Long-Term Consequences of Nutritional Deficiencies

Samantha Stavola

1 Pre-operative Deficiencies

The World Health Organization (WHO) estimates 13% of the world's adult population were obese in 2016 [1]. The sleeve gastrectomy (SG) can be argued as the fastest growing weight loss surgical procedure since 2003, resulting in excess weight loss percentages of 33–90% [2, 3]. From 2003 to 2013, the percentage of sleeve gastrectomy procedures performed in North America increased by 244%, in Europe there was an increase of 48%, South America experienced a 14% increase, and Asia/Pacific countries reported a 75% increase in procedure volume; this details only about 0.01% of the world's population having bariatric surgery [2].

Although there are many health advantages and resolutions of co-morbidities, many micronutrient deficiencies can result from metabolic changes associated with the sleeve gastrectomy [4]. Patients undergoing a sleeve gastrectomy procedure are at risk for nutrient deficiencies due to: limited food intake, increased risk of postoperative nausea and vomiting, food intolerances which may be newly developed since surgery, and reduced amounts of hydrochloric acid and intrinsic factor secretions within the stomach [4]. Nutritional deficiencies can be common in pre-operative patients and should be addressed and treated prior to surgery, to avoid postoperative complications [4, 5].

S. Stavola (✉)
Nutrition for Celebrate Nutritional Supplements, Wadsworth, OH, USA
e-mail: sam@celebratevitamins.com

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2 Post-operative Deficiencies

Weight loss surgery procedures can decrease nutrient intake, specifically in patients undergoing a sleeve gastrectomy procedure, due to the restrictive nature of the procedure [6]. The current and updated 2019 ASMBS(American Society for Metabolic and Bariatric Surgery) Guidelines provide the following early postoperative care and immediate follow up period checklist for monitoring during the first year after a sleeve gastrectomy procedure [7].

Early care related to vitamin supplementation for sleeve gastrectomy:

- Multivitamin plus minerals in 2 tablets to supply minimum requirements
- Elemental calcium in citrate form 1,200–1,500 mg/d
- 3,000 IU/d vitamin D
- Vitamin B12 at dose to maintain normal levels
- Oral hydration of minimum 1.5 L/d.

Immediate follow up care related to vitamin supplementation for sleeve gastrectomy:

- Office visits at one, three, six, twelve months and then annually thereafter
- Comprehensive metabolic panel (CMP) at each visit
- Complete blood count with platelet testing at each visit
- Iron studies test for baseline and as needed thereafter
- Bone density scan at 2 years
- Vitamin B-12 performed annually and every 3–6 months if needing supplementation (methymalonic acid-MMA test- and homocysteine test as preferred)
- Thiamine evaluation as needed.

Postoperative micronutrient deficiencies, specifically in thiamine and vitamin D and calcium, can cause serious complications. Thiamine plays a role in major metabolic pathways within the body by creating many precursors for brain metabolism, separating ATP (adenosine triphosphate) molecules from glucose, and providing the core function in initiating many biochemical reactions in the central and peripheral nervous system [6, 8].

Deficiency in thiamine can lead to Wernicke-encephalopathy, wet Beriberi, and ultimately death, if left untreated. Wernicke-encephalopathy is diagnosed by a change in mental status, ocular movement abnormalities, and ataxia. Early onset symptoms of thiamine deficiency are non-specific and can include: fatigue, lethargy, uneasiness, and headaches [8]. If left untreated, symptoms can progress to congestive heart failure or wet beriberi, peripheral neuropathy, dysphagia, depression, or Korsakoff syndrome [8]. Kröll et al. developed an overview of Wernicke-Encephalopathy after sleeve gastrectomy (Table 1) [8].

Weight loss surgery procedures can increase the risk of developing thiamine deficiency due to nausea and vomiting, rapid weight loss, and excessive alcohol

Table 1 Progression of wernicke-encephalopathy after sleeve gastrectomy

Risk factors	– Recurrent emesis – Non-compliance and inadequate vitamin supplementation – Preoperative vitamin B deficiencies – Surgical complications (stenosis) – Parenteral feedings, caloric carbohydrate diet – Co-morbidities: alcohol consumption, type 2 diabetes, hepatic stenosis, non-alcoholic fatty liver disease, delayed gastric emptying
Time of neurological symptoms	Early: within 2–6 weeks (stores can be depleted) Late: within 7 months with variability, usually 3–5 months
Clinical manifestations	– Wernicke encephalopathy (ocular dysfunction, gait ataxia, encephalopathy) classic triad often not seen – Altered mental status changes – Korsakoff syndrome (amnestic-confabulatory syndrome) – Peripheral neuropathy and polyradiculopathy – Nonspecific symptoms: fatigue, lethargy, restlessness – Atypical symptoms: vestibular dysfunction without hearing loss, dysphagia, depression
Diagnostic tools	– Clinical diagnosis Laboratory examination may not be specific, serum thiamine levels may be reduced MRI may show increased T2 signals in periventricular regions
Differential diagnosis	Other nutrient deficiencies: vitamin B-12, copper, folate, niacin, vitamin E
Treatment	500 mg thiamine IV TID for 2 days, followed by 500 mg/d IV or IM for 5 days with magnesium and other B vitamins, followed by long-term oral supplementation of 50 or 100 mg/d
Outcome	Complete recovery is rare

Adapted from Kröll et al. [8]

intake [8]. Since thiamine is a water-soluble vitamin, daily intake is needed to maintain normal serum levels, in fact, Sechi et al. found that lack of thiamine intake can lead to a deficiency in as few as 20 days without appropriate thiamine supplementation [9]. Angelou et al. found Wernicke encephalopathy onset occurred as early as 2 weeks and as late as 60 weeks after sleeve gastrectomy [10].

Postoperative thiamine deficiency was found to be as great as 25% in patients up to 2 years, and ranged from 0–30.8% by the 5-year mark regardless of supplementation [6]. A study conducted by Johns Hopkins University, found that out of 105 patients status post sleeve gastrectomy, patients with a higher BMI that were

also of a minority ethnicity, or whom were of a minor ethnicity, independently, had a higher risk of developing thiamine deficiency: 20% at 3 months, 17% at 6 months, and 20% at 12 months post-surgery, even while taking recommended 3 mg thiamine supplementation daily [6].

There is evidence that suggests that weight loss procedures can cause a negative effect on bone mineral density, accelerate bone loss, and increase bone fragility [11]. However, these negative effects can mostly be reversed with adequate supplementation after surgery [12]. Serum calcium levels often remain within normal limits in post-operative patients due to the regulatory pathways within the body. Unfortunately, obese individuals typically have abnormal 25(OH)D levels due to sequestration of vitamin D within adipose tissue and due to a sedentary lifestyle with reduced sunlight exposure [12]. It is believed that changes in gut hormone concentrations after the sleeve gastrectomy can cause vitamin D deficiency in post-operative patients [13].

Lu et al. conducted a twelve-year study to observe fracture risk in weight loss surgery patients. Their results showed that out of the total 1,775 patients that had a restrictive procedure, 154 (8.7%) patients had fractures. The fracture rate for the surgical group were: 1.6% for 1 year, 2.37% for 2 years, 1.69% for 5 years, and 2.06% greater than 5 years, with most fractures occurring in the extremities [11].

Likewise, Mihmanli et al. studied 119 post sleeve gastrectomy patients and their vitamin D levels during the first year after surgery. At 12 months after surgery, 32.7% of patients needed high-dose vitamin D supplementation to combat deficiency [13].

Carrasco et al. noted vitamin D deficiency in sleeve gastrectomy patients in 31.6% preop, 5.6% 6 months, and 15.8% 12 months after surgery. Coincidentally, hyperparathyroidism was observed in 57.9% preop, 31.6% 6 months, and 5.3% 12 months after surgery. Patients who achieved higher vitamin D and calcium intake via diet and supplementation had reduced parathyroid hormone levels. Calcium intake of patients, closer to ASMBS recommendations, showed an association with less bone loss in the lumbar region of the spinal cords of sleeve gastrectomy patients [14].

Pluskiewicz et al. noted bone mineral density reductions of 1.2% in the spine, 7% in femoral neck, and 5.3% in total hip in sleeve gastrectomy patients that were 6 months post-surgery [15]. A review of evaluation and management of bone health in the surgical patient (Table 2) and recommendations for calcium and vitamin D supplementation (Table 3) are described below [16].

Although the causes for micronutrient deficiencies is multifactorial, resecting the gastric fundus in the sleeve gastrectomy procedure thus leading to reduced dietary intake, reduced hydrochloric acid and intrinsic factor, and a hypo acidic environment, can lead to micronutrient deficiencies such as iron, folic acid, vitamin B-12, thiamine, vitamin B-6, and copper [17].

In a literature review conducted by Emile and Elfeki, several studies were reviewed to compare nutritional deficiencies after sleeve gastrectomy (Table 4).

Table 2 Evaluation and management of bone health in surgical patients

Parameter	Pre op management	Post-op management	Treatment
Calcium	Serum parathyroid hormone, serum calcium, 25(OH)D, DXA of spine and hip for women aged ≥ 65, men aged ≥ 70, patients with conditions associated with bone loss or low bone mass	1200–1500 mg/d. Monitor serum parathyroid hormone, calcium, and 25(OH)D every 6–12 months and then annually. DXA at spine and hip 2 years post op, then every 2–5 years	Evualate secondary causes, if low bone mass in pre op phase. Consider bisphosphonates when bone density T score is < 2.5
Vitamin D	25 (OH)D, serum parathyroid hormone	3000 IU/d or dose needed to reach 25(OH) D > 30 ng/ml. Monitor serum parathyroid hormone and 25(OH)D every 6–12 months, then annually. 24-h urinary calcium at 6 months, then annually	For rapid correction of vitamin D deficiency ≥ 3,000 IU and ≤ 6,000 IU vitamin D_3/d or 50,000 Iu vitamin D_2 1–3 times/week. Severe malabsorption may require higher dosing of ≤ 50,000 IU D_2 or D_3 1–3 times/week to once daily. High vitamin D dosing should be administered over a limited period of time and should be monitored by medical professionals
Protein	Serum albumin; can also measure serum protein, pre-albumin, DXA of fat-free mass	60–80 g/d or 1.1–1.5 g/kg ideal body weight. Monitor serum albumin 6–12 months and then annually	Oral protein supplementation or enteral/parenteral nutrition as needed
Physical activity	N/A	Moderate aerobic physical activity at minimum 150 min/wk with a goal of 300 min/wk. Strength training 2–3 times/wk	N/A

Adapted from Ben-Porat et al. [16]

Table 3 Recommendations for calcium and vitamin D supplementation

	Calcium	Vitamin D
Threshold values	Serum calcium (without renal disease) 9–10.5 mg/dl Serum parathyroid hormone: hyperparathyroidism >65 pg/ml	25(OH)D: reference range 30–100 ng/ml; preferred range: 30–50 ng/ml; insufficiency: 20–30 ng/ml, deficiency < 20 ng/ml
Routine preventative supplementation	1200–1500 mg/d	3000 IU/d
Supplemental source	Calcium citrate is preferred over calcium carbonate due to it being independent of stomach acidity absorption	D_3 is more potent that D_2, but both can be effective and dose dependent
Additional considerations	Divided doses no greater than 600 mg; separate by at least 2 hours from iron containing products; calcium carbonate should be taken with meals, calcium citrate can be taken with or without meals	Vitamin D should be taken with meals containing a fat source for best absorption
Tolerable daily upper intake level	19–50 yrs: 1500 mg/d, >51 yrs:2000 mg/d, pregnancy/lactation:2500 mg/d	>9 yrs: 4000 IU/d
Safety and risk assessment	Potential adverse effects of excess intake include increased risk of kidney stones, constipation, hypercalciuria, hypercalcemia, vascular and soft tissue calcification, renal insufficiency, and interference with another mineral's absorption	Contraindications for vitamin D supplementation include patients with hypercalcemia or metastatic calcification Serum 25OHD chronically >50 ng/mL may be related to potential adverse effects. Levels of 25(OH)D > 100 ng/mL reflect excess of vitamin D, levels of 25(OH)D > 150 ng/mL indicating intoxication. Vitamin D doses < 10,000 IU/d are unlikely to cause toxicity in adults Excessive vitamin D intake is associated with clinical adverse effects including hypercalcemia, hypercalciuria, and renal stones (when taken together with excess calcium supplementation) In sensitive subpopulations (granuloma-forming disorders, chronic fungal infections, lymphoma, thiazide diuretics treatment) 25(OH)D and calcium levels should be monitored carefully Serum calcium levels should be monitored 1 mo after completing the loading regimen of high-dose vitamin D supplements to treat deficiency. If calcium levels are elevated, any calcium-containing vitamin D supplements should be stopped and further vitamin D loading should be delayed. Elevated calcium despite stopping calcium and vitamin D supplements requires PTH monitoring and referring to endocrinologist

Adapted from Ben-Porat et al. [16]

Table 4 Micronutrient deficiencies after sleeve gastrectomy

		Deficiency percentage (%)												
Study	Type[a]	# of patients	Iron	Anemia	Calcium	Zinc	Magnesium	B1	B6	B12	Vit D	Folic Acid	Hypoalbuinaemia	Follow-Up
Hakeam et al. (2009)	P	61	4.9	4.9	NA	NA	NA	NA	NA	26.2	NA	9.8	NA	12
Salle et al. (2010)	P	33	25	NA	NA	18.8	NA	NA	NA	NA	NA	NA	0	12
Aarts et al. (2011)	P	60	43	26	0	NA	NA	11	0	9	39	15	15	12
Ruiz-Tovar et al. (2012)	R	30	3.3	NA	NA	NA	NA	NA	NA	NA	3.3	NA	NA	24
Moore and Sherman (2014)	P	60	N/A	NA	NA	NA	NA	NA	NA	NA	27.3	NA	NA	3
Damms-Machado et al. 2012	P	54	4.3	NA	4.3	NA	NA	NA	17.2	17.2	70.4	13.8	NA	12
Van Rutte et al. (2014)	P	200	18.5	6.5	2	5	3	9	4	11.5	36	12.5	0.5	12
Ben-Porat et al. 2015	R	77	27.7	20	NA	NA	NA	NA	NA	16.7	93.6	21.4	NA	12
Belfiore et al. (2015)	R	47	8.8	NA	NA	32.4	NA	17.7	NA	6	11.8	11.8	NA	6
Al-Mulhim (2016)	P	112	7.1	6.25	9.8	NA	2.7	NA	NA	14.3	8.9	6.25	NA	12
Saif et al. [18]	R	30	0	28.6	0	14.3	0	30.8	NA	0	42	0	5.5	60
Pellitero et al. (2017)	P	51	NA	4	NA	NA	NA	0	0.2	0	35	0	NA	60
Gehrer et al. (2010)	P	50	18	NA	0	34	NA	0	0	18	56.3	22	4	36
Alexandrou et at (2014)	P	40	30	54.2	N1	NA	NA	NA	NA	5	NA	20	NA	48
Kheniser et al. (2017)	R	50	6	49	N1	NA	NA	NA	NA	12	35.5	NA	NA	48
Median	–	907	8.8	20	1	18.8	2.7	10	0.2	11.7		12.5	4	12

[a]P = prospective, R = retrospective. Adapted from Emile and Elfeki [17]

Table 5 2019 ASMBS guidelines for vitamin/mineral supplementation post weight loss surgery

Vitamin/ mineral	Prevalence of deficiency	Recommended supplementation	Repletion for deficiency	Screening
Thiamin (B1)	<1–49% depending on procedure and post surgery time frame	≥2 mg thiamine daily; preferably a 50–100 mg daily dose of thiamine from a B-complex supplement or high- potency multivitamin	Bariatric patients with suspected thiamine deficiency should be treated before or in the absence of laboratory confirmation and monitored/evaluated for resolution of signs and symptoms Repletion dose for thiamine deficiency varies based on route of administration and severity of symptoms: Oral therapy: 100 mg 2–3 times daily until symptoms resolve IV therapy: 200 mg 3 times daily to 500 mg once or twice daily for 3–5 d, followed by 250 mg/d for 3–5 d or until symptoms resolve, then consider treatment with 100 mg/d orally, indefinitely, or until risk factors have been resolved IM therapy: 250 mg once daily for 3–5 d or 100–250 mg monthly Magnesium, potassium, and phosphorus should be given simultaneously to patients at risk for refeeding syndrome	Recommended for high-risk groups: Females, African Americans, Patients with lack of nutritional care post-surgery, Patients experiencing symptoms such as intractable nausea and vomiting, poor appetite, or constipation, Patients with comorbidities that are taking medications, Excessive alcohol use, Malnutrition, Extreme weight loss Post-WLS patients with signs and symptoms or risk factors should be assessed for thiamin deficiency at least during the first 6 months and then every 3–6 months until symptoms resolve
Cobalamin (B12)	4–20% at 2–5 years post SG	Supplement dose varies based on route of administration Orally by disintegrating tablet, sublingual, or liquid: 350–1,000 mcg daily Nasal spray as directed by manufacturer Parenteral (IM or SQ): 1,000 mcg monthly	1,000 mcg/d to achieve normal levels and then resume dosages recommended to maintain normal levels	Recommended for patients who have undergone SG More frequent screening (every 3 months) recommended in the first-year post-surgery, and then at least annually or as clinically indicated for patients who chronically use medications that exacerbate risk of B_{12} deficiency, such as nitrous oxide, neomycin, metformin, colchicine, proton-pump inhibitors, and seizure medications Screening should include serum MMA with or without homocysteine to identify metabolic deficiency of B_{12} in symptomatic and asymptomatic patients and in patients with history of B_{12} deficiency or preexisting neuropathy Vitamin B_{12} deficiencies can occur due to food intolerances or restricted intake of protein and vitamin B_{12}-containing foods

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Table 5 (continued)

Vitamin/ mineral	Prevalence of deficiency	Recommended supplementation	Repletion for deficiency	Screening
Folic Acid	Up to 65% of patients	400-80 mcg oral folate daily from their multivitamin 800–1,000 mcg oral folate daily in women of child-bearing age	Oral dose of 1000 μg of folate daily to achieve normal levels and then resume recommended dosage to maintain normal levels >1 mg/d supplementation is not recommended because of the potential masking of vitamin B12 deficiency	Screening recommended for all patients, females of childbearing age, noncompliance with vitamin supplementation, and poor dietary intake of folate-containing foods
Iron	<18% SG 3 months-10 years post surgery	Males and patients without a history of anemia: 18 mg of iron from multivitamin Menstruating females and patients who have undergone RYGB, SG, or BPD/DS: 45–60 mg of elemental iron daily (cumulatively, including iron from all vitamin and mineral supplements) Oral supplementation should be taken in divided doses separately from calcium supplements, acid-reducing medications, and foods high in phytates or polyphenols	Oral supplementation should be increased to provide 150–200 mg of elemental iron daily to amounts as high as 300 mg 2–3 times daily Oral supplementation should be taken in divided doses separately from calcium supplements, acid-reducing medications, and foods high in phytates or polyphenols Vitamin C supplementation may be added to increase iron absorption and decrease risk of iron overload IV iron infusion should be administered if iron deficiency does not respond to oral therapy	Iron deficiency can occur after any bariatric procedure, despite routing supplementation Routine post-bariatric screening is recommended within 3 months after surgery, and then every 3 to 6 months until 12 months, and annually thereafter for all patients Iron status should be monitored in post-bariatric patients at regular intervals using an iron panel, complete blood count, total iron-binding capacity, ferritin, and soluble transferrin receptor (if available), along with clinical signs and symptoms Additional screening should be performed based on clinical signs and symptoms and/or laboratory findings or in cases where deficiency is suspected

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Table 5 (continued)

Vitamin/ mineral	Prevalence of deficiency	Recommended supplementation	Repletion for deficiency	Screening
Vitamin D	UP to 100% of patients post-surgery depending on procedure and timeframe post-op	Appropriate dose of daily calcium from all sources varies by surgical procedure SG: 1,200–1,500 mg/d To enhance calcium absorption in post WLS patients Calcium should be given in divided doses Calcium carbonate should be taken with meals Calcium citrate may be taken with or without meals Recommended preventative dose of vitamin D should be based on serum vitamin D levels Recommended vitamin D3 dose is 3,000 IU daily, until blood levels of 25(OH)D are greater than sufficient (30 ng/mL) 7–90% lower vitamin D3 bolus is needed (compared to vitamin D2) to achieve the same effects as those produced in healthy nonbariatric surgical patients	All bariatric patients with vitamin D deficiency or insufficiency should be repleted as follows: Vitamin D3 at least 3,000 IU/d and as high as 6,000 IU/d, or 50,000 IU vitamin D2 1–3 times weekly Vitamin D3 is recommended over vitamin D2 as a more potent treatment when comparing frequency and amount needed for repletion Repletion of calcium deficiency varies by surgical procedure: SG: 1,200–1,500 mg/d	Routine screening is recommending for all patients. 25(OH)D is the preferred biochemical assay Elevated PTH levels and increased bone formation/resorption markers may also be considered
Vitamin A	Up to 70% of patients within 4 years post-surgery depending on procedure	Dosage is based on type of procedure: SG: 5,000–10,000 IU/d Higher maintenance doses of fat-soluble vitamins may be required for bariatric patients with a previous history of vitamin A deficiency Water-miscible forms of fat-soluble vitamins are also available to improve absorption Special attention should be paid to post-bariatric supplementation of vitamin A in pregnant women	For bariatric patients with vitamin A deficiency without corneal changes, a dose of 10,000–25,000 IU/d of vitamin A should be given orally until clinical improvement is evident For bariatric patients with vitamin A deficiency with corneal changes, a dose of 50,000–100,000 IU of vitamin A should be administered IM for 3 d, followed by 50,000 IU/d IM for 2 weeks Bariatric patients with vitamin A deficiency should also be evaluated for concurrent iron and/or copper deficiencies because these can impair resolution of vitamin A deficiency	Screening is recommended within the first postoperative year, especially for those with symptoms of protein-calorie malnutrition

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Vitamin/ mineral	Prevalence of deficiency	Recommended supplementation	Repletion for deficiency	Screening
Vitamin E	Uncommon	15 mg/d Higher maintenance doses of fat-soluble vitamins may be required for post-bariatric patients with a previous history of vitamin E deficiency Water-miscible forms of fat-soluble vitamins are also available to improve absorption	Optimal therapeutic dose for bariatric patients is not defined Potential antioxidant benefits can be achieved with supplements of 100–400 IU/d, which is higher than the amount found in multivitamins. Additional supplementation may be required for repletion	Screening is recommended in patients who are symptomatic
Vitamin K	Uncommon	SG: 90–120 mcg/day Higher maintenance doses of fat-soluble vitamins may be required for post-WLS patients with a previous history of vitamin K deficiency Water-miscible forms of fat-soluble vitamins are also available to improve absorption Special attention should be paid to post-WLS supplementation of vitamin K in pregnant women	A parenteral dose of 10 mg is recommended for bariatric patients with acute malabsorption A dose of either 1–2 mg/d orally or 1–2 mg/week parenterally is recommended for post-WLS patients with chronic malabsorption	Screening is recommended in patients who are symptomatic
Zinc	UP to 19% post SG	All post-WLS patients should take 4 RDA zinc, with dosage based on type of procedure SG: Multivitamin with minerals containing 100% of the RDA (8–11 mg/d) The supplementation protocol should contain a ratio of 8–15 mg of supplemental zinc per 1 mg of copper to minimize the risk of copper deficiency The formulation and composition of zinc supplements should be considered in post-WLS patients to calculated accurate levels of elemental zinc provided by the supplement	A dose-related recommendation for repletion cannot be made due to insufficient evidence Repletion doses should be chosen carefully to avoid inducing a copper deficiency Zinc status should be routinely monitored using consistent parameters throughout treatment	Zinc deficiency is possible, even during zinc supplementation Serum and plasma zinc are the preferred biomarkers for screening in post- bariatric patients

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Table 5 (continued)

Vitamin/ mineral	Prevalence of deficiency	Recommended supplementation	Repletion for deficiency	Screening
Copper	Uncommon	All post-WLS patients should take 4 RDA copper as part of routine multivitamin and mineral supplementation, with dosage based on type of procedure: SG: 100% of the RDA (1 mg/d) Supplementation with 1 mg copper is recommended for every 8–15 mg of elemental zinc to prevent copper deficiency in all post-WLS patients Copper gluconate or sulfate is the recommended source of copper for supplementation	Recommended repletion regimen varies with severity of deficiency: Mild to moderate (including low hematologic indices): 3–8 mg/d oral copper gluconate or sulfate until indices return to normal Severe: 2–4 mg/d intravenous copper can be initiated for 6 d or until serum levels return to normal and neurologic symptoms resolve Copper levels should be monitored every 3 months after they return to normal	Serum copper and ceruloplasmin are recommended biomarkers for copper status

SG Sleeve gastrectomy

The studies ranged in dates from 2009 through to 2017 to provide a comprehensive review of micronutrient deficiencies ranging from 3 months to 5 years after surgery [17].

Obesity related, low grade inflammation caused by obesity can lead to anemia. For the correct diagnosis of anemia after surgery, it is important to conduct a broad assessment of not only iron levels, but also vitamin B-6, B-12, folic acid, copper, selenium and zinc because deficiencies of these vitamins and minerals can lead to iron deficiency anemia [19].

A hypo acidic environment and over supplementation of zinc can lead to copper deficiency, which is a nutrient needed for iron mobilization, and thus will cause a reduction in numbers of red blood cells. Copper deficiencies are often mistaken for iron or vitamin B-12 deficiency, and usually are not diagnosed until advanced neurologic conditions such as unstable gait, numbness in the extremities, or damage to peripheral nerves [19].

The ASMBS released updated 2019 clinical practice guidelines for care and management of patients undergoing weight loss surgery procedures. Table 5 provides a comprehensive review of the vitamin and mineral recommendations for supplementation and repletion of deficiencies.

Saif et al. monitored blood levels of major vitamins and minerals of 82 patients who underwent a sleeve gastrectomy over the course of 5 years. In this study, 20% of the population had low hemoglobin and hematocrit values, however, these values normalized up to year 3. By year 5, levels had returned to preoperative deficiency levels. There was an increase in low levels for thiamine, however, enough values were not collected. Vitamin D status improved by year 1 for those that were deficiency pre-op, but by year 5 parathyroid hormone levels began to rise [18].

Likewise, Ben-Porat et al. observed long term results of 27 patients who underwent a sleeve gastrectomy procedure, below are their findings in Table 6 [20].

Similarly, Moizé et al. conducted a 5 year study to review micronutrient deficiencies in malabsorptive versus restrictive procedures. Of 355 patients, 61 underwent a sleeve gastrectomy with their laboratory findings detailed in Table 7 [21].

Although the sleeve gastrectomy is a restrictive procedure, patients are still at a nutritional risk for developing deficiencies of major micronutrients due to an array of clinical reasons. The research studies reviewed in this chapter, prove

Table 6 Nutrient deficiencies at baseline, 1 year, and 4 years after sleeve gastrectomy

Micronutrient	Baseline deficiency (%)	1 year deficiency (%)	4 year deficiency (%)
Hemoglobin	11.5	20	18.5
Iron	44	41.2	28.6
Vitamin B-12	7.7	13.6	15.4
Folate	46	14.3	12.5
Vitamin D	96.2	89	86.4
Hyperparathyroidism	52	15.4	60

Ben-Porat et al. [20]

Table 7 Percentage of deficiencies of patients post sleeve gastrectomy

Nutrient	Baseline	6 months	12 months	24 months	48 months	60 months
Total protein	5.4	0	3.4	0	4.5	0
Albumin	5.4	4.3	0	0	4.8	0
Prealbumin	11.8	8.7	14.3	3.1	0	0
Hemoglobin	10	12.1	11.5	11.5	15.8	14.3
Ferritin	8.3	0	6.5	20.6	23.8	0
Transferrin	2.8	0	7.1	9.4	0	0
Iron	30.8	4.3	10.3	9.4	9.5	12.5
Folic acid	0	13.6	20.7	6.1	0	12.5
Zinc	8.1	31.8	39.3	25	47.6	12.5
Calcium	2.9	0	3.6	3.1	4.8	12.5
Magnesium	37.8	12.5	10.3	6.3	4.8	12.5
Thiamine	0	4.8	9.1	25	0	0
B-6	75	26.3	11.1	0	16.7	0
B-12	2.7	3.7	3.2	5.9	0	12.5
Vit D sufficiency > 30 ng/ml	6.7	22.7	22.2	13.3	33.3	0
Vit D Insufficiency > 10–<30 ng/ml	3.3	54.5	40.7	20	22.2	100
VIt D Deficiency <10 ng/ml	90	22.7	37	66.7	44.4	0
Parathyroid hormone	62.5	40.9	37	40.6	57.1	87.5

Moize et al. [21]

the importance of, and need for, long-term supplementation for vitamins and minerals after weight loss surgery. There is limited research that has been done on patients greater than 2 years post-surgery. However, the research that has been conducted, shows a trend towards reappearance of deficiencies that were noted in the pre-operative phase for surgery.

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