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Original Article

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Nutritional Deficiencies Before and After Metabolic and Bariatric Surgery in Patients Above 50.0 kg/m²: A Single Center Study

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ABSTRACT

Purpose: Metabolic and bariatric surgery (MBS) is an effective treatment for patients with body mass index (BMI) above 50.0 kg/m² but nutritional deficiencies (ND) may arise. This study aimed to assess if patients with BMI above 50.0 kg/m² have more ND and require more supplementation after MBS compared to patients in lower BMI groups.
Materials and Methods: Retrospective single center study including all patients submitted to MBS from 2019–2020. Several parameters were collected. Statistical analysis was performed to compare ND between BMI groups (<40.0 kg/m²; 40.0 to 49.9 kg/m²; ≥50.0 kg/m²), and between surgeries (Roux-en-Y gastric bypass [RYGB] vs. sleeve gastrectomy [SG]) in the group with BMI ≥50.0 kg/m².
Results: We identified 951 patients, 85 (9.0%) with BMI ≥50.0 kg/m², with RYGB performed in 644 (68.4%) patients. Pre-operatively, vitamin D deficiency was observed in 80.0% of patients with BMI ≥50.0 kg/m², with significant differences between BMI groups. At follow-up there were no significant differences in ND according to BMI groups. In patients with BMI ≥50.0 kg/m², vitamin B12 deficiency was more frequent after RYGB. At 2-year follow-up, 95.4% patients were taking multivitamin supplementation, and 52.4% required additional supplements, namely vitamin D.
Conclusion: ND are common in patients with BMI ≥50.0 kg/m², even before MBS. After surgery, patients with BMI ≥50.0 kg/m² may not have increased risk for ND, compared to other BMI groups. In these patients, RYGB resulted in an increased risk for vitamin B12 deficiency. Adequate supplementation and clinical follow-up are essential to mitigate these complications.

Keywords: Bariatric surgery; Severe obesity; Nutritional deficiencies

INTRODUCTION

The prevalence of obesity is steadily increasing worldwide. The World Health Organization recognizes obesity as a major health concern with pandemic proportions, with one in 8 people globally affected by obesity in 2022 [1].

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Conflict of Interest
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Author Contributions
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Alarmingly, the rising prevalence of obesity has also contributed to an increase in the incidence of other diseases, including type 2 diabetes, dyslipidemia, cardiovascular disorders, and certain types of cancers [2]. Given the continual rise in obesity, the burden of associated comorbidities is expected to increase in the coming years [3].

Among individuals with obesity, those with a body mass index (BMI) above 50.0 kg/m^2 experience significantly reduced longevity and quality of life [4]. These patients carry a higher burden of obesity-related comorbidities and surgical risks compared to individuals with lower BMI [5,6]. The complexity of treating patients with obesity intensifies as BMI and comorbidities increase [7]. Numerous factors may complicate the management of this specific subset of patients, including intraoperative technical challenges resulting from increased intra-abdominal adipose tissue and fatty liver. In addition, baseline conditions in these patients pose a significant hurdle especially in the postoperative course [8].

Although lifestyle changes and pharmacotherapy are part of the obesity treatment approach, metabolic and bariatric surgery (MBS) has proven to be the most effective treatment for achieving significant and sustained weight loss in patients with BMI above 50.0 kg/m^2 [9]. Currently, sleeve gastrectomy (SG) and Roux-en-Y gastric bypass (RYGB) are 2 of the most used bariatric techniques worldwide [10,11].

Despite the benefits, MBS may predispose patients to a range of vitamin and mineral deficiencies, which are common postoperative complications. Although frequently these deficiencies can be preventable and treated, in some instances they might lead to life-threatening nutritional issues [12].

All types of MBS can induce nutritional deficiencies (ND), which are more common after surgeries that bypasses long intestinal segments. However, even after SG, the resection of the gastric funds and eventual changes in gastro-duodenal transit may impact the absorption of certain micronutrients, such as iron, zinc, and vitamin B12 [13,14]. Other procedures, such as RYGB, will exert a greater impact on the absorption of essential vitamins, minerals, and trace elements due to the lower intestinal absorption and metabolic alterations [15]. Furthermore, these ND can also result from decreased food intake and postoperative nausea and vomiting, which may occur after MBS [12]. Additionally, red meat intolerance is frequent after MBS, which is a source of a high biological value protein, vitamin B12 and iron [16].

Patients with obesity already have an elevated risk of ND preoperatively [17], most consistently observed for iron, vitamin D, vitamin B12, and vitamin B9 [10,18,19]. Furthermore, some studies found that this risk may be increased in patients with higher BMI [17,20,21]. As a result, patients with obesity who are candidates to MBS require rigorous nutritional assessment pre- and postoperatively to improve their prognosis and minimize surgical and postsurgical risks, which is especially important in patients with BMI above 50.0 kg/m^2. Given the wide variation in postoperative supplementation practices for MBS patients worldwide, it is pertinent to question whether patients with a BMI above 50.0 kg/m^2 require tailored supplementation strategies, or if standard MBS postoperative vitamin supplementation is sufficient for all obese patients, regardless of BMI.

The main objective of this study was to investigate specific factors contributing to ND in patients with BMI above 50.0 kg/m^2, before and after MBS. Additionally, we examined how variations in ND among patients in different BMI groups might impact supplementation

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requirements and management strategies, with the aim of determining whether patients with a BMI above 50.0 kg/m^2 may benefit from additional or customized supplementation.

MATERIALS AND METHODS

1. Study design

We performed a retrospective study including all patients submitted to SG and RYGB between January/2019 and December/2020 at a high-volume specialized obesity center. Data access was granted after approval by the Hospital São João Ethical Committee and Data Protection Officer (CES-416-2023).

2. Participants

Inclusion criteria were: (1) age 18–65 years; (2) patients with an initial BMI ≥40.0 kg/m^2 or BMI ≥35.0 kg/m^2 with associated comorbidities; (3) patients submitted to SG or RYGB; (4) patients without significant or sustainable weight loss after appropriate medical care. Exclusion criteria were: (1) age <18 years or >65 years; (2) pregnant women; (3) secondary causes of obesity (e.g., hypothalamic diseases, endocrine diseases); (4) patients with acute inflammatory conditions; (5) patients with associated comorbidities or diseases contraindicating MBS (e.g., psychiatric disorders, active alcohol or substance abuse).

All patients were pre-operatively evaluated by a multidisciplinary team, consisting of specialized surgeons, endocrinologists, nutritionists, psychiatrists and psychologists. All patients received pre-operative counselling regarding dietitian care after surgery, and multivitamin supplementation requirements.

3. Surgical technique and peri-operative care

In the period selected for this study, RYGB and SG were performed in a standardized fashion by the same team of 8 surgeons. In RYGB we used a small gastric pouch of approximately 4×8 cm. The gastro-jejunostomy was calibrated with a 36F bougie and performed side-to-side using a linear stapler and then a running 3-0 polydioxanone manual suture. The limb lengths were 100 cm for the biliopancreatic limb and 120 cm for the alimentary limb. In SG we preserved approximately 6 cm of antrum, and 48F bougie was used to calibrate the vertical gastrectomy. All surgeries were performed by standard 5-port laparoscopy.

Postoperatively, all patients were prescribed a liquid diet for one month: in this period, patients who underwent RYGB were prescribed both protein and multivitamin supplementation, while those who performed SG were given only multivitamin supplementation. One month after surgery, all patients were observed by specialized nutritionists, and alimentary diversification was resumed. Multivitamin supplementation was advised for, at least, the first years after MBS. Per protocol, all patients submitted to MBS were screened for ND at 6 months, 1 year, 2 years and 3 years after surgery, which implied blood analysis, and consultation with surgeon, endocrinologists, and nutritionists. Specific supplementation (e.g., iron, magnesium) was added to the multivitamin as mandated clinically, and according to the results of the blood analysis.

4. Variables

Anthropometric data (such as height, weight, and BMI), gender and age were recorded. Weight was measure with patient wearing light clothes and no shoes to the nearest,

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in kilograms. BMI was calculated as weight in kilograms divided by height in meters squared. Analytical parameters, such as hemoglobin, albumin, iron, transferrin, ferritin, calcium, vitamin D, vitamin B9, vitamin B12, magnesium, and phosphorus were collected preoperatively, and 1 and 2 years after MBS. The type of surgical procedure was recorded, as well the supplements prescribed preoperatively, 1 year and 2 years after MBS.

Transferrin saturation was calculated using the formula: {[Iron (μg/dL)]/[Transferrin (mg/dL)]}×71.24. The following definitions were considered, according to local laboratory reference ranges:

- Anemia: hemoglobin <12.0 g/L;
- Albumin deficiency: ≤35.0 g/L;
- Iron deficiency: ferritin <15.0 ng/mL and transferrin saturation (TSAT) <16.0%;
- Vitamin B12 deficiency: <200 pg/mL;
- 25(OH) Vitamin D deficiency: <20 ng/mL;
- Vitamin B9 deficiency: ≤2.20 ng/mL;
- Ionized calcium deficiency: <2.25 mEq/L;
- Phosphorus deficiency: ≤2.70 mg/dL;
- Magnesium deficiency: ≤1.50 mEq/L.

5. Statistical methods

Patients were divided in 3 groups: BMI <40.0 kg/m^2, BMI 40.0 to 49.9 kg/m^2 and BMI ≥50.0 kg/m^2, and comparison between groups was performed. The data was analysed using IBM SPSS Statistics® (Version 29; IBM Corp., Armonk, NY, USA). Statistical significance (P value) was assumed for 5%. In descriptive statistics, central values were described as mean or median for variables with normal or non-normal distribution, respectively. The preferred dispersion measures were standard deviation (SD) for mean, and interquartile range (IQR) for median. Variables were assessed for normality using both visual (histogram and Q-Q Plot) and Shapiro-Wilk test. Assessment of patient's characteristics that may influence the development of ND was performed. Standard parametric tests (Student's t-test) were used to compare variables with normal distribution (after Levene test for variance) and Mann-Whitney or Kruskal-Wallis tests to compare variables with non-normal distributions. Relations between categorical variables were studied using χ^2 or Fisher's exact test.

RESULTS

We identified 951 patients with median BMI (IQR) 41.8 (6.5) kg/m^2, of which 85 (9.0%) had BMI ≥50.0 kg/m^2. Mean age ± SD of the patients was 46.1±10.6 years, and 81.8% were female. RYGB was performed in 644 (68.4%) patients. Preoperative multivitamin supplements were prescribed for 3.3% patients. Baseline characteristics are resumed in **Table 1**.

ND pre-operatively, at 1-year follow up, and at 2-years follow up after MBS, according to BMI groups, are presented in **Table 2**. Preoperatively, the most common ND were vitamin D (66.2%), and magnesium (26.5%) (**Fig. 1**). Significant differences between BMI groups, were only observed for vitamin D deficiency, being more frequent in patients with BMI ≥50.0 kg/m^2 (80.0%, P=0.017).

At 1-year follow up, the most prevalent ND remained vitamin D (30.5%), being more frequent in patients with BMI ≥50.0 kg/m^2 (33.3%), but without significant differences between BMI groups (P=0.74). Although not reaching statistical significance, patients with BMI ≥50.0 kg/

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Table 1. Patients' characteristics at baseline

Variables	N	Values
Age (years)	950	46.1±10.6
Women	951	778 (81.8)
BMI (kg/m^2)	951	41.8 (6.5)
BMI groups (kg/m^2)		
<40.0		329 (34.9)
40.0–49.9		530 (56.1)
≥50.0		85 (9.0)
Type of surgery		
SG		298 (31.6)
RYGB		644 (68.4)
Revisional surgery		150 (15.8)
Supplements[a]		
Multivitamin	807	27 (3.3)
Iron	811	17 (2.1)
Vitamin D	811	40 (4.9)
Calcium	818	9 (1.1)
Magnesium	810	12 (1.5)

Values are presented as number (%), mean ± standard deviation, or median (interquartile range).
BMI = body mass index, SG = sleeve gastrectomy, RYGB = Roux-en-Y gastric bypass, N = total of patients studied, sample size.
[a]Supplements refer to preoperative nutritional interventions prescribed to address relevant deficiencies detected before surgery (patients taking supplements before surgery).

Table 2. Deficits of the respective parameters according to BMI groups at baseline and after surgery

Variable	BMI group (kg/m^2)	Baseline	Number of patients	P	FU 1 year	Number of patients	P	FU 2 years	Number of patients	P
Anemia	<40.0	10 (3.2)	309	0.42	22 (8.3)	264	0.23	12 (9.8)	123	0.33
	40.0–49.9	26 (5.2)	504		48 (11.6)	413		34 (14.4)	236	
	≥50.0	3 (3.9)	77		9 (14.5)	62		7 (17.5)	40	
Iron deficiency	<40.0	4 (3.1)	131	0.37	17 (6.6)	259	0.73	12 (10.0)	120	0.7
	40.0–49.9	13 (6.1)	214		30 (7.4)	405		30 (12.9)	232	
	≥50.0	1 (2.8)	36		3 (4.8)	62		4 (10.5)	38	
Albumin deficiency	<40.0	1 (0.3)	328	0.32	5 (1.7)	302	0.07	3 (1.9)	157	0.94
	40.0–49.9	7 (1.3)	527		7 (1.4)	499		7 (2.4)	292	
	≥50.0	1 (1.2)	82		4 (5.2)	77		1 (2.0)	50	
Vitamin B12 deficiency	<40.0	7 (5.4)	130	0.28	46 (17.8)	259	0.81	27 (22.7)	119	0.66
	40.0–49.9	15 (6.6)	228		78 (19.3)	405		60 (26.0)	231	
	≥50.0	0 (0)	36		13 (21.0)	62		8 (20.5)	39	
Vitamin B9 deficiency	<40.0	1 (0.8)	129	0.3	1 (0.4)	257	0.12	2 (1.7)	119	0.37
	40.0–49.9	6 (2.7)	222		4 (1.0)	401		3 (1.3)	227	
	≥50.0	0 (0)	35		2 (3.2)	62		0 (0)	38	
Vitamin D deficiency	<40.0	88 (58.7)	150	**0.017**[a]	72 (28.9)	249	0.74	50 (43.5)	115	0.26
	40.0–49.9	182 (68.2)	267		129 (31.1)	399		79 (35.4)	225	
	≥50.0	36 (80.0)	45		21 (33.3)	63		17 (43.6)	39	
Calcium deficiency	<40.0	4 (1.5)	275	0.25	2 (0.8)	256	0.36	3 (2.5)	120	0.5
	40.0–49.9	16 (3.5)	453		7 (1.8)	397		3 (1.3)	228	
	≥50.0	2 (3.2)	63		0 (0)	59		0 (0)	39	
Phosphorus deficiency	<40.0	26 (8.9)	291	0.12	10 (3.8)	261	0.18	6 (50)	120	0.81
	40.0–49.9	61 (13.1)	466		9 (2.2)	401		10 (4.4)	228	
	≥50.0	5 (7.4)	68		0 (0)	62		1 (2.6)	39	
Magnesium deficiency	<40.0	57 (25.6)	223	0.86	38 (20.0)	190	0.41	18 (20.2)	89	0.94
	40.0–49.9	97 (27.3)	355		57 (18.6)	307		37 (21.1)	175	
	≥50.0	14 (25.0)	56		5 (11.4)	44		7 (23.3)	30	

Values are presented as number (%). Columns in blue indicate pre-operative data; columns in green show data from 1 year post-surgery; columns in yellow represent data from 2 years post-surgery. Bold text indicates statistically significant results (P<0.05).
The variables presented were defined as follow: Anemia: hemoglobin <12.0 g/L; Albumin deficiency: ≤35.0 g/L; Iron deficiency: ferritin <15.0 ng/mL and transferrin saturation <16.0%; Vitamin B12 deficiency: <200 pg/mL; 25(OH) Vitamin D deficiency: <20 ng/mL; Vitamin B9 deficiency: ≤2.20 ng/mL; Ionized calcium deficiency: <2.25 mEq/L; Phosphorus deficiency: ≤2.70 mg/dL; Magnesium deficiency: ≤1.50 mEq/L.
BMI = body mass index, FU = follow-up.
[a]An additional statistical analysis directly comparing BMI groups identified significant difference only between BMI group <40.0 kg/m^2 vs. BMI group ≥50 kg/m^2: vitamin D deficiency rates of 58.7% vs. 80.0%, respectively (χ^2, P=0.009).

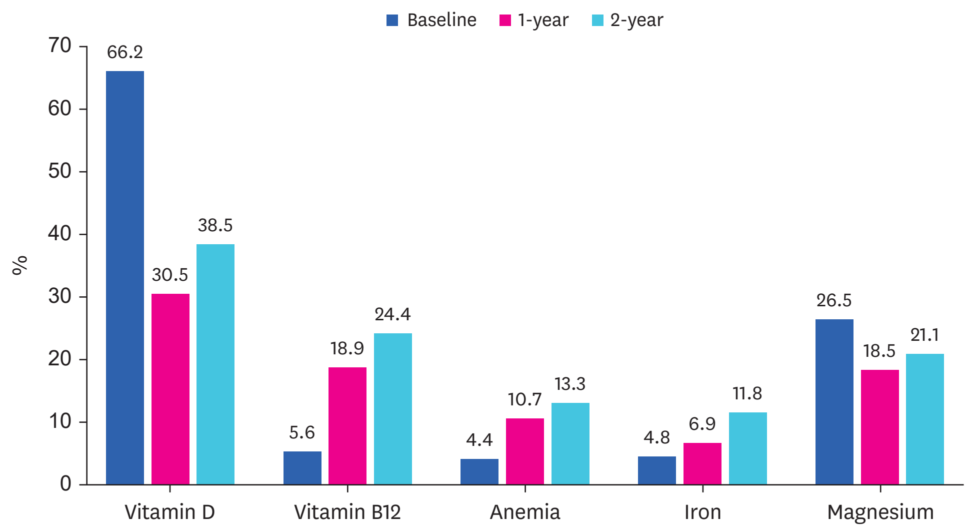

Fig. 1. Prevalences of the most common deficiencies at baseline and surgery.

m², 1-year after MBS, presented more anemia (14.5%, P=0.23), vitamin B12 deficiency (21.0%, P=0.81) and hypoalbuminemia (5.2%, P=0.07). These are non-significant findings. At 2-year follow up after MBS, there was a high prevalence of deficiencies in vitamin D, vitamin B12 and magnesium: 38.5%, 24.4% and 21.1%, respectively. Significant differences between BMI groups were not observed.

Statistical analysis of patients with BMI ≥50.0 kg/m², relating type of surgery (RYGB vs. SG) to the development of ND, is presented in **Table 3**. Both at 1-year and at 2-years follow-up, significant differences were only observed for vitamin B12 deficiency, being more frequent in

Table 3. Deficits of the respective parameters in patients with BMI ≥50.0 kg/m², according to type of surgery at 1 and 2-year follow-up

Variable	Type of surgery	Baseline	Number of patients	P	FU 1 year	Number of patients	P	FU 2 years	Number of patients	P
Anemia	RYGB	3 (7.1)	41	0.25	6 (18.2)	33	0.49	4 (19.0)	21	1.0
	SG	0 (0)	34		3 (10.7)	28		3 (15.8)	19	
Iron deficiency	RYGB	4 (16.0)	25	1.0	2 (6.1)	33	1.0	1 (5.0)	20	0.33
	SG	2 (16.7)	12		1 (3.6)	28		3 (16.7)	18	
Albumin deficiency	RYGB	1 (2.4)	42	1.0	3 (7.9)	38	0.61	1 (4.2)	23	0.48
	SG	0 (0)	38		1 (2.7)	37		0 (0)	26	
Vitamin B12 deficiency	RYGB	0 (0)	22	-	11 (33.3)	33	**0.013**	7 (33.3)	21	**0.049**
	SG	0 (0)	13		2 (7.1)	28		1 (5.6)	18	
Vitamin B9 deficiency	RYGB	0 (0)	22	-	0 (0)	33	0.45	0 (0)	21	-
	SG	0 (0)	12		1 (3.7)	27		0 (0)	17	
Vitamin D deficiency	RYGB	22 (75.9)	29	0.46	12 (35.3)	34	0.57	8 (38.1)	21	0.45
	SG	14 (87.5)	16		8 (28.6)	28		9 (50.0)	18	
Calcium deficiency	RYGB	2 (5.9)	34	0.49	0 (0)	31	-	0 (0)	21	-
	SG	0 (0)	28		0 (0)	27		0 (0)	18	
Phosphorus deficiency	RYGB	3 (8.6)	35	0.62	0 (0)	33	-	0 (0)	21	0.46
	SG	1 (3.2)	31		0 (0)	28		1 (5.6)	18	
Magnesium deficiency	RYGB	9 (28.1)	32	0.40	3 (12.5)	24	1.0	4 (23.5)	17	1.0
	SG	4 (18.2)	22		2 (10.0)	20		3 (23.1)	13	

Values are presented as number (%). Columns in blue indicate pre-operative data; columns in green show data from 1 year post-surgery; columns in yellow represent data from 2 years post-surgery. Bold text indicates statistically significant results (P<0.05).
The variables presented were defined as follow: Anemia: hemoglobin <12.0 g/L; Albumin deficiency: ≤35.0 g/L; Iron deficiency: ferritin <15.0 ng/mL and transferrin saturation <16.0%; Vitamin B12 deficiency: <200 pg/mL; 25(OH) Vitamin D deficiency: <20 ng/mL; Vitamin B9 deficiency: ≤2.20 ng/mL; Ionized calcium deficiency: <2.25 mEq/L; Phosphorus deficiency: ≤2.70 mg/dL; Magnesium deficiency: ≤1.50 mEq/L.
BMI = body mass index, FU = follow-up, RYGB = Roux-en-Y gastric bypass, SG = sleeve gastrectomy.

Table 4. Prevalence of adherence to supplements in patients with body mass index ≥50.0 kg/m^2, according to type of surgery, at 1 and 2-year follow-up

Supplement	Type of surgery	FU 1 year	Number of patients	P	FU 2 years	Number of patients	P
Multivitamin	RYGB	34 (94.4)	36	0.67	23 (100.0)	23	0.22
	SG	32 (91.4)	35		19 (90.5)	21	
Iron	RYGB	4 (11.8)	34	1.0	3 (13.6)	22	1.0
	SG	3 (10.3)	29		2 (9.5)	21	
Vitamin B12	RYGB	2 (5.9)	34	1.0	1 (4.5)	22	1.0
	SG	2 (6.9)	29		1 (4.8)	21	
Vitamin B9	RYGB	0 (0)	34	-	0 (0)	22	-
	SG	0 (0)	29		0 (0)	21	
Vitamin D	RYGB	6 (17.6)	34	0.20	7 (31.8)	22	0.17
	SG	10 (31.3)	32		11 (52.4)	22	
Calcium	RYGB	0 (0)	35	-	0 (0)	24	-
	SG	0 (0)	29		0 (0)	21	
Magnesium	RYGB	2 (5.9)	34	0.41	4 (18.2)	22	1.0
	SG	4 (13.3)	30		3 (14.3)	21	

Values are presented as number (%). Columns in blue indicate pre-operative data; columns in green show data from 1 year post-surgery; columns in yellow represent data from 2 years post-surgery.
FU = follow-up, RYGB = Roux-en-Y gastric bypass, SG = sleeve gastrectomy.

Table 5. Adherence to supplementation prescribed, according to BMI groups

Supplementations	BMI groups (kg/m^2)	FU 1 year	Number of patients	P	FU 2 years	Number of patients	P
Multivitamin Supp	<40.0	257 (93.8)	274	0.67	119 (87.5)	126	0.18
	40.0–49.9	416 (92.0)	452		244 (92.1)	265	
	≥50.0	68 (93.2)	73		42 (95.5)	44	
Specific additional Supp	<40.0	85 (33.5)	254	0.67	46 (34.3)	134	**0.042**[a]
	40.0–49.9	129 (30.3)	426		101 (38.8)	260	
	≥50.0	21 (32.8)	64		24 (55.8)	43	

Values are presented as number (%). Columns in blue indicate pre-operative data; columns in green show data from 1 year post-surgery; columns in yellow represent data from 2 years post-surgery. Bold text indicates statistically significant results (P<0.05).
Supp = supplementation, BMI = body mass index, FU = follow-up.
[a]An additional statistical analysis directly comparing BMI groups identified significant difference between BMI group <40.0 kg/m^2 vs. BMI group ≥50 kg/m^2: Specific additional supplementation rates were 34.3% vs. 55.8%, respectively (χ^2, P=0.012), and between BMI group 40.0–49.9 kg/m^2 vs. BMI group ≥50 kg/m^2: Specific additional supplementation rates were 38.8% vs. 55.8%, respectively (χ^2, P=0.036).

patients submitted to RYGB: 11 (33.3%) patients after RYGB compared to 2 (7.1%) patients after SG (P=0.013). These differences are noted in relatively small sample sizes. Assessment of ND associated with RYGB or SG in other BMI groups were not conducted, as they were considered beyond the scope of this study.

Adherence to nutritional supplementation after MBS, in patients with BMI ≥50.0 kg/m^2 according to type of surgery, is presented in **Table 4**. At 1-year and 2-years follow-up, 92.9% and 95.4% patients (respectively) were taking multivitamin/mineral supplementation, and up to 52.4% patients required additional specific supplements, namely vitamin D. Adherence to supplementation prescribed according to BMI groups is presented in **Table 5**. Patients with BMI ≥50.0 kg/m^2, 2-years after MBS, more frequently were taking specific additional supplementation (P=0.042) than patients in other BMI groups.

Key findings with statistical significance are summarized in **Fig. 2**.

DISCUSSION

MBS is an effective treatment for severe obesity, that can induce postoperative ND, which require appropriate intervention/supplementation [12]. To the best of our knowledge, this is the first study exploring nutritional status in patients with BMI above 50.0 kg/m^2 after MBS.

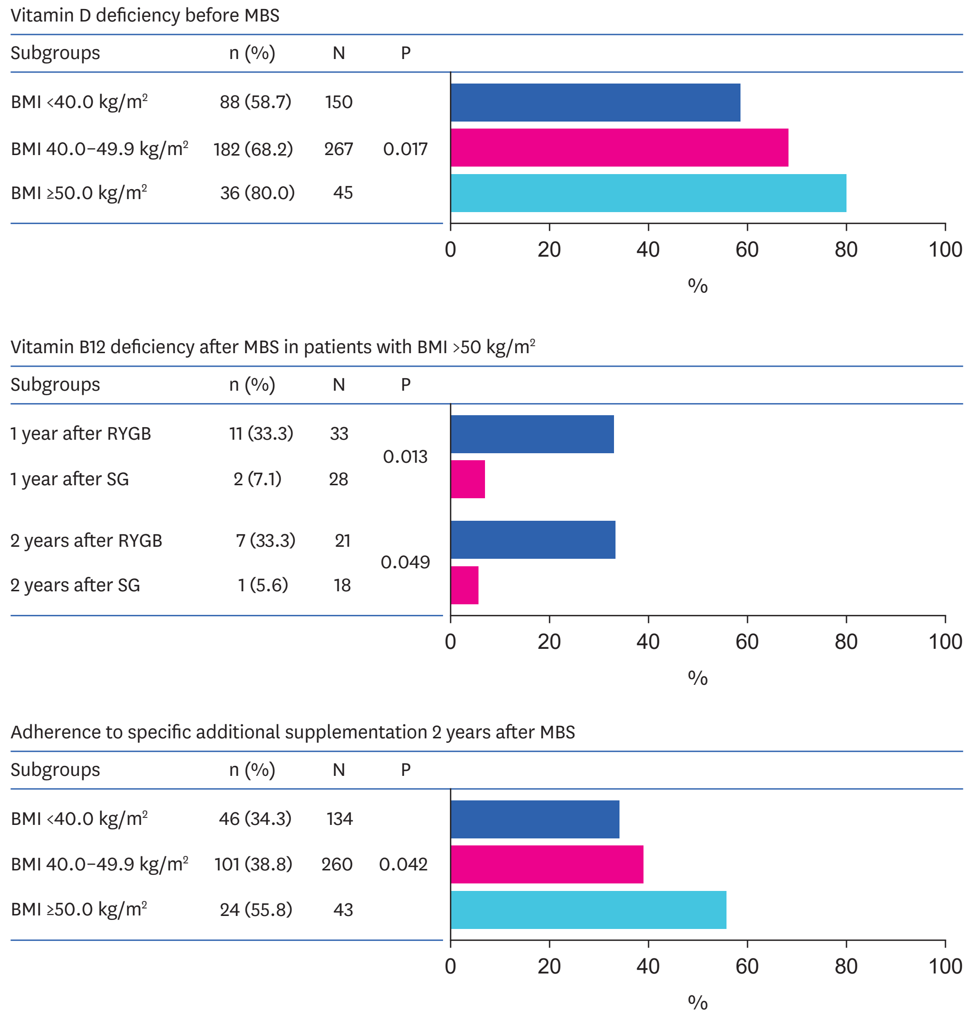

Fig. 2. Key statistically significant findings.
MBS = metabolic and bariatric surgery, BMI = body mass index, RYGB = Roux-en-Y gastric bypass, SG = sleeve gastrectomy, N = total of patients studied, sample size.

We were able to demonstrate a high prevalence of micronutrients deficiency in patients with BMI above 50.0 kg/m^2 that undergo MBS. The most prevalent deficiencies were vitamin D, magnesium, phosphorus, and vitamin B12. The other studied ND had a prevalence below 7.0%.

Multiple ND have been reported in patients with obesity even before MBS, that may be explained by poor-quality diet, incorrect dietary regimens to lose weight, and abnormal storage or bioavailability of nutrients [12,22]. Furthermore, differences in age, gender distribution, ethnicity, criteria for defining deficiencies, as well as geographical and seasonal factors [23], may also contribute to discrepancies in reported deficiencies [12,19,22]. In our patients, phosphorus, magnesium, and vitamin D deficiencies were prevalent. Notably, 80% of patients with a BMI above 50.0 kg/m^2 exhibited vitamin D deficiency prior to surgery. Additional contributing factors may also include obesity-associated inflammation, malabsorption, and other metabolic or hormonal alterations.

Preoperative correction of ND is crucial, as untreated deficiencies can adversely impact postoperative outcomes. Inadequate ND management may reduce weight loss after MBS

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by lowering patient adherence due to symptoms like muscular pain or neuropsychiatric effects. Additionally, anemia, immune dysfunction, and poor wound healing can increase surgical complications, while osteoporosis, asthenia and sarcopenia may compromise long term quality of life following MBS. Adequate management of these and other potential consequences of ND should begin preoperatively and continue for years after surgery to optimize outcomes.

After MBS, multiple factors may contribute to impaired nutritional status: decreased absorption due to bypass of intestinal segments, non-compliance with dietary and supplementation prescribed, nausea and vomiting, as well as gut bacterial overgrowth [12,22]. We found that, in some patients, namely those with BMI above 50.0 kg/m^2, ND after MBS could be as high as 33% for vitamin D and 21% for vitamin B12. However, there were no statistically significant differences between BMI groups.

Vitamin D deficiency was the most prevalent nutritional deficiency before and after MBS, in our series. Proposed explanations include poor diet, reduced sunlight exposure due to social stigma, and decreased bioavailability of vitamin D related to increased uptake by the adipose tissue [12,19]. Patients with obesity have a higher dilution volume, resulting in lower levels of circulating vitamin D, despite relatively normal body stores [24]. Low levels of vitamin D are associated with significant clinical complications, including impaired musculoskeletal health, secondary hyperparathyroidism, higher risk of infections and eventually reduced weight loss after surgery [25].

In our study, patients with BMI above 50.0 kg/m^2 presented more vitamin D deficiency compared to patients in other BMI groups, before MBS. In contrast, Krzizek et al. [21], did not reported such differences between BMI groups which may be explained by different definitions for vitamin D deficiency. Despite low levels of vitamin D, hypocalcemia was present in only 3.2% patients with BMI above 50.0 kg/m^2. After MBS, we observed an increase of vitamin D levels in all BMI groups that may be explained by decreasing subcutaneous fat (that has a high storage capacity for lipophilic compounds), and adherence to recommended pre and postoperative supplementation. Notably, there were no differences in vitamin D deficiencies when comparing the type of MBS performed.

As secondary objective, we investigated the impact of different surgeries (RYGB vs. SG) in ND in the subgroup of patients with BMI above 50.0 kg/m^2. The only identified ND with statistically significant differences was observed for vitamin B12. RYGB resulted in more vitamin B12 deficiency than SG in this subset of patients (33.3% vs. 5.6%, respectively, at 2 years follow-up). These results must be carefully interpreted due to relatively small sample sizes. Antoniewicz et al. [26] reported that, in patients with mean BMI 49.8 kg/m^2, RYBG presented higher vitamin B12 deficiency compared to patients submitted to SG (25.5% vs. 7.8%, respectively), at 1 year follow-up.

Absorption of vitamin B12 is highly complex and dependent of intrinsic factor (IF) and acid production. As RYGB excludes 80–85% of the stomach, duodenum and proximal jejunum, leading to decreased binding of IF and reduction in absorptive area [27,28], ultimately vitamin B12 levels are profoundly affected. Clinical manifestations of vitamin B12 deficiency ranges from megaloblastic anemia through neurological symptoms, which mandates careful surveillance after MBS. Oral supplementation may not be sufficient after MBS which may justify the almost same incidence of this deficiency in our series, 1 year and 2 years after surgery. Consideration must be given to other routes of supplementation, namely intramuscular or sublingual.

Magnesium deficiency was seen in 23.5% of our patients with BMI above 50.0 kg/m^2 submitted at RYGB, which is in line with Dalcanale et al. [29] that reported deficit of magnesium in 32.1% patients with mean BMI of 56.5 kg/m^2. Hypomagnesemia following MBS can be due to malabsorption and steatorrhea that may result in significant symptoms and impaired quality of life.

Per protocol, all our patients submitted to MBS were prescribed multivitamin supplementation after surgery. We observed high rates of compliance (>90%) to multivitamin supplementation, with no differences between BMI groups. Additionally, all patients were screened post-operatively for ND 1 year and 2 years after surgery, which included blood analysis. Specific supplements were prescribed according to ND detected, which in our study, was required in up to 52% patients, namely vitamin D additional supplementation. Remarkably, we found that patients with BMI above 50.0 kg/m^2 exhibited a greater need for specific supplements 2 years after surgery compared to those patients with lower BMI. This finding suggests the need for careful analysis of the ND previously reported in this subset of patients, as these deficiencies may be underdiagnosed due to higher levels of prescribed supplementation.

Long-term adherence to supplementation after MBS is challenging. Costs and limited access to specialized supplements further impact adherence. Tailored protocols for each type of MBS, including clinical follow-up, analytical assessments and appropriate supplementation prescriptions, are essential. For instance, vitamin B12 and iron deficiencies may require high oral doses or intramuscular/intravenous injections under proper medical and nutritional supervision. Clear, procedure-specific, and BMI-adjusted guidelines are likely needed to ensure optimal short- and long-term outcomes after MBS.

The present study has some limitations: it is a retrospective study, from a single center, with relatively few patients with BMI above 50.0 kg/m^2. Potential confounding factors, including the level of dietary control, specifications of nutritional supplement intake, and exercise regimen, were not considered, which may influence the results. Assessment of ND associated with RYGB or SG in other BMI groups were not conducted, though such analyses might had provided valuable insights to better understand our findings. Additional statistical methods could have been utilized to enhance the analysis of temporal changes within each group. Nonetheless, we analysed a large sample of patients, and several parameters were collected, focusing in comparing ND after the main bariatric surgeries between BMI groups, particularly patients with BMI above 50.0 kg/m^2.

CONCLUSION

Our study demonstrates a high prevalence of ND before and after MBS, specifically in patients with BMI above 50.0 kg/m^2. Vitamin D was the most prevalent deficiency, but it improved after surgery probably related to weight changes and adherence to supplementation.

In patients with BMI above 50.0 kg/m^2, RYGB seems to induce more vitamin B12 deficiency that SG, but other ND were not significantly affected by the type of surgery performed in this subset of patients.

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We found a high adherence to multivitamin supplementation after MBS. Additional specific supplementation was frequently required, namely in patients with BMI above 50.0 kg/m^2, 2 years after surgery.

Adequate follow-up with active surveillance and patient enrolment is mandatory after MBS, specifically for patients with BMI above 50.0 kg/m^2 that may require additional and tailored supplementation to treat and prevent ND.

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