 92.12% and a standard deviation of 25.78%. The Kruskal-Wallis test showed statistically significant differences in the median %EWL between the groups ($p = 0.013$), suggesting that the effectiveness of the procedures may vary significantly. Figure 1 shows the comparison of weight loss at 3, 6, 12, 24, 36, 48, 60 months after surgery for the three most common procedures. The averages of the percentage weight loss (%WL) show that SG and OAGB have similar weight loss trajectories, while RYGB shows from the third year onwards a further weight loss, which is not noticeable in the other two surgeries. However, the differences between the procedures at each time point were not statistically significant. AGB patients (data not shown) exhibited significantly lower %EWL at the final follow-up compared to the other procedures. This outcome aligns with the restrictive nature of AGB and its declining use in clinical practice due to its suboptimal long-term efficacy.

Comparison of primary and revision procedures

In our analysis, revised patients are those who underwent a second bariatric surgical procedure due to insufficient weight loss or complications related to the primary intervention. Among the revised patients ($n = 38$), revisions were most common among those who had previously undergone LSG (55.3%), followed by AGB (26.3%), RYGB (15.8%), and MGB (2.6%). The mean time since the initial operation was 9.9 Full details on revision indications and surgical techniques are provided in the Supplementary Material. A total of 38 patients (15.3%) underwent revision surgery. Among those who initially underwent AGB, 1 case was converted to SG due to band slippage, while 5 cases were revised to OAGB and 4 to RYGB, primarily due to insufficient weight loss. For patients who had previously undergone BPD, 1 case was revised to RYGB due to malabsorption, 1 case was converted to a banded absorption and restriction system due to persistent malnutrition, and 1 case required a revision to enhance nutrient absorption due to severe deficiencies. Among those initially treated with RYGB, 5 cases were revised to OAGB due to weight regain or insufficient weight loss, while 1 case required a revision to another RYGB due

Table 1 Comparison of age, initial weight, and BMI across different metabolic bariatric surgery procedures

	Overall sample	AGB	LSG	OAGB	RYGB	BPD	Other procedures	*p*-value
n.	249 (F 238)	16	118	54	49	7	5	-
Age	38.5 ± 9.1	40.8 ± 7.5	35.4 ± 9.2	43.4 ± 8.5	39.7 ± 7.7	37.2 ± 9.3	40.7 ± 6.5	0.0000045
Body Weight	118.5 ± 19.5	110.8 ± 20.9	116.8 ± 17.3	114.1 ± 15.6	123.4 ± 19.8	147.2 ± 32.3	139.4 ± 27.1	0.0024
BMI	43.2 ± 4.67	42.6 ± 5.0	43.4 ± 4.5	41.4 ± 4.5	44.1 ± 4.1	48.5 ± 7.8	45.0 ± 5.5	0.060
%EWL at 60 months (all sample)	92.1 ± 25.8	72.9 ± 28.4	88.3 ± 25.9	96.1 ± 24.3	95.9 ± 24.1	115.6 ± 11.2	103.1 ± 22	0.013
%EWL at 60 months (non revised) *	95.2 ± 24.3	82.5 ± 34.1	91 ± 23.7	95.8 ± 24.8	97.3 ± 25.3	114.7 ± 15.6	103 °	0.094
%EWL at 60 months (revised) *	86.1 ± 27.9	70.4 ± 28.9	84.6 ± 28.7	102.1 °	91.5 ± 21.3	116.2 ± 11.2	102 °	0.087

Age, Weight, and BMI of different types of bariatric surgeries and the total sample. P-values indicate the statistical significance of differences across groups. Data as mean ± SD. AGB, Adjustable gastric banding SG, laparoscopic vertical gastrectomy, RYGB, laparoscopic Roux-en-Y gastric bypass; OAGB, one anastomosis gastric bypass, BPD, biliopancreatic diversion. %EWL = [(Initial Weight) - (Postop Weight)]/[(Initial Weight) - (Ideal Weight)] x 100, ideal weight is defined by the weight corresponding to a BMI of 25 kg/m2. Other procedures include: Biliopancreatic Diversion with Duodenal Switch (BPD/DS) (1 patient), Vertical Banded Gastroplasty (2 patients), Bilio-intestinal bypass (1 patient), Overstichs (1 patient), Sleeve Gastrectomy Endozip (1 patient), and SWEECH Duodenale (1 patient). (*) Mann-Whitney U tests showed no statistically significant differences in mean %EWL at 60 months between revised and non-revised patients for each type of intervention. The p-values obtained are: LSB ($p = 0.613$), OAGB ($p = 0.818$), RYGB ($p = 0.475$), AGB ($p = 0.711$), Other procedures ($p = 1.000$), and BPD ($p = 0.800$). The number of patients who underwent revised surgery is as follows: AGB (8), SG (20), RYGB (6), BPD (3), OAGB (1), and Other Procedures (1). (°) Due to the low number of cases for OAGB and Other Procedures (only one patient each), standard deviations were not calculated for these categories

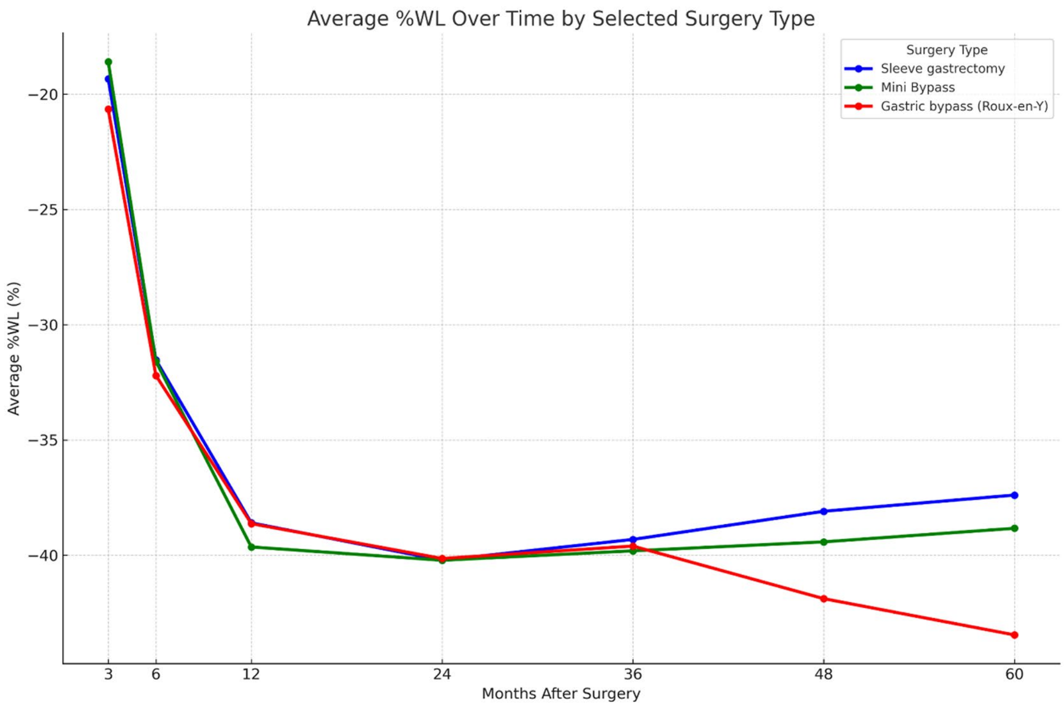


Fig. 1 Comparison of percentage weight loss (%WL) post metabolic bariatric surgery between sleeve gastrectomy, one anastomosis gastric bypass or mini bypass and gastric bypass (Roux-en-Y). Longitudinal analysis of percent weight loss (%WL) at 3, 6, 12, 24, 36, 48, and 60 months after Sleeve Gastrectomy, OAGB, and Gastric Bypass (Roux-en-Y) surgeries. The p-values for differences between surgery types at each time point were calculated using one-way ANOVA: 3 months ($p=0.262$), 6 months ($p=0.905$), 12 months ($p=0.774$), 24 months ($p=0.999$), 36 months ($p=0.963$), 48 months ($p=0.234$), and 60 months ($p=0.349$)

to anatomical complications. Revisions were most frequent in LSG patients, with 10 cases revised to a bypass procedure due to GERD and insufficient weight loss, 7 cases converted to mini bypass due to GERD and weight regain, 1 case requiring resleeve due to inadequate weight loss, and 1 case revised to Roux-en-Y esophagojejunostomy to address severe reflux complications. Non-revised patients, on the other hand, are those who only underwent the primary surgery without the need for further intervention. Differences in %EWL between revised and non-revised patients were analysed for each type of intervention using the Mann-Whitney U test. The p-values refer to these comparisons between the two groups, for each type of surgery at 60 months follow-up. In most of the comparisons, no statistically significant differences emerged. Figure 1S (Supplementary Material) shows the comparison between the effect of SG revisions and that of patients who did not undergo revisions. In addition, a t-test revealed no significant differences in %EWL at 60 months between the revised and non-revised groups (data not shown, $p=0.970$). In the comparison between revised and non-revised RYGB patients (Fig. 2S), the weight loss trajectory differed significantly between the groups.

Nutritional deficiencies and supplements

Figure 2 provides a comprehensive assessment of nutrient deficiencies after various types of MBS, distinguishing between patients who underwent initial surgery and those who required revision. In particular, iron deficiency remains a significant problem in almost all types of surgery. Despite the widespread use of supplements, targeted supplementation shows potential benefits in reducing deficiencies of essential nutrients such as vitamin D and B12, especially in patients who have undergone revisions or more malabsorptive interventions. Furthermore, comparison of initial and revision surgery reveals significant disparities in deficiency rates. For example, patients who underwent SG revision have significantly higher deficiencies in iron, vitamin D and folic acid than those who did not undergo revision. When assessing the occurrence of new nutritional deficiencies after surgery, it is observed that these are relatively lower but still significant in some groups, such as 11.6 per cent new vitamin D deficiencies in patients with unrevised RYGB and 14.3 per cent new iron deficiencies in patients with revised SG. Table 1S provides detailed data on nutrient deficiencies, illustrating higher deficiencies of iron, vitamin D, and folic acid in patients revised from SG to RYGB compared to non-revised patients. The analysis shows that the percentage of supplement use varies significantly between

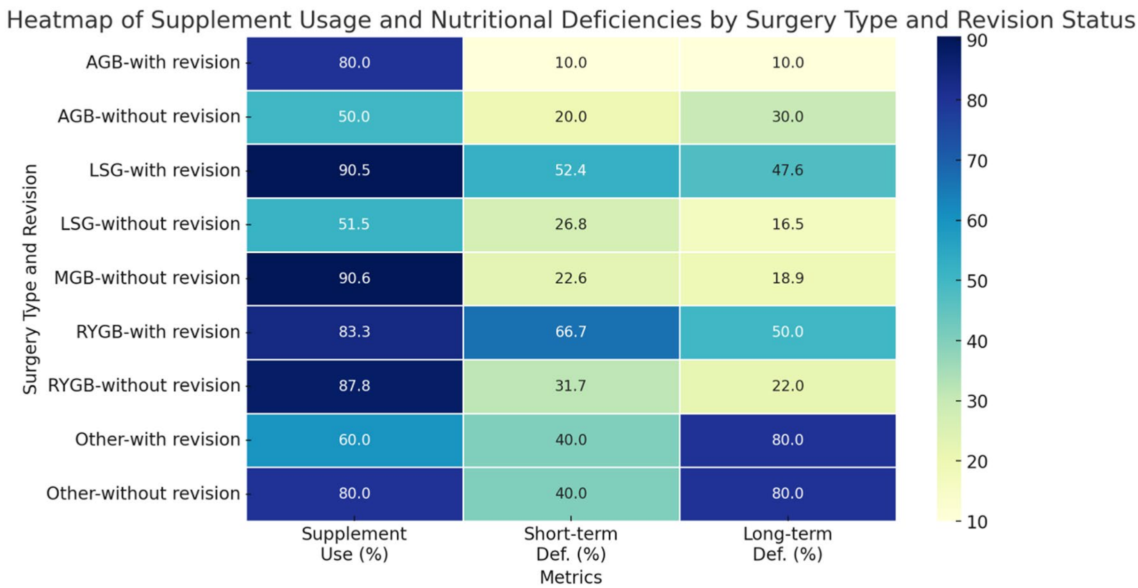


Fig. 2 Heatmap of supplement use and nutritional deficiencies post metabolic bariatric surgery by type of surgery and presence of revisions. The heatmap shows the short- and long-term utilisation rates of supplements and nutritional deficiencies for patients undergoing MBS. The data are broken down by type of surgery: AGB (Adjustable Gastric Banding), SG (Laparoscopic Sleeve Gastrectomy), OAGB (one anastomosis gastric bypass), RYGB (Roux-en-Y Gastric Bypass), and other types of surgery grouped as 'Other'. Other procedures: Vertical Banded Gastroplasty (2 subjects); Biliopancreatic Diversion with Duodenal Switch (2), Endoscopic Sleeve Gastroplasty (ESG) using the OverStitch device (1). Chi-square test was used. Surgery Type vs. Supplement Use ($p = 0.00018$), Surgery Type vs. Long-Term Deficiency ($p = 0.0039$), Revision Status vs. Short-Term Deficiency ($p = 0.0358$), Revision Status vs. Long-Term Deficiency ($p = 0.0019$)

Table 2 Use of supplements in bariatric patients by type of surgery

Type of Surgery	Generic Bariatric Multivitamins	Bariatric-Specific Supplements	Complete Nutritional Support	Generic Multivitamins	Other Supplements	Total Supplement Use (%)
AGB	18.8% ✓	6.2%	12.5%	12.5%	6.2%	**56.2%**
SG	22.0% ↑	1.7%	5.9%	19.5% ✓	7.6%	**56.8%**
OAGB	38.2% ↑↑	20.0% ↑	9.1%	14.5%	3.6%	**85.5%** ↑↑
Other	9.1%	9.1%	36.4% ↑↑	9.1%	0.0%	**63.6%** ↑
RYGB	30.6% ↑	26.5% ↑	2.0%	18.4% ✓	6.1%	**83.7%** ↑↑
Total Use (%)	26.5%	11.2%	7.6%	17.3%	6.0%	**68.7%**

Table 2 presents the percentage of patients using different types of supplements, categorized by type of metabolic bariatric surgery. To improve readability, arrows indicate higher prevalence, and bold text highlights total supplement use per intervention type. Notably, OAGB and RYGB patients reported the highest overall supplement use (85.5% and 83.7%, respectively), with a strong preference for bariatric-specific and generic multivitamins. In contrast, SG and AGB patients exhibited lower rates of bariatric-specific supplement use. The 'Other' category showed the highest use of complete nutritional support (36.4%)

the different types of surgery and between patients with and without revision surgery (Fig. 2). In general, patients undergoing SG and OAGB with revision report a higher use of supplements and a higher incidence of short- and long-term nutritional deficiencies than those without revision. The difference in long-term nutritional deficiencies between intervention types is statistically significant ($p = 0.0039$), as is the difference in short-term ($p = 0.0358$) and long-term ($p = 0.0019$) deficiencies between patients with and without revision intervention.

The analysis reveals significant differences in the use of supplements between the various types of surgery (Table 2). Bariatric-specific supplements are most commonly used in OAGB and RYGB patients, whereas complete nutritional support is prevalent in 'Other' procedures. General multivitamin supplements are used relatively evenly across the different types of surgery, with a slight predominance in SG and RYGB patients.

The analysis indicates varying percentages of nutritional deficiencies associated with different categories of supplements (Table 3). Supplements specifically for MBS show a higher incidence of short-term deficiencies (47.1%) than the other categories. In contrast, multivitamins are associated with the highest long-term deficiencies (46.7%). The most common deficiencies in all categories include iron and vitamin D, reflecting their critical role in post-surgical recovery and health maintenance.

Table 3 Analysis of nutritional deficiencies and supplement use after metabolic bariatric surgery

Supplement Category	Short-term Deficiencies (%)	Short-term Deficiencies °	Long-term Deficiencies (%)	Long-term Deficiencies °
generic bariatric multivitamin supplements	19.1%	Iron (33.3%), Vitamin D (33.3%), Vitamin B12 (13.3%)	20.6%	Iron (36.7%), Vitamin D (20%), Vitamin B12 (16.7%)
bariatric specific supplements	47.1%	Iron (29.2%), Vitamin D (29.2%), Proteins (20.8%)	23.5%	Iron (41.7%), Vitamin D (16.7%), Zinc (16.7%)
complete nutritional support	27.3%	Iron (62.5%), Folic Acid (12.5%), Vitamin B12 (12.5%)	27.3%	Iron (62.5%), Vitamin D (25%), Vitamin B12 (12.5%)
generic multivitamin supplements	33.3%	Vitamin D (33.3%), Iron (33.3%), Calcium (16.7%)	46.7%	Vitamin D (44.4%), Iron (22.2%), Folic Acid (16.7%)
other supplements	40%	Vitamin D (39.1%), Iron (34.8%), Magnesium (13%)	34.3%	Iron (60%), Vitamin D (40%)

The table presents the percentages of short- and long-term nutritional deficiencies associated with each category of supplements taken by patients undergoing metabolic bariatric surgery (MBS). Short-term deficiencies were defined as those occurring within the first 12 months after surgery, while long-term deficiencies were those persisting or emerging beyond 12 months. Deficiencies assessed include iron, vitamin D, vitamin B12, calcium, folic acid, zinc, proteins, and magnesium. Type of supplements: (a) generic bariatric multivitamin supplements generally formulated for patients undergoing MBS without specific adjustments according to the type of surgical intervention; (b) bariatric specific supplements specifically designed to meet the nutritional needs specific to the type of MBS performed; (c) complete nutritional support: This category encompasses patients who require comprehensive supplementation, typically including a multivitamin combined with additional nutrients to address individual deficiencies; (d) generic multivitamin supplements: This group includes all forms of multivitamin supplements, whether standalone or combined with proteins or other components; (e) other supplements: Supplements used to target specific diagnosed deficiencies are categorised here, such as symbiotics, zinc, calcium and Vitamin D, iron supplements, Vitamin C, Omega 3, and folic acid. Only the 3 most common deficiencies (°) for each supplement category are shown to highlight the most clinically relevant outcomes

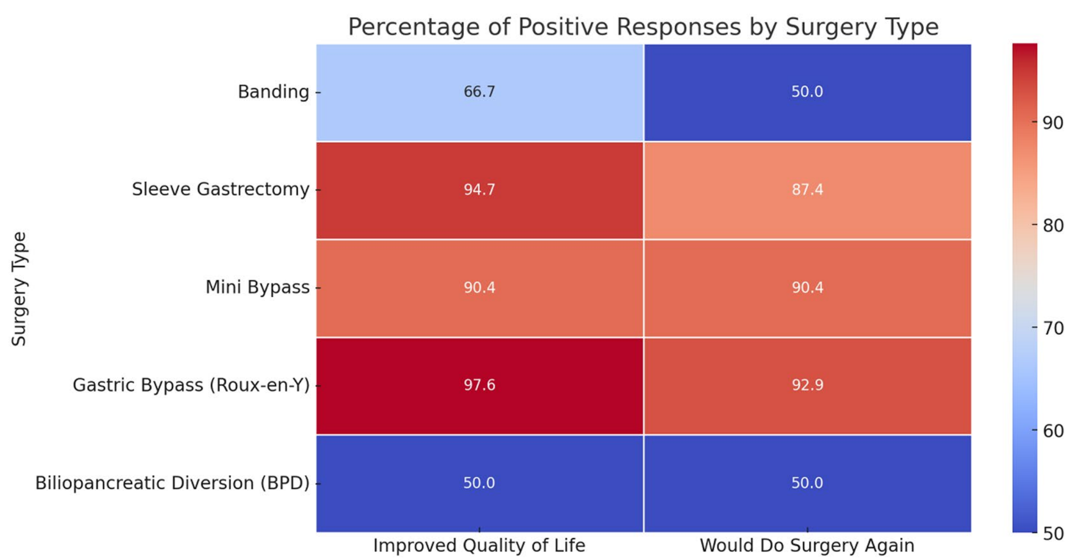


Fig. 3 Impact of surgical type on patient outcomes and satisfaction in metabolic bariatric surgery. Heatmap showing the percentage of positive responses to questions about improvements in quality of life and willingness to undergo the same surgery again, by type of surgical intervention. Chi-squared tests indicate significant differences in responses across surgical types (p-values: Improved Quality of Life: 0.0028; Would Do Surgery Again: 0.0019)

Satisfaction and quality of life

Significant differences were observed in patient-reported improvements in quality of life and willingness to repeat the surgery, with p-values of 0.0028 and 0.0019, respectively. The heatmap visualisation (Fig. 3) clearly indicates higher satisfaction rates in patients undergoing SG, OAGB and RYGB, as reflected by higher percentages of positive responses. The heatmap indicates varied levels of satisfaction across different surgery types, with most showing high satisfaction in quality of life improvements. Willingness to undergo the same surgery again also demonstrated high satisfaction, though some variations exist.

Figure 4 gives an overview of the results reported by patients after the different combinations of MBS revisions, showing a high percentage of patients reporting an improvement in quality of life in all groups. In particular, all patients who underwent Banding with RYGB or OAGB reported a 100% improvement in quality of life and willingness to undergo the surgery again. However, in the LSB plus OAGB group, less willingness to repeat the operation was observed, with only 42.9% of patients opting for reoperation despite a 71.4% improvement in quality of life.

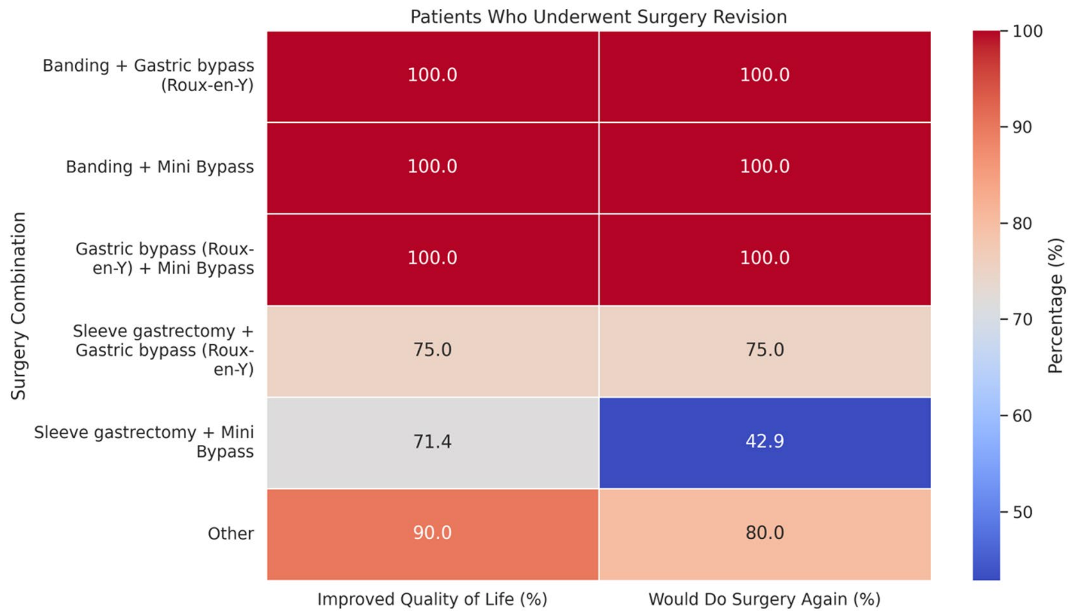


Fig. 4 Outcomes of surgical revision: a heatmap analysis of quality of life and repeat surgery willingness among patients. Heatmap displaying the percentages of patients reporting improved quality of life and willingness to undergo the same surgery again, based on the type of surgical revision. This data includes both specific interventions and an aggregated 'Other' category for less common surgeries. The p-values for improved quality of life and willingness to undergo surgery again are 0.937 and 0.195, respectively. Included surgery combinations for 'Other' are: Sleeve gastrectomy + Esophagojejunostomy, Biliopancreatic diversion (BPD) + Absorption and restriction system with banding, Sleeve gastrectomy + Re-sleeve, Biliopancreatic diversion (BPD) + Gastric bypass (Roux-en-Y), Biliopancreatic diversion (BPD) + Revision to increase absorption, OAGB+ Converted to traditional bypass for biliary reflux, Biliopancreatic Diversion with Duodenal Switch (BPD/DS) + OAGB, Banding + Sleeve gastrectomy, and Overstitch + Gastric bypass (Roux-en-Y)

Discussion

Weight loss outcomes

The comparison of the effectiveness of bariatric surgeries such as SG, OAGB and RYGB is a critical area of study for both clinical practice and patient decision-making. SG and OAGB are both popular choices for bariatric surgery and have been shown to provide substantial benefits in terms of short- and medium-term weight loss [15]. The early results of these procedures provide useful guidance for patients and physicians in choosing the initial intervention, considering factors such as patient preferences, comorbidities and individual metabolic responses [16]. However, while short-term results are often similar, long-term data provide a different perspective, highlighting in particular the superior efficacy of RYGB in maintaining weight loss. Starting in the third year post-intervention, our data shows that patients who have undergone RYGB experienced a more pronounced weight loss, a trend not commonly observed with SG or OAGB [17].

The sustained weight reduction from RYGB likely results from its malabsorptive component, offering a metabolic advantage. Bypassing a portion of the small intestine, absent in SG and OAGB, likely improves long-term control of comorbid conditions such as diabetes and hyperlipidaemia, offering not only weight loss benefits but also broader metabolic improvements [18]. These results are consistent with previous research suggesting that RYGB's dual mechanism of restriction and malabsorption plays a crucial role in its long-term efficacy [19]. In addition to these mechanical effects, RYGB induces significant hormonal changes that further contribute to its success [20]. RYGB lowers ghrelin levels, reducing hunger, while increasing the secretion of glucagon-like peptide 1 (GLP-1) and peptide YY (PYY), key regulators of satiety and glucose homeostasis. Additionally, RYGB enhances bile acid circulation, promoting fat metabolism and stimulating further GLP-1 release, creating a synergistic effect that supports weight loss and broader metabolic improvements. RYGB also raises oxytomodulin (OXM) levels, enhancing satiety, delaying gastric emptying, and improving insulin sensitivity. The combined effect of reduced ghrelin, elevated GLP-1, PYY, and OXM, and bile acid interactions with receptors like TGR5 and FXR, leads to improved glucose and lipid metabolism [21]. Changes in the gut microbiota after RYGB may also contribute to its long-term efficacy. MBS, including RYGB, not only alters the anatomy of the gut, but also significantly remodels the gut microbiota, leading to a beneficial microbial composition associated with metabolic improvements. In particular, RYGB has been associated with alterations in the gut microbiota, including changes in the *Firmicutes*/*Bacteroidetes* ratio, which may influence energy balance and glucose homeostasis. While some studies suggest that an increased

Firmicutes-to-Bacteroidetes ratio may be linked to greater energy harvest and obesity, the direct association between shifts in this ratio and increased energy expenditure in humans remains unclear. Magne et al. [22] highlighted the variability in findings across studies, emphasizing that the Firmicutes/Bacteroidetes ratio alone may not be a definitive marker of metabolic adaptations following surgery. Further research is needed to elucidate the causal relationship between gut microbiota composition and energy metabolism post-RYGB. Furthermore, RYGB can promote the proliferation of beneficial bacteria such as *Akkermansia muciniphila*, which has been associated with improved metabolic health. For instance, Depommier et al. [23] demonstrated that supplementation with pasteurized A. muciniphila improved insulin sensitivity and reduced plasma cholesterol levels in overweight and obese individuals, suggesting a role in enhancing metabolic functions. However, despite these positive changes, the gut microbiota does not fully recover after surgery and dysbiosis may persist, contributing to micronutrient deficiencies that require long-term supplementation and careful dietary management [24–27]. AGB is known to produce lower long-term weight loss than procedures such as RYGB and SG. The main reason is its restrictive mechanism, which does not address the malabsorptive component that contributes to the success of the other procedures. Therefore, in this study, we presented the results of AGB separately to avoid inappropriate comparisons. The lower %EWL observed in patients with AGB is in line with the expected results of this procedure, further supporting the abandonment of its use in favour of more effective bariatric techniques. Our data corroborate the findings of Yilmaz et al. [28], who reported the need for revision after SG due to insufficient weight loss, weight recovery and problems such as gastroesophageal reflux disease (GERD). In our cohort, as in Yilmaz's study, revision from SG to RYGB resulted in better outcomes than other revision options, supporting the effectiveness of RYGB as a revision strategy. Although no significant differences in long-term %WL emerged between the revised and non-revised groups (Fig. 1s), patients revised to RYGB showed a more favourable weight loss trajectory, consistent with Yilmaz's observations regarding the metabolic benefits of RYGB, especially in cases of GERD and high-calorie food consumption. Given the higher success rate observed with RYGB revisions, this may be considered the preferred revision strategy, particularly for patients who have achieved suboptimal results from SG [27]. Interestingly, as shown in Fig. 2S, patients undergoing RYGB revision initially have a more pronounced %WL than non-revised patients, with significant differences emerging as early as 6 months and persisting up to 36 months. However, from 48 months onwards, the difference between the two groups tends to decrease, indicating that the effect of revision may stabilise in the long term, with a levelling off of weight loss results. This reflects what Alexandrou et al. [29] reported, which highlights the complexity of managing patients with post-RYGB failure. Although revisions may temporarily improve weight loss, long-term success depends not only on the choice of procedure, but also on nutritional management and post-operative follow-up [30].

Nutritional deficiencies

Changes in gastrointestinal anatomy and nutrient absorption following bariatric surgery significantly impact micronutrient status, particularly for iron and vitamin D. Iron deficiency is among the most prevalent long-term complications, with prevalence rates ranging from 18 to 53% after RYGB and 1–54% after SG, due to bypassing the duodenum and reduced gastric acid secretion, both of which are crucial for iron absorption [31]. Despite routine supplementation, persistent deficiencies remain an issue, particularly in revision patients, as observed in our cohort (41.2% iron deficiency in SG-to-RYGB revisions). Prior studies confirm that post-RYGB patients require higher iron supplementation due to impaired absorption compared to SG patients [32]. Similarly, vitamin D deficiency is highly prevalent both pre- and post-surgery, affecting up to 80% of MBS patients prior to intervention. Postoperatively, the reduced capacity for vitamin D absorption, coupled with limited dietary intake and altered fat metabolism, exacerbates this deficiency, particularly in malabsorptive procedures such as RYGB and BPD [33]. Our results further highlight that long-term vitamin D deficiency remains a concern even in non-revised patients, with 11.6% of unrevised RYGB patients developing new deficiencies. This aligns with reports showing that patients undergoing bariatric surgery require higher doses of vitamin D supplementation to maintain adequate serum levels [34]. The prevalence of iron deficiency after RYGB and SG ranges from 18 to 53% and 1 to 54% respectively [35]. Our results suggest the need for more aggressive or alternative supplementation strategies to address this ongoing challenge. Interestingly, the use of specific supplements for MBS does not seem to offer significant advantages over generic multivitamins. Patients undergoing revision surgery require particular attention; in our cohort, iron deficiency rose from 17.7 to 41.2% in those revised from SG to RYGB. Duodenum bypass in RYGB and reduced gastric acid production both contribute to iron absorption problems [36]. Despite targeted supplementation, iron deficiency remains common, stressing the need for ongoing monitoring and alternative approaches.

In our study, a long-term deficiency of crucial nutrients such as vitamin D and B12 was observed. Our results reveal significant disparities in deficiency rates between initial surgery and subsequent revisions. In particular, patients undergoing revision SG have greater vitamin D and folic acid deficiencies than their non-revised counterparts [37]. This is in line with studies suggesting that surgical revisions may further alter intestinal homeostasis, possibly intensifying malabsorption problems [38]. Although in the case of severely malnourished patients (especially in the case of BPD) revision can be effective in discontinuing supportive nutrition [39]. Furthermore, the occurrence of new nutritional deficiencies after surgery, although relatively low, remains clinically significant. For example, 11.6% of patients with unrevised RYGB develop new vitamin D deficiencies and 14.3% of patients with revised SG report new iron deficiencies. These results are of particular concern because they suggest that surgery may induce new metabolic demands or malabsorption problems that were not present prior to surgery, even in patients compliant with prescription supplements. Longitudinal studies have documented similar trends, in which patients develop new deficiencies several years after surgery, necessitating ongoing nutritional assessments and interventions [40, 41].

Supplementation and recommendations

The data in Tables 2 and 3 indicate that there are no significant differences in efficacy between generic multivitamin supplements for bariatric use, specific supplements for bariatric use and complete nutritional support, as all show comparable short- and long-term deficiency rates. This suggests that each of these types of supplements, whether specifically designed for bariatric patients or providing a more comprehensive range of nutrients, tend to perform similarly in meeting nutritional needs postoperatively. Our data are in contrast to the results of a previous study [42], which found that formulated vitamins had no significant differences in micronutrient levels or costs compared to separate standard vitamin supplements. However, the study also found that formulated bariatric vitamins improved patient compliance. This suggests that although the biochemical efficacy of formulated and separate supplements may be comparable, the convenience and personalised nature of formulated bariatric vitamins appear to improve patient adherence to the supplementation regimen [43]. Therefore, the type of supplement may affect not just nutrition, but also patient adherence and recovery. On the other hand, generic multivitamin supplements show lower efficacy, indicated by higher long-term deficiency rates. This may be due to their less targeted nature, which may not meet the more specific and sometimes more severe nutritional needs after MBS. This highlights the need for more specialised multivitamin formulations to better meet the unique challenges faced by patients undergoing MBS, reinforcing the importance of choosing the right type of supplement for optimal post-operative nutritional management [44]. While our results suggest that bariatric-specific supplements did not offer significant advantages over generic multivitamins, it is important to consider that 16.9% of patients had pre-existing nutritional deficiencies before undergoing MBS. This could indicate that some deficiencies originate preoperatively rather than being solely a consequence of surgery. Identifying and correcting these deficiencies before intervention may enhance post-surgical nutritional outcomes, an aspect that future research should investigate. Post-bariatric surgery patients face the dual challenge of preventing nutritional deficiencies while preserving lean body mass, particularly given the risk of sarcopenic obesity. As highlighted before, sarcopenic obesity results from a combination of muscle loss and excess adiposity, which may be exacerbated by inadequate protein intake and suboptimal micronutrient status [45].

Figure 4 shows higher satisfaction rates in patients undergoing SG, OAGB and RYGB, indicated by high percentages of positive responses. This higher satisfaction is probably related to the lower nutritional deficiencies observed with these types of procedures compared to procedures such as BPD and the limited efficacy in weight loss observed with banding procedures. The heat map shows varying satisfaction levels across interventions, with most reporting high satisfaction and improved quality of life.

Patients' satisfaction

SG, OAGB and RYGB, reported a 100% improvement in quality of life and an equivalent willingness to undergo surgery again. This unanimous positive feedback underlines the effectiveness of these combined procedures in improving patient satisfaction and overall quality of life after surgery. This higher satisfaction is probably related to the lower nutritional deficiencies observed in these types of intervention compared to procedures such as BPD and the limited effectiveness in weight loss observed with banding procedures [46]. In contrast, SG combined with OAGB shows a significant disparity between the reported improvement in quality of life (71.4%) and the willingness to undergo the same procedure again (42.9%). This gap may reflect issues beyond improvements in physical health, such as the surgical experience, the recovery process, long-term complications, or unfulfilled expectations regarding results. Furthermore, psychological factors such as mood disorders and patient attitude play a crucial role in determining adherence to lifestyle changes after surgery. Addressing these aspects through psychological interventions is essential to improve general well-being and quality of life. Improvements in mental health conditions, probably brought about by weight loss, hormonal changes and strengthening of self-esteem and body image after the intervention, further contribute to improved long-term health outcomes. This underlines the importance of a holistic approach in MBS care, including both medical and psychological support to optimise patient outcomes [47].

Limitations and future directions

This study has several limitations. Firstly, the retrospective design limits the ability to establish causality between the type of intervention and long-term outcomes such as weight loss and nutritional deficiencies. Furthermore, we did not use a validated instrument such as the BAROS questionnaire to assess patient outcomes. Instead, we used a simple, customised survey tailored to the specific needs of our cohort. In future studies, we plan to integrate validated instruments such as BAROS to improve the comparability and robustness of our results. Second, the use of self-reported data for supplement intake and patient satisfaction introduces the potential for recall bias. Self-reported adherence to supplementation regimens may be subject to overestimation, and subjective assessments of quality of life can be influenced by personal expectations and cognitive biases. Future studies should consider integrating objective monitoring systems, such as electronic medical records, automated supplement tracking, or direct biochemical assessments, to improve data accuracy and reduce reliance on patient-reported outcomes. Comparison with clinical parameters, including serum micronutrient levels, could further validate self-reported supplementation adherence and deficiency rates, enhancing the robustness of future analyses. Third, the predominantly white European population limits the generalisability of our results to more diverse populations. The substantial gender imbalance in our cohort, with females comprising 95.6% of the sample, is consistent with the higher prevalence of bariatric surgery among women. However, this limited male representation (4.4%) constrains our ability to analyze potential gender differences in surgical outcomes, nutritional deficiencies, and patient satisfaction. Previous studies suggest that sex-specific hormonal, metabolic, and behavioral factors may influence weight loss trajectories and micronutrient status post-surgery. While our data predominantly reflect female patients, a more gender-balanced sample would provide valuable insights into differential responses to MBS. Future research should consider stratified analyses or targeted recruitment of male patients to better elucidate these differences. Additionally, qualitative studies focusing on the lived experiences of male MBS patients could help uncover unique barriers and adherence challenges in this population. The cohort's heterogeneity, with different procedures over five years, limits direct comparisons. Although this reflects real-world clinical practice, it limits direct comparison between procedures. To overcome this problem, we performed a multivariable regression analysis to adjust for baseline differences, but future studies should focus on more homogeneous cohorts or analyses stratified by procedure type to minimise this problem. Furthermore, the use of a simple, personalised questionnaire to assess quality of life may not have captured all aspects of the post-surgical experience as comprehensively as validated instruments would. Thus, Dietary factors influence gut microbiota and metabolism, but we did not systematically assess dietary intake post-surgery. Future studies should integrate detailed dietary assessments to better understand diet-microbiota interactions after RYGB. While we assessed long-term nutritional outcomes and supplement adherence, we did not collect specific data on food tolerability, particularly during the first year after MBS. Early post-surgical dietary tolerance can influence nutrient intake, compliance with supplementation, and overall patient adaptation to dietary recommendations. Additionally, we did not investigate specific dietary patterns, such as adherence to a plant-based diet, which could impact micronutrient status and long-term metabolic outcomes. Given the growing interest in sustainable nutrition and the role of plant-based protein sources in maintaining muscle mass post-MBS, future studies should explore the impact of legume consumption on nutritional adequacy in bariatric patients [48] highlight the importance of culinary and educational strategies to enhance legume intake, which could be particularly relevant for post-bariatric dietary recommendations.Finally, the small number of patients undergoing revision surgery reduces the statistical power of comparisons between groups. Although these preliminary results provide insight into potential differences in outcomes, larger samples and the use of validated questionnaires in future research will help to confirm these findings and strengthen statistical analyses.

To provide practical clinical insights based on our findings, Table 4 summarizes our key recommendations for optimizing long-term MBS outcomes, with a focus on supplement use, monitoring for deficiencies, and managing revisions.

Conclusions

Our study emphasises the importance of personalised nutritional management and careful selection of surgical techniques to optimise the long-term outcome of MBS. Persistent nutritional deficiencies, particularly of iron, vitamin D and B12, highlight the need for customised supplementation protocols and long-term monitoring. The efficacy of RYGB, especially in reviews, demonstrates the critical role of choosing the right surgical strategy, while recognising the associated nutritional challenges.

Table 4 Key recommendations for optimizing post-MBS nutritional management and surgical outcomes

Category	Recommendation	Rationale
Supplementation	Ensure continuous, tailored multivitamin and mineral supplementation for all patients post-surgery.	Persistent deficiencies (e.g., iron, vitamin D) highlight the need for ongoing, individualized support.
Iron Deficiency	Monitor iron levels regularly, especially after RYGB and in revision patients.	Our data showed higher rates of deficiency in RYGB (41.7%) and revisions, requiring careful follow-up.
Vitamin D Deficiency	Pay particular attention to vitamin D levels, even pre-surgery.	Vitamin D deficiencies appear prevalent even preoperatively and do not significantly worsen post-surgery.
Revision Surgeries	Consider RYGB as a preferred revision option, particularly for patients experiencing weight regain.	Patients revised to RYGB demonstrated better weight loss outcomes compared to other revision strategies.
Patient Follow-Up	Implement regular long-term nutritional assessments post-surgery, especially for revision patients.	Long-term deficiencies can develop or worsen after revisions, requiring ongoing monitoring and interventions.
Supplement Choice	Encourage the use of bariatric-specific supplements when possible.	Bariatric-specific supplements, though not always superior, may improve adherence and long-term deficiency outcomes.
Quality of Life	Address both physical and psychological aspects in patient follow-up.	Improved quality of life is linked to both nutritional management and psychological support post-surgery.

Summary of the main recommendations based on the study results, focusing on post-surgical nutritional management, monitoring and supplement use. These recommendations emphasise the importance of individualised supplementation, regular nutritional assessments and careful selection of revision strategies to address long-term deficiencies and ensure optimal outcomes for patients undergoing both primary and revision MBS procedures

Future research should focus on larger cohorts and validated tools to further these findings and refine clinical guidelines for primary and revision interventions.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12967-025-06224-9.

Supplementary Material 1

Author contributions

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Data availability

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The study protocol conformed to the ethical guidelines of the 1975 Declaration of Helsinki and was approved by the Lazio Area 5 Territorial Ethics Committee (100/SR/24). All participants provided written informed consent before being included in the study.

Consent for publication

All authors and participants have provided consent for the publication of this manuscript and its findings.

Competing interests

The authors declare that they have no competing interests.

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References

1. Global BMIM, Di Collaboration E, Bhupathiraju SN, Wormser D, Gao P, Kaptoge S, Berrington de Gonzalez A, Cairns BJ, Huxley R, Jackson CL, Joshy G, Lewington S, Manson JE, Murphy N, Patel AV, Samet JM, Woodward M, Zheng W, Zhou M, Bansal N, Barricarte A, Carter B, Cerhan JR, Smith GD, Fang X, Franco OH, Green J, Halsey J, Hildebrand JS, Jung KJ, Korda RJ, McLerran DF, Moore SC, O'Keeffe LM, Paige E, Ramond A, Reeves GK, Rolland B, Sacerdote C, Sattar N, Sofianopoulou E, Stevens J, Thun M, Ueshima H, Yang L, Yun YD, Willeit P, Banks E, Beral V, Chen Z, Gapstur SM, Gunter MJ, Hartge P, Jee SH, Lam TH, Peto R, Potter JD, Willett WC, Thompson SG, Danesh J, Hu FB. Body-mass index and all-cause mortality: individual-participant-data meta-analysis of 239 prospective studies in four continents. Lancet. 2016;388(10046):776–86. https://doi.org/10.1016/S0140-6736(16)30175-1. Epub 2016 Jul 13. PMID: 27423262; PMCID: PMC4995441.
2. Cosentino C, Marchetti C, Monami M, Mannucci E, Cresci B. Efficacy and effects of bariatric surgery in the treatment of obesity: Network meta-analysis of randomized controlled trials. Nutr Metab Cardiovasc Dis. 2021;31(10):2815–24. https://doi.org/10.1016/j.numecd.2021.06.018. Epub 2021 Jul 2. PMID: 34348877.
3. Courcoulas AP, Johnson E, Arterburn DE, Haneuse S, Herrinton LJ, Fisher DP, Li RA, Theis MK, Liu L, Taylor B, Cooper J, Chin PL, Grinberg GG, Gupta A, Saurabh S, Um SS, Yenumula PR, Zelada JL, Coleman KJ. Reduction in long-term Mortality after Sleeve Gastrectomy and gastric bypass compared to nonsurgical patients with severe obesity. Ann Surg. 2023;277(3):442–8. https://doi.org/10.1097/SLA.0000000000005155. Epub 2021 Aug 13. PMID: 34387200; PMCID: PMC8840990.
4. Gulinac M, Miteva DG, Peshevska-Sekulovska M, Novakov IP, Antovic S, Peruhova M, Snegarova V, Kabakchieva P, Assyov Y, Vasilev G, Sekulovski M, Lazova S, Tomov L, Velikova T. Long-term effectiveness, outcomes and

complications of bariatric surgery. World J Clin Cases. 2023;11(19):4504–12. https://doi.org/10.12998/wjcc.v11.i19.4504. PMID: 37469732; PMCID: PMC10353499.

5. Wang Y, Guo X, Lu X, Mattar S, Kassab G. Mechanisms of weight loss after sleeve gastrectomy and adjustable gastric banding: Far more than just restriction. Obes (Silver Spring). 2019;27(11):1776–83. https://doi.org/10.1002/oby.22623. Epub 2019 Sep 23. PMID: 31545007.
6. Mahawar KK, Sharples AJ. Contribution of Malabsorption to Weight Loss After Roux-en-Y Gastric Bypass: a Systematic Review. Obes Surg. 2017;27(8):2194–2206. https://doi.org/10.1007/s11695-017-2762-y. PMID: 28585108.
7. Anderson B, Gill RS, de Gara CJ, Karmali S, Gagner M. Biliopancreatic diversion: the effectiveness of duodenal switch and its limitations. Gastroenterol Res Pract. 2013;2013:974762. https://doi.org/10.1155/2013/974762. Epub 2013 Nov 21. PMID: 24639868; PMCID: PMC3929999.
8. Noria SF, Shelby RD, Atkins KD, Nguyen NT, Gadde KM. Weight regain after bariatric surgery: scope of the Problem, causes, Prevention, and treatment. Curr Diab Rep. 2023;23(3):31–42. https://doi.org/10.1007/s11892-023-01498-z. Epub 2023 Feb 8. PMID: 36752995; PMCID: PMC9906605.
9. Lombardo M, Franchi A, Biolcati Rinaldi R, Rizzo G, D'Adamo M, Guglielmi V, Bellia A, Padua E, Caprio M, Sbraccia P. Long-term Iron and vitamin B12 Deficiency are Present after bariatric surgery, despite the widespread use of supplements. Int J Environ Res Public Health. 2021;18(9):4541. https://doi.org/10.3390/ijerph18094541. PMID: 33922904; PMCID: PMC8123142.
10. Gu L, Huang X, Li S, Mao D, Shen Z, Khadaroo PA, Ng DM, Chen P. A meta-analysis of the medium- and long-term effects of laparoscopic sleeve gastrectomy and laparoscopic Roux-en-Y gastric bypass. BMC Surg. 2020;20(1):30. https://doi.org/10.1186/s12893-020-00695-x. PMID: 32050953; PMCID: PMC7014764.
11. Dogan K, Homan J, Aarts EO, de Boer H, van Laarhoven CJHM, Berends FJ. Long-term nutritional status in patients following Roux-en-Y gastric bypass surgery. Clin Nutr. 2018;37(2):612–617. https://doi.org/10.1016/j.clnu.2017.01.022. Epub 2017 Feb 3. PMID: 28202272.
12. Heusschen L, Berendsen AAM, Deden LN, Hazebroek EJ, Aarts EO. Nutritional deficiencies 3 years after Sleeve Gastrectomy can be limited by a Specialized Multivitamin supplement. Obes Surg. 2022;32(11):3561–70. https://doi.org/10.1007/s11695-022-06256-w. Epub 2022 Aug 26. PMID: 36018421; PMCID: PMC9613574.
13. Ben-Porat T, Weiss R, Sherf-Dagan S, Nabulsi N, Maayani A, Khalaileh A, Abed S, Brodie R, Harari R, Mintz Y, Pikarsky AJ, Elazary R. Nutritional deficiencies in patients with severe obesity before bariatric surgery: what should be the Focus during the Preoperative Assessment? J Acad Nutr Diet. 2020;120(5):874–84. Epub 2019 Dec 28. PMID: 31892499.
14. Basolo A, Bechi Genzano S, Vitti J, et al. Efficacy of multivitamin support following bariatric surgery in patients with obesity: a prospective observational study. Eat Weight Disord. 2024;29:34. https://doi.org/10.1007/s40519-024-01655-7.
15. Brethauer SA, Kim J, el Chaar M, Papasavas P, Eisenberg D, Rogers A, et al. Standardized outcomes reporting in metabolic and bariatric surgery. Surg Obes Relat Dis. 2015;11:489–506.
16. Jain M, Tantia O, Goyal G, Chaudhuri T, Khanna S, Poddar A, Majumdar K, Gupta S. Obes Surg. 2021;31(3):1223–32. https://doi.org/10.1007/s11695-020-05119-6. Epub 2020 Nov 16. PMID: 33200309. LSG vs MGB-OAGB: 5-Year Follow-up Data and Comparative Outcome of the Two Procedures over Long Term-Results of a Randomised Control Trial.
17. Pereira SS, Guimarães M, Monteiro MP. Towards precision medicine in bariatric surgery prescription. Rev Endocr Metab Disord. 2023;24:961–77. https://doi.org/10.1007/s11154-023-09801-9.
18. Guimarães M, Osório C, Silva D, Almeida RF, Reis A, Cardoso S, Pereira SS, Monteiro MP, Nora M. How sustained is Roux-en-Y gastric bypass long-term efficacy? Roux-en-Y gastric bypass efficacy. Obes Surg. 2021;31(8):3623–9. https://doi.org/10.1007/s11695-021-05458-y. Epub 2021 May 22. PMID: 34021884; PMCID: PMC8270797.
19. Lager CJ, Esfandiari NH, Luo Y, Subauste AR, Kraftson AT, Brown MB, Varban OA, Meral R, Cassidy RB, Nay CK, Lockwood AL, Bellers D, Buda CM, Oral EA. Metabolic parameters, weight loss, and Comorbidities 4 years after Roux-en-Y gastric bypass and Sleeve Gastrectomy. Obes Surg. 2018;28(11):3415–23. https://doi.org/10.1007/s11695-018-3346-1. PMID: 29909517; PMCID: PMC8933864.
20. Tadross JA, le Roux CW. The mechanisms of weight loss after bariatric surgery. Int J Obes (Lond). 2009;33 Suppl 1:S28-32. https://doi.org/10.1038/ijo.2009.14. PMID: 19363504.
21. Pucci A, Batterham RL. Mechanisms underlying the weight loss effects of RYGB and SG: similar, yet different. J Endocrinol Invest. 2019;42(2):117–28. https://doi.org/10.1007/s40618-018-0892-2. Epub 2018 May 5. PMID: 29730732; PMCID: PMC6394763.
22. Magne F, Gotteland M, Gauthier L, Zazueta A, Pesoa S, Navarrete P, Balamurugan R. The Firmicutes/Bacteroidetes ratio: a relevant marker of gut dysbiosis in obese patients? Nutrients. 2020;12(5):1474. https://doi.org/10.3390/nu12051474. PMID: 32438689; PMCID: PMC7285218.
23. Depommier C, Van Hul M, Everard A, Delzenne NM, De Vos WM, Cani PD. Pasteurized Akkermansia muciniphila increases whole-body energy expenditure and fecal energy excretion in diet-induced obese mice. Gut Microbes. 2020;11(5):1231–45. https://doi.org/10.1080/19490976.2020.1737307.
24. Basolo A, Hohenadel M, Ang QY, et al. Effects of underfeeding and oral Vancomycin on gut microbiome and nutrient absorption in humans. Nat Med. 2020;26:589–98. https://doi.org/10.1038/s41591-020-0801-z.
25. Martinou E, Stefanova I, Iosif E, Angelidi AM. Neurohormonal changes in the gut–brain Axis and underlying neuroendocrine mechanisms following bariatric surgery. Int J Mol Sci. 2022;23:3339. https://doi.org/10.3390/ijms23063339.
26. Ciobârcă D, Cătoi AF, Copăescu C, Miere D, Crişan G. Bariatric surgery in obesity: effects on Gut Microbiota and Micronutrient Status. Nutrients. 2020;12(1):235. https://doi.org/10.3390/nu12010235. PMID: 31963247; PMCID: PMC7019602.
27. Zambrano AK, Paz-Cruz E, Ruiz-Pozo VA, Cadena-Ullauri S, Tamayo-Trujillo R, Guevara-Ramírez P, Zambrano-Villacres R, Simancas-Racines D. Microbiota dynamics preceding bariatric surgery as obesity treatment: a comprehensive review. Front Nutr. 2024;11:1393182. https://doi.org/10.3389/fnut.2024.1393182. PMID: 38633602; PMCID: PMC11021787.
28. Yilmaz H, Ece I, Sahin M. Revisional Surgery After Failed Laparoscopic Sleeve Gastrectomy: Retrospective Analysis of Causes, Results, and Technical Considerations. Obes Surg. 2017;27(11):2855–2860. https://doi.org/10.1007/s11695-017-2712-8. PMID: 28493043.
29. Alexandrou A, Sakarellos P, Davakis S, Vailas M, Dimitriou N, Papalampros A, Schizas D, Charalabopoulos A, Felekouras E. Revision of Roux-en-Y Gastric Bypass for Inadequate Weight Loss or Weight Regain. In Vivo. 2022 Jan-Feb;36(1):30–39. https://doi.org/10.21873/invivo.12673. PMID: 34972697; PMCID: PMC8765156.
30. Dang JT, Vaughan T, Mocanu V, Mubashir H, Barajas-Gamboa JS, Codina RC, Rodriguez J, Karmali S, Kroh M. Conversion of Sleeve Gastrectomy to roux-en-Y gastric bypass: indications, prevalence, and Safety. Obes Surg. 2023;33(5):1486–93. https://doi.org/10.1007/s11695-023-06546-x. Epub 2023 Mar 15. PMID: 36922465; PMCID: PMC10017068.
31. Lombardo M, Franchi A, Biolcati Rinaldi R, Rizzo G, D'Adamo M, Guglielmi V, Bellia A, Padua E, Caprio M, Sbraccia P. Long-term Iron and vitamin B12 Deficiency are Present after bariatric surgery, despite the widespread use of supplements. Int J Environ Res Public Health. 2021;18:4541. https://doi.org/10.3390/ijerph18094541.
32. 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. 2021;12:679066. https://doi.org/10.3389/fendo.2021.679066.
33. Lespessailles E, Toumi H. Vitamin D alteration associated with obesity and bariatric surgery. Exp Biol Med (Maywood). 2017;242(10):1086–1094. doi: 10.1177/1535370216688567. Epub 2017 Jan 1. PMID: 28103699; PMCID: PMC5444639.
34. Lanzarini E, Nogués X, Goday A, Benaiges D, de Ramón M, Villatoro M, Pera M, Grande L, Ramón JM. High-Dose Vitamin D Supplementation is Necessary After Bariatric Surgery: A Prospective 2-Year Follow-up Study. Obes Surg. 2015;25(9):1633-8. https://doi.org/10.1007/s11695-015-1572-3. PMID: 25596938.
35. Lombardo M, Franchi A, Padua E, Guglielmi V, D'Adamo M, Annino G, et al. Potential nutritional deficiencies in obese subjects 5 years after bariatric surgery. Bariatr Surg Pract Patient Care. 2019;14(3). https://doi.org/10.1089/bari.2019.0009.
36. Steenackers N, Van der Schueren B, Mertens A, et al. Iron deficiency after bariatric surgery: what is the real problem? Proc Nutr Soc. 2018;77(4):445–55. https://doi.org/10.1017/S0029665118000149.
37. Steenackers N, Vanuytsel T, Augustijns P, Tack J, Mertens A, Lannoo M, Van der Schueren B, Matthys C. Adaptations in gastrointestinal physiology after sleeve gastrectomy and Roux-en-Y gastric bypass. Lancet Gastroenterol Hepatol. 2021;6(3):225–237. https://doi.org/10.1016/S2468-1253(20)30302-2. PMID: 33581761.

38. 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;16(2):e55062. https://doi.org/10.7759/cureus.55062. PMID: 38550458; PMCID: PMC10977614.
39. Gehrer S, Kern B, Peters T, et al. Fewer nutrient deficiencies after laparoscopic sleeve gastrectomy (LSG) than after laparoscopic Roux-Y-Gastric bypass (LRYGB)—a prospective study. OBES SURG. 2010;20:447–53. https://doi.org/10.1007/s11695-009-0068-4.
40. Lourensz K, Himantoko I, Shaw K, et al. Long-term outcomes of Revisional Malabsorptive bariatric surgery: do the benefits outweigh the risk? OBES SURG. 2022;32:1822–30. https://doi.org/10.1007/s11695-022-06019-7.
41. Vahibe A, Aizpuru MJ, Sarr MG, Mundi MS, Vierkant RA, McKenzie T, Abu Dayyeh BK, Ghanem OM. Safety and Efficacy of Revisional surgery as a treatment for Malnutrition after bariatric surgery. J Am Coll Surg. 2023;236(1):156–66. Epub 2022 Dec 15. PMID: 36102543.
42. Aderinto N, Olatunji G, Kokori E, Olaniyi P, Isarinade T, Yusuf IA. Recent advances in bariatric surgery: a narrative review of weight loss procedures. Ann Med Surg (Lond). 2023;85(12):6091–104. https://doi.org/10.1097/MS9.0000000000001472. PMID: 38098582; PMCID: PMC10718334.
43. Ba DM, Hu A, Shen C, Leslie DL, Chinchilli VM, Rogers AM, Al-Shaar L. Trends and predictors of nutritional deficiencies after bariatric surgeries: analysis of real-world data. Surg Obes Relat Dis. 2023;19(9):935–43. Epub 2023 Feb 23. PMID: 37005153.
44. Wong DH, Kim E, Rim DS, Sharma K, Tran T, Shin JH, Kim DW. Evaluating the compliance, efficacy, and cost of formulated vitamins Versus separate supplements in post-bariatric surgery patients. Obes Surg. 2023;33(10):3127–32. https://doi.org/10.1007/s11695-023-06802-0. Epub 2023 Aug 26. PMID: 37632584.
45. Lombardo M, Boaria A, Aulisa G, Padua E, Annino G, Pratesi A, Caprio M, Iellamo F, Bellia A. Sarcopenic obesity: etiology and lifestyle therapy. Eur Rev Med Pharmacol Sci. 2019;23(16):7152–7162. https://doi.org/10.26355/eurrev_201908_18761. PMID: 31486518.
46. El Ansari W, Elhag W. Weight regain and Insufficient Weight loss after bariatric surgery: definitions, prevalence, mechanisms, predictors, Prevention and Management Strategies, and knowledge Gaps-a scoping review. Obes Surg. 2021;31(4):1755–66. https://doi.org/10.1007/s11695-020-05160-5. Epub 2021 Feb 8. PMID: 33555451; PMCID: PMC8012333.
47. Jumbe S, Hamlet C, Meyrick J. Psychological aspects of bariatric surgery as a treatment for obesity. Curr Obes Rep. 2017;6:71–8. https://doi.org/10.1007/s13679-017-0242-2.
48. Amoah I, Ascione A, Muthanna FMS, Feraco A, Camajani E, Gorini S, Armani A, Caprio M, Lombardo M. Sustainable strategies for increasing Legume Consumption: Culinary and Educational approaches. Foods. 2023;12:2265. https://doi.org/10.3390/foods12112265.

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