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ORIGINAL CONTRIBUTIONS

Is the Current Micronutrient Supplementation Adequate in Preventing Deficiencies in Indian Patients? Short- and Mid-Term Comparison of Sleeve Gastrectomy and Roux-en-Y Gastric Bypass

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Abstract

Purpose Bariatric procedures reduce the capacity of the gut and alter the gastrointestinal transit time predisposing to micro-nutritional deficiencies. This study analyzed and compared the micro-nutritional parameters following laparoscopic sleeve gastrectomy (LSG) and Roux-en-Y gastric bypass (RYGB) in the Indian population.

Materials and Methods This is a retrospective study of patients who underwent LSG or RYGB for morbid obesity at a tertiary care center between January 2015 and December 2016. The micronutrient parameters, namely, serum ferritin, vitamin B12, ionized calcium, vitamin D3, and parathormone (PTH) in the preoperative settings and subsequently at 1, 2, and 3 years were analyzed.

Results A total of 390 patients were studied, of which 258 (66.15%) underwent LSG while 132 (33.85%) underwent RYGB. Baseline micronutrient parameters were comparable in the two groups. Anemia (58.1% vs. 59.1%), deficiencies of ferritin (31.7% vs. 34.3%), vitamin B12 (18.8% vs. 36.4%), ionized calcium (65.1% vs. 72.7%), vitamin D3 (95.3% vs. 90.9%), and secondary hyperparathyroidism (45.5% vs. 58.1%) were seen following LSG and RYGB at the end of 3 years, respectively. There was no significant difference found between LSG and RYGB in terms of micronutrient deficiencies studied, including rising in PTH at 1, 2, and 3 years. Vitamin D3 levels were significantly lower at 2 and 3 years following RYGB ($p = 0.035$ and $p = 0.032$, respectively).

Conclusion LSG and RYGB have comparable micronutrient deficiencies in the short- and mid-term except for vitamin D3, which is higher following RYGB. Long-term studies are needed to define optimum micronutrient supplement dosages for the Indian population.

Keywords Bariatric surgery · Weight loss · Micronutrition · Sleeve gastrectomy · LSG · RYGB · Midterm

Introduction

Obesity is a global pandemic carrying a significant amount of socioeconomic burden [1]. The WHO has considered obesity as one of the significant global health concerns in its 2013 World Health Assembly. The National Family Health Survey 4 reported that 20.6% of Indian women and 18.9% of Indian men were overweight or obese in 2015–2016. The high prevalence of obesity in India could be attributed to the consumption of energy-dense foods coupled with a sedentary lifestyle. India is still a developing nation and also differs from its western counterparts in terms of predominantly being vegetarian with carbohydrate-abundant diet consumption, body composition (Y-Y paradox), and metabolism [2].

Individuals with obesity are resistant to maintaining weight loss achieved by conventional therapies, such as consuming lesser calories, increasing exercise, and commercial weight-

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loss programs. Although intensive lifestyle intervention does have proven efficacy, the outcomes are not as great as bariatric surgery [3]. Bariatric surgery is the only proven modality that leads to long-standing weight loss when compared with traditional weight-loss programs for the majority of individuals who have severe obesity. Overall, bariatric surgery is associated with a 42% reduction of cardiovascular risk and a 30% reduction of all-cause mortality [4].

LSG and RYGB are the most commonly performed bariatric surgeries worldwide. With the growing number of these surgeries performed worldwide, there is a greater need for evidence-based nutrition guidelines for managing these patients. Bariatric procedures reduce the capacity of the gut and alter the ability of the diet and supplements to mix with gastric acid and various hormones that are necessary for the absorption of micronutrients, which is one of the factors that place patients at risk for micronutrient deficiencies. Similar to RYGB, rapid gastrointestinal transit time is also seen following LSG, as shown in a study by Shah et al. [5]. We believe that this rapid gastrointestinal transit could potentiate micronutrient deficiencies following LSG are comparable with RYGB. There exist few studies that have analyzed the micro-nutritional aspect of post-bariatric surgery from India. The study aims to analyze and understand the micronutritional parameters such as ferritin, vitamin B12, ionized calcium, vitamin D3, and PTH following LSG and RYGB in the Indian population.

Material and Methods

Study Design and Setting

The study is a retrospective analysis of a prospectively maintained data of bariatric patients who underwent LSG or RYGB and were followed up postoperatively at 1, 2, and 3 years. The study was conducted in Gem Hospital and Research Centre, Coimbatore, India, which is a high-volume tertiary center, where over 250 bariatric surgeries are performed annually. The study was pursued after obtaining institutional ethics committee clearance.

The patients were selected for bariatric surgery according to the IFSO-APC guidelines [6]. The patients were evaluated by a multidisciplinary team of surgeons, dieticians, and psychologists. All patients underwent thorough preoperative counseling. Indications, merits, demerits, associated risk factors, and complications, including nutritional requirements post-surgery, were explained in detail to the patients. A team of only two bariatric surgeons performed all the procedures.

The preoperative diet comprised of either a partial or complete formula-based diet or meal replacement and a food-based diet, having an overall low amount of carbohydrate. All the patients were subjected to a liquid (low calorie) liver shrinkage diet for a minimum of 2 weeks in the preoperative period. Low molecular weight heparin (Enoxaparin), with a dosage ranging from 40 to 60 mg, as once or twice daily frequency, depending upon the patient's weight was given to the patients. It was given on the evening before surgery and continued to a minimum of 1-week post-surgery in all patients. Gradual pneumatic compression stockings were applied to the patients for DVT prophylaxis. LSG was done as a standard five-port procedure in which the greater curvature was removed, 5 cm from the pyloric ring toward the angle of His, after complete mobilization of the fundus. LSG was performed using linear cutter staplers and calibrating the sleeve with a 37.8 Fr gastric calibration tube. The proximal third of the sleeve was reinforced and buttressed with omentum, as a routine protocol followed in our institution. Laparoscopic RYGB was performed in the standard six-port technique. The biliopancreatic and the Roux limb were kept as 75 and 150 cm, respectively. The gastric pouch was 15–30 ml. No nasogastric tube or urinary drainage tube was kept in any of the patients. Clear liquid diet was started after performing an oral water-soluble contrast dye study (30–50 ml of diatrizoate meglumine) on postoperative day (POD) 1. The patients were discharged on POD 1 or 2 when they met the discharge criteria. There was no mortality noted in any of the cases.

Inclusion criteria—all the patients who underwent LSG and RYGB between January 2015 and December 2016 were included in the study.

Exclusion criteria—patients who did not attend follow-up visits and who could not be contacted through telephone/e-mail were excluded from the study.

The data were collected from the hospital electronic storage system as well as by reviewing the case sheets. The demographic profile of the patients was obtained. The micronutrient parameters, namely, serum ferritin, vitamin B12, ionized calcium, vitamin D3, and parathormone (PTH) levels during the preoperative, 1, 2, and 3 years' post-surgery, were collected. The effect of LSG and RYGB on the micronutrient parameters at 1, 2, and 3 years following surgery was analyzed.

Postoperative Supplementation Post-LSG and post-RYGB patients were advised life-long medications which comprised of calcium (1500 mg/day), Vit D3 (3000 IU/day), Vit B12 (500 mcg/day), 45 mg of iron, and 400 mcg of folic acid along with supplementation of trace elements like copper, zinc, and selenium daily. The supplements were given as a combination of poly-vitamin tablets and specific supplements [7].

Laboratory Analysis Nutrient deficiencies were diagnosed by blood analysis. Baseline reference values taken into consideration are depicted in Table 1. Laboratory values were regarded as deficient when they did not meet the reference values.

Follow-Up of the Patients We reviewed the patients at 2 weeks, 1 month, 3 months, 6 months, 9 months, and 1 year after surgery and then annually after that. The data were recorded through outpatient visits as well as through telephonic/e-mail communication. At each follow-up, the adherence to micronutrient supplements was documented, as reported by the patient. Follow-up records for the patients have been mentioned in Table 2.

Statistical Analysis

The statistical software SPSS version 20 had been used for the statistical analysis. Categorical variables were compared across the groups using Pearson's Chi-square test. For the quantitative variables, we calculated the mean and standard deviation. Continuous variables were expressed as descriptive statistics and were compared using the paired *t* test for parametric data. We used the Student's *t* test to compare the means between the types of surgery to which the patients were submitted. A p value of < 0.05 was considered significant.

Results

A total of 390 patients underwent LSG (n-258) and RYGB (n-132) during the study period. The baseline demographic parameters of patients in the two groups were comparable, as shown in Table 3, except for the type 2 diabetes mellitus status, which was more common in patients who underwent RYGB. We found a statistically significant reduction in body weight, body mass index (BMI), and percentage total weight loss (%TWL) in patients in both the groups over 3 years, as shown in Table 4. However, at 2 and 3-year duration, %TWL, BMI, and weight change were significantly more in the RYGB group than the LSG group. We also found a statistically significant decrease in the mean values of hemoglobin, ferritin, vitamin B12, ionized calcium, and Vit D3 in both groups. At the same time, there was a statistically significant increase in serum PTH levels following both LSG and RYGB (Tables 5 and 6). The micro-nutritional deficiencies following LSG and RYGB are depicted in Figs. 1 and 2. The prevalence of secondary hyperparathyroidism is shown in Fig. 3. Both LSG and RYGB were comparable in terms of postoperative micronutrient deficiencies, except for vitamin D3, which was significantly higher following RYGB at the end of 2 and 3 years ($p = 0.035$ and $p = 0.032$, at 2 and 3 years, respectively). The mean values of various micronutrient parameters during the pre-op period, 1, 2, and 3 years comparing LSG and RYGB are summarized in Table 7.

Table 1 Reference values

Parameters	Reference values
Hemoglobin	
Male	13–17 g/dl
Female	12–15.5 g/dl
Serum ferritin	20–300 ng/ml
Vitamin B12	220–911 pg/dL
Ionized calcium	1.15–1.32 mEq/L
Vitamin D3	20–50 ng/ml
Parathormone	11.1–79.5 pg/ml

Table 2 Follow-up

	n	One year	Two years	Three years
LSG	258	240 (93.02%)	210(81.40%)	204(79.06%)
RYGB	132	122 (92.4%)	114 (86.4%)	105(79.5%)

LSG laparoscopic sleeve gastrectomy, *RYGB* Roux-en-Y gastric bypass

Discussion

Morbid obesity is a significant public health problem not only in Western countries but also in developing countries like India. The incidence and prevalence of morbid obesity are increasing at an alarming rate owing to poor lifestyle choices and lack of knowledge among the general public about the grave consequences it can have on the quality of life apart from the risks of premature deaths. Though dietary modifications and increased physical activities are frequently the first-line management of obesity, the improvements noted are not as effective as following bariatric surgery. Medications to promote weight loss also have not helped much to establish a sustained significant weight loss [8].

Bariatric surgery is the only valid form of treatment to bring about a meaningful, sustained weight reduction in the long term, thereby having the potential to reduce the adverse impacts associated with morbid obesity [9]. The general operative complications and operative mortality of bariatric

Table 3 Preoperative demography

	LSG	RYGB	*p* value
Age (yr)	38.26 ± 11.35	40.09 ± 10.2	0.526
Female (%)	144(55.81%)	78(59.09%)	0.652
Height (cm)	161.23 ± 8.99	158.64 ± 8.84	0.272
Weight (kg)	116.19 ± 24.06	107.36 ± 22.91	0.160
BMI (kg/m^2)	44.64 ± 8.12	42.49 ± 5.78	0.272
T2DM (%)	42(16.28%)	60(45.45%)	< 0.001
HT (%)	102(39.53%)	54(40.90%)	0.563

BMI body mass index, *T2DM* type 2 diabetes mellitus, *HT* hypertension, *LSG* laparoscopic sleeve gastrectomy, *RYGB* Roux-en-Y gastric bypass

Table 4 Weight parameters

	LSG	RYGB	*p* value
Preop wt.	116.19 ± 24.06	107.36 ± 22.91	0.160
Wt. 1 yr	81.92 ± 18.52	74.89 ± 15.68	0.133
Wt. 2 yr	83.88 ± 19.34	72.59 ± 13.49	0.017
Wt. 3 yr	87.38 ± 19.63	75.08 ± 12.64	0.010
Preop BMI	44.64 ± 8.12	42.49 ± 5.78	0.272
1 yr BMI	31.51 ± 6.62	29.54 ± 4.22	0.210
2 yr BMI	32.26 ± 6.86	28.75 ± 4.25	0.032
3 yr BMI	33.59 ± 6.87	29.81 ± 4.11	0.021
% TWL 1	29.53 ± 5.17	30.15 ± 4.28	0.629
% TWL 2	27.83 ± 6.28	31.78 ± 7.18	0.026
% TWL 3	24.81 ± 5.69	28.83 ± 9.5	0.037
% EWL 1	83.62 ± 58.52	83.04 ± 34.39	0.966
% EWL 2	78.04 ± 51.77	86.51 ± 35.82	0.495
% EWL 3	70.29 ± 52.34	76.3 ± 29.33	0.620

Pre-op preoperative; *wt.* weight, *BMI* body mass index, *%TWL* %total weight loss, *%EWL* %excess weight loss, *LSG* laparoscopic sleeve gastrectomy, *RYGB* Roux-en-Y gastric bypass

surgery have been decreasing. They are now equivalent to some of the commonly performed general surgical procedures due to refinements in techniques and the evolution of specialized high-volume bariatric surgery centers capable of handling this complex group of patients. Having said this, one should also be aware of the nutritional disorders that can accompany obesity surgery due to the alterations in physiology imposed by such procedures. LSG and RYGB are the most commonly done bariatric procedures over the world. LSG is now considered to be more than just a restrictive procedure. Studies have shown rapid gastric emptying time following LSG [10]. Even though the intestinal surface area is unaltered following LSG, similar rates of micronutrient deficiencies are observed when compared to patients that have undergone RYGB [11].

There are changes in the gut hormonal and neuronal signaling mechanisms as well as gut microbiota following these procedures, which can precipitate micronutrient deficiencies [12]. People with obesity are frequently found to have preexisting micronutrient deficiencies, which are further worsened following surgery for reasons previously mentioned [13].

In our patients, preoperative ferritin deficiency was found in 4.5% and 3.1% of LSG and RYGB patients, respectively. Serum ferritin levels significantly decreased following both the procedures. The mean preoperative serum ferritin level was 119.8 ± 45.7 μg/dl and 114.5 ± 41.4 μg/dl in the LSG and RYGB group which plummeted down to 58.21 ± 25.2 μg/dl and 56.05 ± 20.7 μg/dl, respectively, after 3 years ($p < 0.001$). Following LSG, deficiency in serum ferritin levels was observed in 21.2%, 25.4%, and 31.7% at 1, 2, and 3 years, respectively, while the corresponding deficiency in serum ferritin levels during the same time frame after RYGB were 18.6%, 28.5%, and 34.3%, respectively. A similar fall in the ferritin levels was seen in studies by Skroubis et al. and Ruz et al. following RYGB. At the same time, Zarshenas et al. observed a similar trend following LSG [14–16]. We, however, found no significant difference in the fall in serum ferritin levels when LSG and RYGB were compared at any time interval after surgery. In a comparative study between LSG and RYGB, Ferraz et al. noted that 20.4% and 17.8% of patients were deficient in serum ferritin after 1 and 2 years following LSG, while 16.4% and 23.7% had ferritin deficiency 1 and 2 years after RYGB, respectively. Similar to our study, they also noticed no difference in serum ferritin deficiency between LSG and RYGB [17].

Serum ferritin is an acute-phase reactant, and its concentration can be spuriously high in inflammatory conditions despite

Table 5 Micro-nutritional follow-up in patients undergoing LSG

LSG	Pre-op	One year	Two years	Three years
Hemoglobin	13.09 ± 1.46	12.09 ± 1.24 ($p < 0.001$)	12 ± 1.31 ($p < 0.001$)	12.16 ± 1.43 ($p < 0.001$)
Ferritin	119.79 ± 45.77	83.79 ± 26.11 ($p < 0.001$)	67.45 ± 27.79 ($p < 0.001$)	58.21 ± 25.19 ($p < 0.001$)
Vitamin B12	449.87 ± 108.38	369.88 ± 132.59 ($p < 0.001$)	359.41 ± 149.63 ($p < 0.001$)	329.37 ± 110.22 ($p < 0.001$)
Ionized calcium	1.29 ± 0.18	1.12 ± 0.05 ($p < 0.001$)	1.18 ± 0.24 ($p = 0.007$)	1.14 ± 0.09 ($p < 0.001$)
Vitamin D3	19.08 ± 4.66	17.11 ± 4.31 ($p < 0.001$)	15.24 ± 3.44 ($p < 0.001$)	15.05 ± 3.94 ($p < 0.001$)
Parathormone (PTH)	39.3 ± 17.11	70.22 ± 28.52 ($p < 0.001$)	69.73 ± 16.37 ($p < 0.001$)	77.97 ± 20.36 ($p = 0.041$)

Pre-op preoperative, *LSG* laparoscopic sleeve gastrectomy

Table 6 Micro-nutritional follow-up in patients undergoing RYGB

RYGB	Pre-op	One year	Two years	Three years
Hemoglobin	12.64 ± 1.31	11.87 ± 1.16 ($p < 0.001$)	11.42 ± 1.28 ($p < 0.001$)	11.76 ± 1.19 ($p < 0.001$)
Ferritin	114.5 ± 41.39	81.71 ± 32.97 ($p < 0.001$)	65.17 ± 26.45 ($p < 0.001$)	56.05 ± 20.75 ($p < 0.001$)
Vitamin B12	440.46 ± 87.94	338.03 ± 62.34 ($p < 0.001$)	316.93 ± 104.08 ($p < 0.001$)	282.18 ± 89.03 ($p < 0.001$)
Ionized Calcium	1.29 ± 0.11	1.09 ± 0.18 ($p < 0.001$)	1.16 ± 0.15 ($p < 0.001$)	1.14 ± 0.05 ($p < 0.001$)
Vitamin D3	20.65 ± 4.39	15.02 ± 4.17 ($p < 0.001$)	12.9 ± 4.44 ($p < 0.001$)	12.45 ± 4.82 ($p < 0.001$)
Parathormone (PTH)	44.66 ± .4	72.32 ± 18.6 ($p < 0.001$)	75.57 ± 24.82 ($p < 0.001$)	81.01 ± 25.46 ($p < 0.001$)

Pre-op preoperative, *RYGB* Roux-en-Y gastric bypass

iron deficiency. It has been found that serum ferritin levels of up to 100 ng/ml may be found in the presence of iron deficiency when the CRP level is more than 8 mg/L [18]. It is, therefore, essential to estimate serum iron with serum transferrin saturation and total iron-binding capacity for diagnosing iron deficiency and not serum ferritin levels in isolation [7]. This being a retrospective study, serum transferrin, total iron-binding capacity (TIBC), nor CRP levels were part of our protocol during the study period. Hence, those parameters could not be studied and analyzed in our study.

The obese population may have a high prevalence of vitamin B12 deficiency, reported being as high as 13% [19]. Following bariatric surgery, vitamin B12 level tends to fall further due to a combination of reduced gastric acidity, impaired intrinsic factor release from the parietal cells of the stomach, and the non-availability of duodenum for the absorption of B12 [4]. We noticed a significant fall in Vitamin B12 levels at 1, 2, and 3-year post-surgery following both LSG and RYGB ($p < 0.001$). In the LSG group, vitamin B12 deficiency was noted in 4.7% and 18.8% preoperatively and at the end of 3 years, respectively. While none of our RYGB patients were deficient before surgery, more than one-third (36.4%) of the patients became deficient after 3 years. Vargas-Ruiz et al. reported a similar profile in terms of vitamin B12 deficiency of 33.3% at 2 years and 27.2% at 3 years following RYGB [20]. Studies have shown variable results comparing Vit B12 deficiencies following LSG and RYGB. In a meta-analysis done by Kwon et al. comparing LSG and RYGB, the odds ratio of developing vitamin B12 deficiency was 3.55 in the RYGB group ($p < 0.001$) [21]. We, however, found no difference in vitamin B12 levels between LSG and RYGB at any time after surgery in our study population. Moize et al. have also reported no significant difference in vitamin B12 levels between LSG and RYGB at 1, 2, 4, and 5 years after surgery, which correlates with our study [22]. We observed deficiencies in Vit B12, despite giving regular supplementation, for all the patients. This could throw light on the inadequacy of the dosage given postoperatively. A similar hypothesis had been put

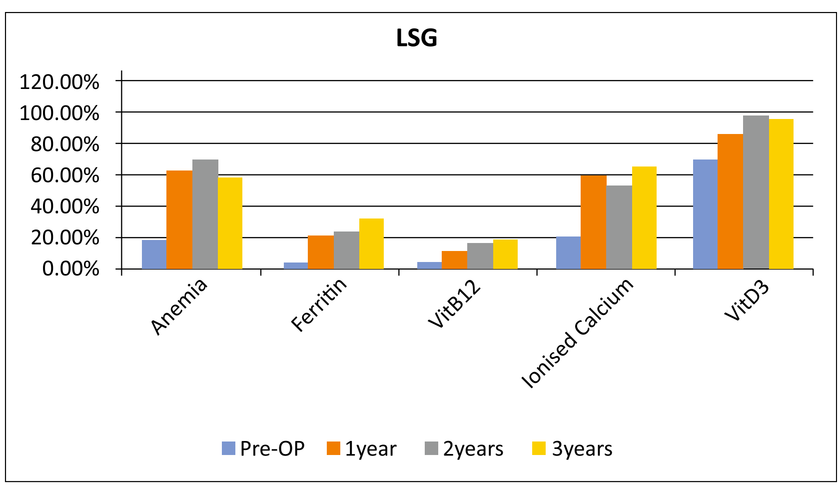
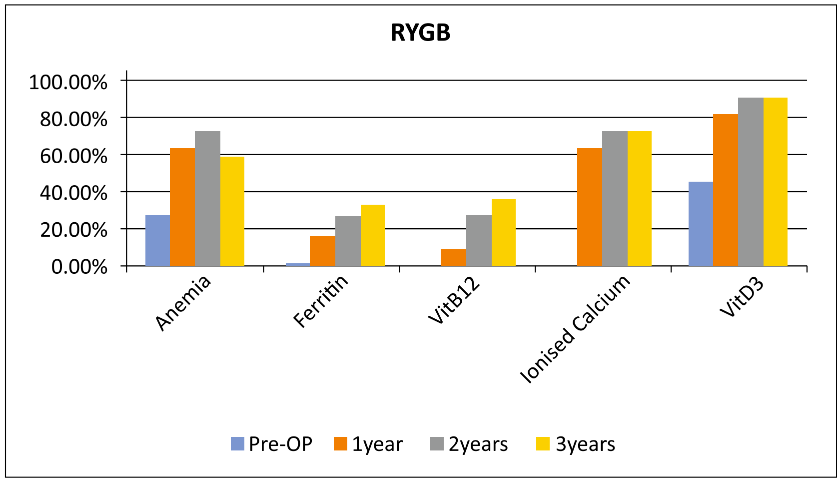


Fig. 1 Micro-nutritional deficiencies after LSG

Fig. 2 Micro-nutritional deficiencies after RYGB



forward by Vargas-Ruiz et al. The authors had pointed out that generic multivitamin supplementation is often inadequate to prevent vitamin B12 and iron deficiency in bariatric surgery patients, and fortified supplements should be used instead [20].

The fall in serum ferritin and vitamin B12 can lead to anemia, which was also seen in our set of patients. The prevalence of anemia was 18.60% and 27.30% in LSG and RYGB patients in the preoperative period, which increased to 58.10% and 59.20%, respectively, during the 3-year follow-up. The mean preoperative hemoglobin in LSG patients was 13.09 ± 1.46 g/dL which significantly dropped down to 12.16 ± 1.43 g/dL ($p < 0.001$) at the end of 3 years while the corresponding values for RYGB were 12.64 ± 1.31 g/dL and 11.76 ± 1.19 g/dL ($p < 0.001$), respectively. We, however, found no significant difference between the two populations in terms of mean hemoglobin values at different time intervals after surgery. In a meta-analysis of 1104 patients by Kwon et al., LSG and RYGB were found to be comparable in terms of risk of anemia, consistent with our findings [21]. In contrast to our results, Kheniser et al. noted a high prevalence of anemia in the LSG group than in the RYGB at the end of 24, 36, and 48 months [23]. However, authors of the study had acknowledged that discrepancy existed in the extent of iron supplementation between the two groups, which could be a reason why their results were different compared with our study.

Anemia following bariatric surgery has been reported in several other studies as well. Ferraz et al. have reported a prevalence of anemia of the order of 30% at the end of 1 year, which increased to 40% at the end of 2 years post-RYGB [17]. Ben-Porat et al. reported that the prevalence of anemia increased from 15% to 20% at 1 year following LSG [19]. We, however, had an increased incidence of anemia in both LSG and RYGB groups when compared with the above-quoted studies. The anemia could be attributed to the vegetarian food culture predominance in India, an insufficient amount of meat consumption, and low socioeconomic conditions prevalent in India.

Isolated measurements of serum calcium provide a poor marker of calcium metabolism, while ionized calcium level offers a better indicator of hypocalcemia following bariatric surgery. Calcium levels are tightly regulated by an interplay

Fig. 3 Secondary hyperparathyroidism after LSG and RYGB

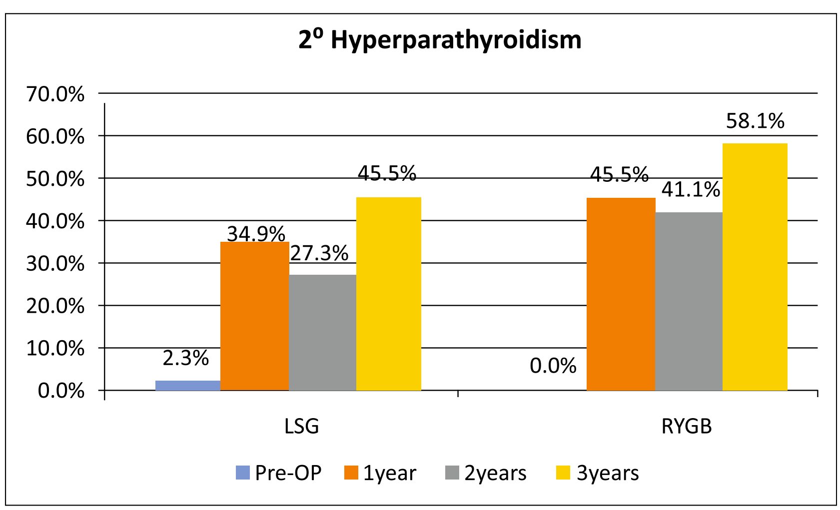


Table 7 Comparison of micronutritional parameters between LSG and RYGB

Micronutrient	Pre-op LSG RYGB *p* value	One year LSG RYGB *p* value	Two years LSG RYGB *p* value	Three years LSG RYGB *p* value
Hemoglobin	13.09 ± 1.46 12.64 ± 1.31 0.223	12.09 ± 1.24 11.87 ± 1.16 0.500	12 ± 1.31 11.42 ± 1.28 0.089	12.16 ± 1.43 11.76 ± 1.19 0.265
Ferritin	119.79 ± 45.77 114.5 ± 41.39 0.651	83.79 ± 26.11 81.71 ± 32.97 0.783	67.45 ± 27.79 65.17 ± 26.45 0.751	58.21 ± 25.19 56.05 ± 20.75 0.730
Vitamin B12	449.87 ± 108.4 440.46 ± 87.94 0.726	369.88 ± 132.6 338.03 ± 62.34 0.291	359.41 ± 149.6 316.93 ± 104.08 0.238	329.37 ± 110.2 282.18 ± 89.03 0.087
Ionized calcium	1.29 ± 0.18 1.29 ± 0.11 0.949	1.12 ± 0.05 1.09 ± 0.18 0.392	1.18 ± 0.24 1.16 ± 0.15 0.783	1.14 ± 0.09 1.14 ± 0.05 0.974
Vitamin D3	19.08 ± 4.66 20.65 ± 4.39 0.193	17.11 ± 4.31 15.02 ± 4.17 0.063	15.24 ± 3.44 12.9 ± 4.44 0.035	15.05 ± 3.94 12.45 ± 4.82 0.032
Parathormone (PTH)	39.3 ± 17.11 44.66 ± 12.4 0.197	70.22 ± 28.52 72.32 ± 18.6 0.756	69.73 ± 16.37 75.57 ± 24.82 0.322	77.97 ± 20.36 81.01 ± 25.46 0.630

Pre-op preoperative, *LSG* laparoscopic sleeve gastrectomy, *RYGB* Roux-en-Y gastric bypass

between the kidneys, intestine, parathyroid gland, and the skeleton [24]. An inverse relationship between BMI and 25-hydroxyvitamin D has been confirmed [25]. Preoperative deficiency of vitamin D in obese patients is due to altered diet, reduced sun exposure, decreased bioavailability of vitamin D, secondary to its sequestration in visceral and subcutaneous fat, compared with lean control subjects [26]. Non-alcoholic fatty liver disease, leading to reduced expression of 25-hydroxylase enzyme activity, is also considered a reason for preoperative Vit D deficiency in the obese population [27]. Following both restrictive and malabsorptive procedures, dietary intolerance following intake of dairy products, vomiting combined with non-adherence to supplement recommendation aggravates vitamin D deficiency status [28]. Both LSG and RYGB have been found to decrease acid secretion. Reduced acid secretion alters disintegration and the respective solubility of nutritional components [24]. Calcium deficiency could be precipitated due to the effects of bypassing the duodenum and proximal jejunum, where most of the active transporters for calcium are located [29]. Alteration in fat digestion due to a reduction in pancreatic lipolytic enzymes because of decreased cholecystokinin secretion is one of the reasons for vitamin D malabsorption in surgeries involving bypassing the duodenum [30].

Calcium deficiency was noted in 20.9% of LSG patients preoperatively, which increased to 65.1% at the end of 3 years ($p < 0.001$). While none of the patients who underwent RYGB had calcium deficiency preoperatively, its prevalence steeply increased to 72.7% at the end of 3 years ($p < 0.001$). Similarly, we noticed a progressive worsening of vitamin D deficiency in our patients. To begin with, a little over two-thirds (69.8%) of our LSG patients and almost half (45.5%) of our RYGB patients were vitamin D deficient, which increased to 95.3% and 90.9%, respectively, at the end of 3 years ($p < 0.001$). We did not notice any significant difference in the mean ionized calcium levels between the two groups at 1, 2, and 3 years. In contrast, vitamin D levels were significantly lower following RYGB at 2 and 3 years after surgery when compared with the LSG group ($p = 0.035$ and $p = 0.032$, respectively).

Our study finds its place in congruence with a meta-analysis of 13 studies done by Tian et al., where RYGB was found to be associated with lower levels of calcium and vitamin D3 compared to LSG [31]. Carrasco et al., in their 2-year prospective study, reported a Vit D deficiency prevalence of 26.3%, 16.7%, and 53.8% at baseline, 1 and 2 years, respectively, after LSG. In contrast, the deficiency in the RYGB group was higher during the same period being 60.9%, 0%, and 57.1%, respectively [32].

Calcium and phosphate are the primary ions for bone strength. Low dietary calcium supply and low vitamin D status cause calcium deprivation that leads to secondary hyperparathyroidism. Calcium and Vit D deficiency is even commoner in the obese population owing to the sedentary lifestyle prohibiting them from adequate sunlight and consumption of fast foods [33]. Calcium and vitamin D deficiency causes secondary hyperparathyroidism, which leads to a fall in bone mineral density. Consequently, there is an increased risk of fracture following bariatric procedures as reported by Nakamura et al [34]. Further, obese individuals may already have high PTH levels even before they are subjected to any surgery [35]. The proportion of patients with hyperparathyroidism increased in both LSG and RYGB groups from 2.3% to 45.5% and 0% to 58.1% at baseline and after 3 years, respectively, in our study. The extent of the rise in serum PTH was not, however, influenced by the type of surgery. Alexandrou et al., similar to our study, have reported that there was no difference in serum PTH levels between LSG and RYGB at a median follow-up of 3 years [36].

In our study, we have analyzed and observed that in the Indian scenario, the recommended supplementation dosage of micronutrients might not cater to the actual postoperative requirements in the patients undergoing LSG and RYGB. There still exists a nutritional deficit gap that needs to be explored concerning micronutrition, especially in the Indian population undergoing bariatric surgery.

The strengths of our study include a large sample size, with nearly 80% follow-up at the end of 3 years. Data from the Indian subcontinent are sparse, and available Western data may not apply to Indian patients considering the differing genetic makeup and dietary preferences. There are, however, certain limitations in our study. Firstly, it is a retrospective single-center analysis with all the inherent shortcomings of a retrospective study. Secondly, serum ferritin is not a reliable indicator for iron deficiency, and we did not have adequate data on serum transferrin saturation, total iron-binding capacity, or CRP. Lastly, although we noticed a fall in serum calcium and vitamin D levels with secondary hyperparathyroidism, we did not study the clinical significance in terms of bone mineral density or fracture risk.

Conclusion

Although bariatric surgery leads to a sustained weight loss and reduction in associated comorbidities, it can worsen or precipitate micronutrient deficiencies. Micronutrient deficiencies can occur following both LSG and RYGB in comparable frequencies, except for vitamin D deficiency, which is more common after RYGB. Our findings emphasize the need for careful monitoring, periodic evaluation, and regular micronutrient supplementation for both LSG and RYGB groups of patients to prevent or treat early micronutrient deficiencies. It also stresses the need for more long-term studies and specific nutritional guidelines specific for the Indian population to study and analyze the recommended dosages of micronutrients following LSG and RYGB in the Indian subcontinent.

Compliance with Ethical Standards

Conflict of Interest “Shivanshu Misra, Shankar Balasubramanian, Usha Isaac, Menaka Srinivasan, Christinajoice Saminathan, S Saravana Kumar, and P Praveen Raj” have no conflicts of interest to disclose.

Ethical Clearance The study was pursued after obtaining institutional ethics committee clearance.

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