European Journal of Nutrition (2022) 61:55–67
https://doi.org/10.1007/s00394-021-02619-8

REVIEW

Micronutrients deficiences in patients after bariatric surgery

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Received: 23 December 2020 / Accepted: 9 June 2021 / Published online: 23 July 2021

Abstract
Bariatric surgery is an effective option for managing obesity and has gained general acceptance among patients in recent years. Generally, despite the high caloric intake, a bad nutritional habit of obese people results in the deficiency of several vitamins, minerals, and trace elements essential for body metabolism and normal physiological processes. Additionally, the current bariatric surgical approaches such as sleeve gastrectomy (SG), Roux-en-Y-gastric bypass (RYGB), laparoscopic adjustable gastric banding (LAGB), and jejunoileal bypass (JIB) can cause or exacerbate these deficiencies. Based on several reports, it appears that the various bariatric surgical procedures affect nutrient absorption differently. Being purely restrictive, LAGB and SG affect the absorption of iron, selenium, and vitamin B_{12}, while RYGB, JIB, and biliopancreatic diversion have a more profound impact on the absorption of essential vitamins, minerals, and trace elements. Nutritional deficiencies in vitamins, minerals, and trace elements may follow bariatric surgery and are associated with clinical manifestations and diseases, including anemia, ataxia, hair loss, and Wernicke encephalopathy. The present review summarizes some of the major vitamin and micronutrient deficiencies associated with bariatric surgery, particularly those presented post-surgically. To avoid any adverse consequences of vitamin and trace element deficiency, proper monitoring and tests are recommended at any stage, from pre- to post-surgery (periodical check-up), followed by specific and individual nutritional supplementation treatments and a proper healthy diet.

Keywords Bariatric surgery · Nutritional supplements · Micronutrients deficiency · Trace elements deficiency · Vitamins deficiency

Introduction

Obesity has become a global public health issue with an increased incidence in recent decades [1]. Alarmingly, a higher prevalence rate of obesity has also fueled other health epidemics such as type 2 diabetes mellitus, dyslipidemia, insulin resistance, and cardiovascular disorders [1]. Bariatric surgery has recently gained attention as an effective option to manage obesity, and the acceptance of this surgical procedure has increased in the past few years [2, 3]. The strategies for the management of obesity include lifestyle changes, medications, and surgery. Generally, individuals with very

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high body mass index (BMI) (> 40) or obese subjects with BMI in the range of 35–39.9 and suffering from one of the obesity-associated metabolic complications are advised for weight-loss surgery. For individuals with BMI around 30, the decision to conduct bariatric surgery can be taken after consideration [4]. According to the International Diabetes Federation, those patients with type 2 diabetes mellitus who have suboptimal blood glucose control on a background of adequate medical therapy are recommended bariatric surgery even though their BMI could be just 30 kg/m^2 [5]. In bariatric surgery, the stomach size is reduced to limit the calorie intake of the obese patient leading to reduced food intake and a progressive loss of weight with time. For instance, the stomach size is reduced by 80% in the sleeve gastrectomy (SG), thus significantly reducing solid food and calories. SG spares the upper part of the intestine and is today one of the most common surgical procedures for weight loss as it is widely performed in the USA, Canada, Europe, and several Asian countries [6]. In a biliopancreatic diversion with the duodenal switch (BPD/DS), the stomach is resected in the same way as in SG with a subsequent connection of the intestine end portion to the duodenum near the stomach [7]. In another type of bariatric surgery, called the Roux-en-Y-gastric bypass (RYGB), the stomach is divided into two parts: the smaller upper part and the bigger lower part. The small intestine is rearranged into a Y-configuration to connect to both parts of the stomach, and as a result, the major part of the small intestine is preserved from nutrients absorption. The reversal of RYGB is possible but might technically be demanding compared with removing a gastric band [8]. Laparoscopic adjustable gastric banding (LAGB) is an alternative procedure but less effective in achieving weight loss than RYGB and SG [2, 3, 9]. Another type of bariatric surgery, the jejunoileal bypass (JIB), was the first bariatric surgery performed and led to dramatic weight loss in patients. However, subjects who undergone JIB showed severe side effects, and many died due to liver failure and other complications making this bariatric procedure out of favor. Since then, SG and RYGB have been the two commonest bariatric procedures to effectively manage obesity and weight loss [9–11]. However, these surgical procedures still have some side effects, and individuals who have undergone bariatric surgery often display the signs of vitamin and micronutrient deficiencies (Table 1) [2, 3, 10].

Different types of bariatric surgeries impact the absorption of micronutrients differently. Being purely restrictive, LAGB and SG affect the absorption of iron, zinc, selenium, folate, and B12, while RYGB, JIB, and biliopancreatic diversion (BPD) have a more profound impact on the absorption of essential vitamins, minerals, and trace elements [12]. Over the past decade, several international publications tried to address the issue of micronutrient supplementation in post-bariatric patients [13–15]. The present review summarizes some of the major vitamin and micronutrient deficiencies associated with bariatric surgery, focusing particularly on those presented post-surgically. Further, the co-existent pathologies and the most common symptoms associated with them are discussed.

Methods

A comprehensive search through the scientific literature on bariatric surgery and micronutrient deficiencies was carried out via Pubmed and Cochrane Library databases to meet the review goal fully. All searches in Pubmed were performed

Table 1 Deficiencies of vitamins and trace elements after bariatric surgery and the associated clinical manifestations and diseases

Deficiency	Clinical manifestations—diseases
Vitamins	
Vitamin B12	Lost of body coordination, numbness, neurological complications, memory impairment, macrocytic anemia, leucopenia, infertility
Vitamin B1	Wernicke–Korsakoff syndrome, constipation, nausea, fatigue, anorexia, numbness, weakness
Vitamin A	Insomnia, acne, hyperkeratosis, night blindness, fatigue, immune impairment, dry hair
Vitamin K	Blood clotting disorders, osteoporosis
Vitamin C	Fatigue, delayed wound healing, depression, scurvy
Minerals	
Iron	Anemia, immunodeficiency, fatigue, weakness, pale skin, headaches, dizziness, heart palpitations, shortness of breath, cold extremities, hair loss, gastrointestinal complaints
Calcium	Osteoporosis, tooth decay, depression, heart problem, weak nails, dermatitis, hypertension, muscle spams, sleeplessness
Zinc	Slow healing, hair loss, acrodermatitis, anxiety, depression, hormone disturbance, poor concentration, immune dysfunction
Copper	Fatigue, weakness, pallor, join pains, muscle pain, numbness, tingling, osteoporosis, anemia, frequent illness, skin inflammation, cold sensitivity
Selenium	Immune system dysfunction, vulnerability to infection, fatigue, hair loss, liver dysfunction, thyroid dysfunction, reproductive disorders

with the help of the following keywords: ["Bariatric Surgery" (MeSH)] OR ["Gastric Bypass" (MeSH)] OR ["Gastroplasty" (MeSH)] OR ["Jejunoileal Bypass" (MeSH)] AND ["Micronutrients" (MeSH)] OR ["Trace Elements" (MeSH)]. The search was limited to papers in the English language published from inception to 30 April 2021. According to their titles, all papers were initially screened to decide about their relevance for the scope of the review. As a next step, all papers were evaluated based on their abstracts with subsequent selection of papers meeting the inclusion criteria: (i) publications reporting about micronutrient deficiencies associated with bariatric surgery; (ii) studies on human subjects; and (iii) studies published in the English language.

As for the exclusion criteria, the following filters were applied: (i) unavailability of the full text, (ii) studies of low methodological quality (i.e., case reports, letters, or commentaries), and (iii) studies published in languages other than English. As soon as all irrelevant publications were excluded, a check for duplicates was performed, and the final list of papers to be included in the present review was prepared. Finally, all full texts were accessed and analyzed to exclude papers not meeting the inclusion criteria.

An initial version of the review was drafted after extracting data from the selected papers and followed a structure of the review. This initial draft was discussed between all co-authors, which helped obtain ideas and suggestions to reflect the review scope better. After the initial draft was amended based on the suggestions made, the final version of the review was prepared, repeatedly sent to all co-authors for re-evaluation and approval. After all, co-authors ranted the permission for publication, and the corresponding author was assigned.

Bariatric surgery techniques and risk of deficiencies

Bariatric surgery aims to manage weight gain by primarily reducing the calorie intake of an individual. Bariatric surgeries are classified into restrictive and malabsorptive categories based on the mechanism used to reduce calorie intake. In the restrictive type to which SG belongs, the stomach size is reduced to reduce food intake and early satiety. However, in the malabsorptive type, the amount of calories absorbed by the body is reduced by bypassing the food route [16, 17]. This leads to reduced contact between the food and the digestive juices secreted by the pancreas. In another strategy, the main absorptive regions of the small intestine (the duodenum and the proximal jejunum) are bypassed to prevent the absorption of calories. However, the ultimate reduction in energy intake and absorption of nutrients also depends on the overall manipulations with the gastrointestinal tract.

In malabsorptive procedures, the main cause of vitamin, mineral, and trace element deficiencies is bypassing the main sites where the absorption of micronutrients occurs. Besides, created bypass excludes the "intestinal phase" of pancreatic secretion, induced by food entering the duodenum. Instead, the bypass results in the permanent ileal brake stimulation since undigested food particles enter the ileum stimulating the secretion of glucagon-like peptides 1 and 2 and peptide YY, which suppress pancreatic secretion and further exacerbate malabsorption [18]. As for restrictive procedures, the resected gastric fundus decreases the absorption of certain micronutrients, including iron, zinc, selenium, and vitamin B12. Moreover, the resulting caloric restriction contributes to folic acid, vitamin B1, vitamin B6, and copper deficiencies [19]. RYGB is one of the most commonly performed bariatric surgeries and, together with SG, constitutes approximately 95% of the total bariatric surgeries performed [20]. RYGB drastically reduces the gastric capacity by 90–95%, leading to a massive decline in calorie intake [16, 17]. Such a drastic reduction in consumed calories may be associated with adverse side effects and gastrointestinal symptoms. The prevalence of anemia in RYGB is twofold within 12 months of the surgery, and such patients showed a reduction in hemoglobin/hematocrit with time. Osteopenia and secondary hyperparathyroidism were also attributed to RYGB because of reduced calcium absorption, and this may even result in an increased rate of fractures, especially two years after the surgery. This happens due to the bypass of the duodenum, which has the highest concentration of calcium transporters [21].

Similarly, malabsorptive procedures like biliopancreatic diversion (BPD) and biliopancreatic diversion with duodenal switch (BPD/DS) also induce vitamin, mineral, and trace element deficiencies [22]. A recent study by Homan et al. [22] demonstrated that patients with BPD and BPD/DS frequently suffered from anemia, and deficiency of fat-soluble vitamins was common in post-surgery even after vitamin supplementation. However, it is important to remember that lack of supplementation is associated with worse outcomes, and thus, it was proposed to enable life-long monitoring at a specialized bariatric center and possibly a better micronutrient supplementation [23]. The other study reported on nutrient deficiency post SG, which has been shown to reduce protein absorption by 25%, while fat absorption is reduced by 72%. This leads to a reduction in the absorption of various fat-soluble vitamins and zinc [24].

Besides, increased gallstones formation secondary to a rapid weight loss after surgery and enhanced lithogenicity of bile was reported. Hyperoxaluria is also a side effect of bariatric surgery, and it may lead to oxalate nephropathy and even renal failure [25]. Another dangerous side effect is rhabdomyolysis, associated with acute kidney injury but occurs quite seldom [26].

Based on the above-cited studies, it is evident that various bariatric surgical procedures affect nutrients absorption differently. Furthermore, the high frequency of micronutrients and vitamin deficiencies in obese patients before bariatric surgery, which could aggravate the surgical procedure and lead to postoperative complications, should be considered carefully.

Deficiencies before bariatric surgery

Obesity is generally a consequence of excessive consumption of energy-dense foods leading to a positive energy balance. Thus, it is intriguing that individuals suffering from obesity and overweight also show signs of nutritional deficiency (Fig. 1).

Several scientific studies have shown that obese and overweight individuals suffer from micronutrient deficiency, with the deficiency more pronounced in individuals with extreme obesity (BMI > 40 kg/m^2) [27]. The co-existence of obesity and diabetes leads to altered vitamin D status associated with low serum calcium concentrations and induced secondary hyperparathyroidism [28]. Decreased vitamin D levels are also observed in obese patients with associated cardiovascular disease [29]. Iron deficiency is also common in obese subjects because chronic low-grade inflammation, a characteristic feature of obesity, stimulates the synthesis of hepcidin, which blocks the iron absorption in the body [30, 31]. This inflammation further reduces iron absorption secondary to the inhibition of duodenal ferroportin expression with a simultaneous increase in hepcidin levels [32].

It is important to highlight that intake of energy-dense foods and a higher number of calories does not necessarily bring adequate quantities of vitamins, minerals, and trace elements needed for the body. In other words, individuals with obesity and overweight often consume less fruits, vegetables, and nutritionally poor-quality and more processed foods [27]. For example, a study has shown that increased consumption of fat-rich foods leads to a deficiency of several vitamins such as folate, vitamin A, and vitamin C [33, 34]. In another observation, increased fat in the body decreases fat-soluble vitamins such as vitamin D in the serum [35]. Similarly, increased intake of sugar-rich beverages generally reduces milk consumption, leading to deficiency of milk-derived nutrition such as calcium and vitamin D [36]. In the European population, obese individuals have lower vitamin D concentrations regardless of the season when measured

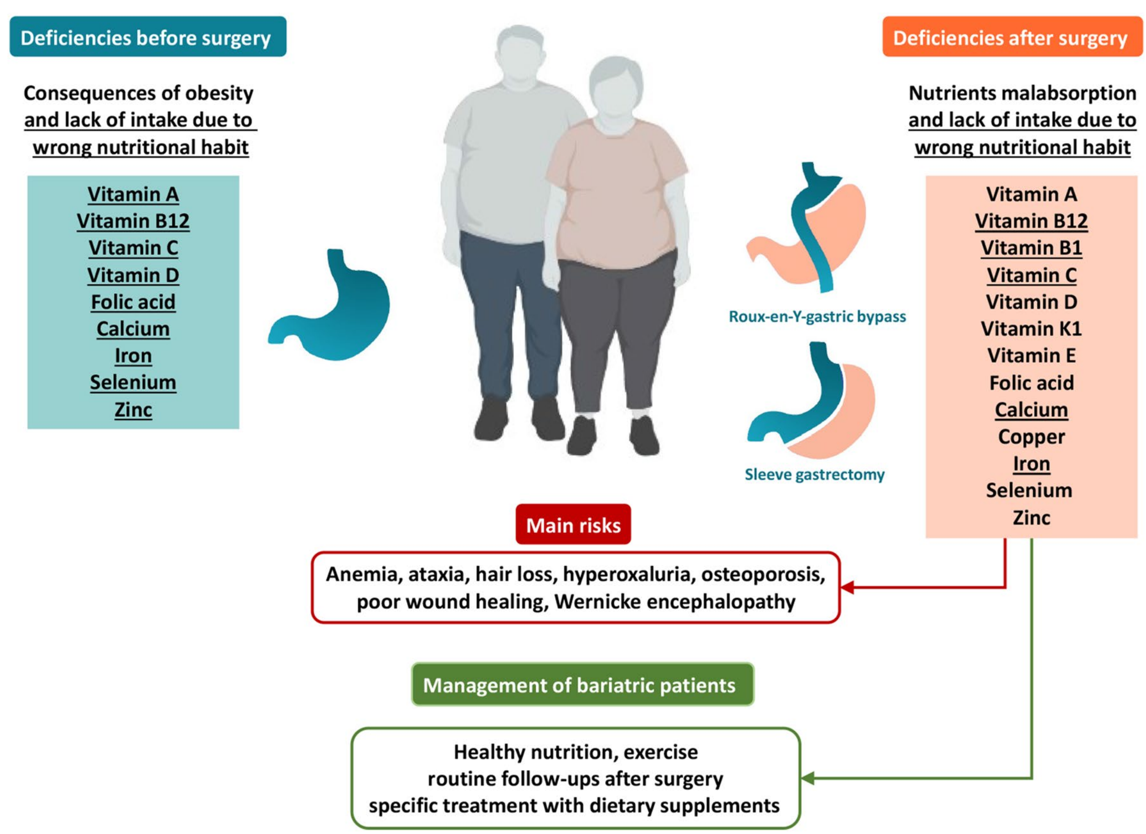

Fig. 1 Micronutrient deficiencies in obesity and after bariatric surgery, risks and management

[37], and similar findings have been obtained for the Asian population [38].

Thus, obese individuals exploring the possibility of bariatric surgery are often diagnosed with a deficiency of micronutrients and vitamins. Ernst et al. [39] measured the serum levels of important micronutrients including zinc, calcium, magnesium, the vitamins D3, B1, B3, and B6, copper, selenium, and parathyroid hormone in 232 individuals before bariatric surgery. The results showed that individuals suffer from very high degrees of micronutrient deficiency, with 25.4% subjects faced vitamin D3 deficiency, 32.6% showed selenium deficiency, 24.6% displayed zinc deficiency, and 18.1% were found with vitamin B12 deficiency. In a study by Schweiger et al [40], 114 patients were recruited, and the plasma levels of various vitamins, minerals, and trace elements were examined. It was observed that 35% of subjects were iron deficient while 24% had too little folic acid and/or ferritin, 3.6% had vitamin B12 deficiency, 2% had too little phosphorus, and 0.9% had calcium deficiency. Nineteen percent of the subjects showed hemoglobin deficiency, defined as a level below 12 gm/dL for women and a level below 14 gm/dL for men. These cut-offs corresponded with the definition of anemia given by the World Health Organization. At the same time, higher levels of parathyroid hormone were reported in 39% of patients [41]. De Luis et al. [18] supported similar findings in which women undergoing bariatric surgery showed lower blood levels for several essential vitamins, minerals, trace elements, and proteins such as folic acid (25.2%), zinc (73.9%), vitamin D (67.8%), and prealbumin (21.7%). Thus, based on the studies cited, it is quite common for obese subjects to face micronutrient deficiency, and the same has to be taken into consideration while and after performing the surgery [42, 43].

Meanwhile, it is very important to prevent or timely treat nutrient deficiencies as failure to do this may lead to undesirable consequences. For example, altered DNA methylation patterns were identified in such tissues of diabetic patients as pancreatic islets, adipose tissue, and skeletal muscle. Potentially, epigenetic changes may alter gene expression and contribute to hyperglycemia and impaired metabolism. Since a methyl donor supply-consumption imbalance could induce these changes, nutrient deficiencies, like folate deficiency, may influence DNA methylation levels and affect gene expression and cell functions [44]. Except for folate, all the B vitamins are involved in at least one step of the energy-production system within the cell, and thus, a shortfall in any of the B vitamins limits energy production with potential metabolic and health consequences [45].

Another example could be made of vitamin D deficiency, contributing to the development of initial insulin resistance and β-cell death secondary to excessive Ca^{2+} and reactive oxygen species signaling with subsequent onset of diabetes. Vitamin D also maintains the epigenome as it increases the expression of DNA demethylases, which protect against hypermethylation of multiple gene promoter regions of many diabetes-related genes [46]. Besides, vitamin C is needed to produce two dioxygenase enzymes, which take part in the carnitine biosynthesis. In turn, carnitine serves as an essential cofactor in the transport of long-chain fatty acids into the mitochondria, and so, impaired carnitine metabolism that may be due to vitamin C deficiency can lead to weakness and physical fatigue [47].

Deficiencies after bariatric surgery

Deficiencies of vitamins

As reported earlier, obese individuals face the deficiency of several vitamins, minerals, and trace elements essential for body metabolism and normal physiological processes. However, it has been observed that several patients who had undergone bariatric surgery also suffer from micronutrient deficiency post-surgery (Fig. 1) [48]. The deficiencies of these micronutrients are associated with several clinical manifestations and disorders (Table 1).

For instance, the American Society of Hematology reported anemia in 33–49% of the cases within 2 years after bariatric surgery [7]. One of the most common causes of anemia post-bariatric surgery is the deficiency of vitamin B12, which develops due to poor its absorption, as the major sites of its absorption are bypassed during bariatric surgery [49]. However, other causes, such as lower secretion of intrinsic factor (IF), a glycoprotein crucial for vitamin B12 absorption, also reduces the absorption secondary to BPD and RYGB [7, 50]. Generally, the body shows the symptoms of vitamin B12 deficiency after a certain period since body reserves of vitamin B12 are considerable, and clinical symptoms appear when the reserves deplete to 5–10% of the initial deposits [7, 50]. The duration of this period varies, depending on the amount of dietary B12 intake and the extent of effective absorption. It has to be noted that intolerance of and, thus, limited consumption of animal proteins may also occur, contributing to exacerbation of vitamin B12 deficiency [51].

Folic acid deficiency is also one aspect in individuals after bariatric surgery and affects 9 to 39% of individuals exposed to restrictive and malabsorptive procedures, respectively [52]. Still, folate deficiency could also be attributed to an inadequate intake of this essential dietary nutrient. Folic acid is absorbed throughout the small intestine, and its deficiency can be easily corrected by oral supplementation [7]. Moreover, the deficiency of folate has a direct correlation with vitamin B12 deficiency because the latter is essentially required for the inactive folate form (methyltetrahydrofolic acid) to be activated (tetrahydrofolic acid) [53].

Bariatric surgery also leads to vitamin D deficiency, with 10% of individuals suffering from this post-surgery issue, although the incidences can also reach as high as 73% [54]. Vitamin D deficiency is primarily due to reduced calcium absorption because the main absorption sites, the duodenum, and the proximal jejunum, are bypassed during the surgical intervention. Vitamin D deficiency leads to increased bone loss post-surgery, and the situation may also aggravate if the intake of milk products is low [55]. It might appear logical that malabsorptive procedures result in a higher reduction of Vitamin D levels, but according to a meta-analysis by Chakhtoura et al. [54] the effect of the surgical procedure, restrictive versus malabsorptive, is inconsistent.

Interestingly, as already mentioned, lower vitamin D levels are observed in 48.7% of the subjects before bariatric surgery [56]. The lower absorption of dietary fat post-bariatric surgery is one reason for decreased vitamin D absorption since it is a fat-soluble vitamin and requires bile salts. Bariatric surgery removes/bypasses critical sites of vitamin D absorption in the small intestine leading to its deficiency, which is more prominent in malabsorptive procedures like RYGB [56]. Bariatric surgery may also lead to the deficiency of other fat-soluble vitamins such as vitamins A, E, and K [57]. For instance, vitamin A deficiency was reported in 69% of the subjects.

Lower levels of vitamin K are developed in patients after bariatric surgery and lead to health complications associated with blood clotting, given the critical role of vitamin K in the blood clotting process [27, 58]. According to the recent systematic review by Sherf-Dagan et al., patients who undergo major malabsorptive surgeries are at a higher risk of developing vitamin K deficiency. Still, it is unknown if supplementation is required and what oral dose of vitamin K normalizes serum levels. Thus, the protocol for the management of vitamin K deficiency in post-bariatric patients is still uncertain [59]. However, a recent study by Homan et al. observed that individuals who have undergone biliopancreatic diversion (BPD) and BPD with duodenal switch (BPD/DS) generally did not decrease the coagulation factor and did not show sign of bleeding. According to the authors, the synthesis of vitamin K2 in the large intestine compensated for the loss of vitamin K1 activity due to BPD or BPD/DS. This synthesis helped maintain liver stores of vitamin K2 needed for the coagulation process [60].

Apart from the deficiency of fat-soluble vitamins, bariatric surgery also increases the risk of developing vitamin B1 (thiamine) and vitamin C deficiency. According to an estimate, thiamine deficiency can develop in 49% of the subjects after sleeve gastrectomy [61]. The primary cause of poor absorption of thiamine is jejunum bypassing, continuous vomiting, and inadequate nutrition. Moreover, certain complications due to the surgery, such as abnormal bowel movements and stenosis, can also contribute to thiamine deficiency. Finally, individuals skipping the doses of multivitamin supplements [12] also develop thiamine deficiency. Thiamine deficiency leads to the development of Wernicke Encephalopathy (WE) after bariatric surgery [62]. A recent study by Oudman et al. recruited 118 WE patients and observed that bariatric procedures led to an early onset of the disease (median age 33 years) compared to other medical procedures where the mean age was 39.5 years. Moreover, bariatric WE patients often displayed other symptoms such as vomiting, abnormal eye movements, and mental issues. The study suggested that individuals must be tested for thiamine deficiency post-surgery, and appropriate supplementations must be provided to prevent the WE [63].

Vitamin C deficiency is also observed in bariatric subjects. It has been observed that vitamin C deficiency is mainly due to poor diet selection post-surgery and may lead to scurvy. However, scurvy can be managed by proper vitamin-C supplementation [64].

The above-cited studies show that the deficiency of several essential vitamins may occur post-bariatric surgery, and the use of multivitamin supplements [12] may be an effective strategy to combat the health complications resulting from this deficiency. Hair loss, peripheral neuropathies, anemia, and poor wound healing are common postoperative ailments most pronounced during the weight reduction phase. As underlying micronutrient deficiencies provoke these ailments, prescription of vitamins, minerals, and trace elements was reported to cause a speedy recovery [65].

Deficiencies of minerals and trace elements

Like the deficiency of vitamins, bariatric surgery also leads to the deficiency of several minerals and trace elements such as iron, zinc, copper [66], calcium [67], and selenium [68] (Fig. 1). This section describes some of the trace elements and mineral deficiencies associated with bariatric surgery.

Iron

Iron deficiency is one of the most common trace element deficiencies and affects around 33% of patients undergoing bariatric procedures. Iron absorption sites are mainly located in the duodenum and proximal jejunum, and bypassing them severely reduces iron absorption [16, 69]. Moreover, dietary changes such as lower intake of meat and iron-fortified dairy products post-surgery may aggravate the iron deficiency. Of these, oral iron supplementation appears to be the most effective tool [70]. Prospective studies based on iron supplementation strategies are urgently needed.

Calcium

Bariatric surgery also causes calcium deficiency, a critical component of several cell signaling processes and an essential element for bone and teeth health. It has been reported that the prevalence of hypocalcemia after RYGB and BPD ranges from 1 to 25%, depending on the surgical technique adopted [71, 72]. In a more recent retrospective study involving patients that undergo bariatric surgery from 2008 to 2014, it was shown that, in about 1000 patients, the prevalence of hypocalcemia after bariatric surgery was 3.6%. In particular, the prevalence was 10% in the BPD-DS group, 9.3% in the SG group, and 1.9% in the RYGB group, respectively [55]. It is important to highlight that vitamin D deficiency can further exacerbate calcium deficiency because vitamin D is required for normal calcium absorption in the intestine and plays a central role in its homeostasis [16, 73–75]. A strategy based on adequate calcium and vitamin D supplementation should be carefully monitored, particularly in patients at high risk for developing symptomatic hypocalcemia in case of pre-existing renal insufficiency and vitamin D deficiency [55, 75].

Copper

Copper acts as a cofactor for several enzymes associated with various pathways in the cell. For instance, copper is a cofactor for superoxide dismutase (antioxidant pathway), cytochrome C oxidase (involved in energy generation), and amine oxidases (involved in the synthesis of neurotransmitters). Thus, deficiency of copper can have severe clinical consequences. Moreover, copper is also needed for iron mobilization in the system. Hence, copper deficiency can also cause symptoms of iron deficiency, such as anemia. It has been observed that malabsorptive bariatric surgery can cause copper deficiency because it bypasses the duodenum. The concentration of blood copper is reduced post BPD and RYGB and may cause severe deficiency in certain individuals [7]. Studies have shown that copper deficiency affects 10–15% of individuals after RYGB surgery [76]. The other cause of copper deficiency is inadequate intake of copper from the diet [16].

Zinc

Zinc is another important essential divalent cation for which individuals develop deficiency post-bariatric surgery [77]. Zinc is absorbed in the proximal intestine, and bypassing the absorption route leads to poor absorption. It is important to note that 42–65% of patients develop zinc deficiency within 6–18 months post-surgery, indicating a direct and strong association between them. Zinc supplementation early after bariatric surgery is necessary to reach significant clinical and echocardiographic improvement [78]. However, studies have also shown that in some cases, zinc levels can decrease after surgery [16, 79].

Selenium

Selenium is primarily absorbed in the duodenum and proximal jejunum and its deficiency has been evidenced in postoperative bariatric surgery (RYGB and SG) with a prevalence from 11 to 46% [79–81]. Selenium deficiency is strictly associated with cardiomyopathy, myopathy, arrhythmias, muscle wasting, and hypothyroidism complications. Screening for selenium levels should be recommended before and after surgery in particular in case of unexplained anemia, fatigue, metabolic bone disease, chronic diarrhea, or cardiomyopathy, followed by specific supplementation [82]. However, studies with large cohort and longer follow-up, also in dependence of the different type of surgical procedure, are still lacking.

Consequences of micronutrients deficiencies

The deficiency of trace elements and minerals can have severe consequences for human health because several trace elements are essentially required to activate several enzymatic reactions and biochemical pathways in cells [16, 83]. The deficiency of these trace elements manifests in symptoms associated with cardiac, neurological, and gastrointestinal systems (Table 1). Thiamine (vitamin B1) deficiency can lead to Wernicke encephalopathy, constipation, nausea, fatigue, and anorexia. Inadequate absorption of fat due to bariatric surgery reduces the absorption of vitamin D. Vitamin D deficiency can severely compromise bone health and manifests in lower bone density. Calcium deficiency also reduces bone density and impairs several cellular signaling pathways because calcium acts as a secondary messenger in the cell. Vitamin D and calcium deficiency can have similar clinical manifestations, and one deficiency can exacerbate another deficiency. Still, bariatric surgery is not the only cause behind the observed deficiency, and reduction in certain food items such as meat, milk, and other dairy products can also lead to deficiencies of vitamin D and calcium.

Zinc deficiency post-bariatric surgery can cause poor wound healing and promotes hair loss [16]. As for copper deficiency, it can cause weak bones, issues with normal learning, fatigue, vision loss, and hair graying. Selenium deficiency is also observed in post-bariatric patients, and it can cause goiter, thyroid issues, and fatigue [84]. Vitamin C deficiency ranges from 10 to 50% following bariatric surgery [7] and may also cause fatigue, delayed wound healing, depression, and even scurvy [27, 85]. Iron deficiency and the related iron deficiency anemia is also frequently observed and is associated with low baseline ferritin level [86].

It is pertinent to mention that clinical manifestations of vitamin, mineral, and trace element deficiencies are not specific, and ultimate clinical symptoms may be due to deficiencies of many vitamins, minerals, and trace elements. Some of the consequences of micronutrient deficiencies are briefly discussed here.

Anemia

Anemia is one of the most common consequences of micronutrient deficiency post-bariatric surgery [86, 87]. It develops due to a change in food habits, which prohibits the use of meat, leading to reduced iron intake. Gastric hypochlorhydria is another reason for lower iron absorption after bariatric surgery. Moreover, bypassing the duodenum also prevents the reduction of iron to the ferrous state, the main absorbable form of iron. Thus, it is recommended that routine laboratory check-ups to determine iron deficiency must be performed in patients after RYGB, which includes testing complete blood count and measurement of ferritin and total iron-binding capacity [88]. These check-ups are needed to prescribe timely treatment for iron deficiency anemia, which reaches 45–50% after RYGB [7]. With anemia progression, the patients often become symptomatic and complain about fatigue, pallor, and dyspnea on exertion. Moreover, anemia was reported to increase the risk of hospitalizations by two-fold along with the duration of in-hospital stay [89].

Impaired absorption of vitamin B12 and folate is a consequence of both restrictive and malabsorptive bariatric procedures. For instance, vitamin B12 deficiency can reduce body coordination, cause numbness in different parts of the body, various neurological complications, and memory impairment. Along with folate, vitamin B12 deficiency can also lead to the development of macrocytic anemia and leucopenia. In pregnant women, growth retardation and congenital disabilities in the newborn may be possible [90].

Wernicke encephalopathy

Wernicke encephalopathy (WE) is observed in alcoholics, undernourished individuals, and cancer patients. However, lower absorption of thiamine (vitamin B1) post-bariatric surgery also causes WE in patients. Some of the common symptoms of WE are nystagmus, confusion, and issues with body coordination. According to a survey, 49% of patients develop the symptom of WE after bariatric surgery. However, some individuals develop it even after sleeve gastrectomy [61].

Ataxia

Ataxia is a medical condition with impaired voluntary body coordination and displays abnormal body and eye movement. Ataxia is a consequence of neurological complications arising out after bariatric surgery. It is observed in 4.6–16% of subjects after bariatric surgery. Some associated medical complications are peripheral neuropathy, burning feet syndrome, lumbosacral plexopathy, and Wernicke-Korsakoff encephalopathy [91].

Hair loss

Hair loss is a common health issue due to the inadequate availability of several micronutrients such as zinc and iron. However, sudden and excessive weight loss after bariatric surgery contributes to hair loss [92]. A recent large cohort study involving 555 subjects reported that the most frequent nutritional deficiency linked to hair loss is essentially connected to deficiency in blood iron and related proteins than zinc and B vitamins, both in the short term and long term follow-up [93].

Taken together, patients after bariatric surgery can develop several health complications due to weight loss, vitamin deficiency, and dietary changes. Thus, a diet rich in proper nutrients and multivitamin supplements may help ameliorate the health consequences of micronutrient deficiency.

Deficiencies and pregnancy after bariatric surgery

Pregnancy post-bariatric surgery requires special attention and care. The impact of bariatric surgery on pregnancy becomes more important because most of these patients are women of reproductive age [94]. It has been observed that women after bariatric surgery show reduced incidences of pregnancy-associated complications such as hypertension, gestational diabetes, and they are mostly successful [95]. A retrospective study considering 287 women between 18 and 45 years of age who underwent RYGB evidenced this surgical practice's safety without any adverse outcomes [96]. One of the major concerns for pregnant women post-bariatric surgery is the deficiency of essential nutrients and trace elements that can prevent normal growth and development of the fetus [97]. For example, anemia is commonly observed in 10.2% of subjects and generally a direct indication of iron deficiency. Studies have shown that weight loss has a positive impact on fertility due to its direct role in improving hormonal balance in the body. Women should plan the pregnancy 12–24 months after the bariatric surgery when their maximum weight loss is achieved [95, 98]. The American

College of Obstetricians and Gynecologists (ACOG) has prescribed special guidelines for women conceiving after bariatric surgery to improve pregnancy outcomes. As per the guidelines, the following points must be considered [99].

Contraception and preconception counseling

Women of reproductive age should be provided with counseling for contraception and preconception after surgery. It has been observed that oral contraceptives are less effective in women after bariatric surgery due to poor absorption. Thus, a higher conception rate has been observed in women of reproductive age post-bariatric surgery than normal women of reproductive age.

Monitoring of nutritional status

As discussed, it is very common to develop a nutritional deficiency after bariatric surgery. Some of the common deficiencies are iron, folate, vitamin B12, vitamin D, and calcium. As per the guidelines, a dedicated team of doctors and specialists must monitor the nutritional status of pregnant women conceived after bariatric surgery. The use of multivitamins and other nutritional supplements must be considered if needed [100].

Antenatal period

Pregnancy-related complications such as nausea, abdominal pain, and vomiting must be taken seriously because these complications may be due to bariatric surgery. A complete evaluation of symptoms by a bariatric surgeon is highly recommended [95].

Labor and delivery

Bariatric surgery does not affect labor and delivery, but a higher cesarean delivery rate has been observed in women after bariatric surgery [101]. However, if the pregnant woman had a complicated bariatric surgery, a pre-labor consultation with a bariatric surgeon is highly advisable as per the ACOG guidelines [102].

Conclusion

Obesity is a disorder of excessive energy surplus, and its unprecedented rise in recent decades is one of the major causes behind other lifestyle-related disorders such as diabetes, non-alcoholic fatty liver disease, and cardiovascular disorders. Bariatric surgery is a surgical intervention to manage weight gain; it involves bypassing the stomach and the jejunum portions to reduce the calorie intake. It has been well-established that the most common types of bariatric surgery, like SG and RYGB, are associated with deficiencies of several essential vitamins, minerals, and trace elements, and those are being more profound for RYGB. This deficiency is mainly attributed to lower absorption of the vitamin, minerals, and trace elements since the proximal duodenum is an important absorption site. The lack of essential micronutrients severely compromises the normal functioning of the body systems because trace elements, minerals, and vitamins are involved in various biological processes and cell signaling. For instance, iron deficiency can hinder normal oxygen transport, and vitamin C deficiency can lead to scurvy. Paradoxically, obesity and overweight are also associated with a deficiency of several vitamins, minerals, and trace elements. Thus, individuals undergoing bariatric surgery should be checked before and after the surgery to detect and correct nutrient inadequacies or deficiencies effectively. Then again, periodic screening for micronutrient deficiencies after bariatric surgery is necessarily required. However, further prospective studies are needed to determine which categories of patients might benefit most and the primary cause of malnutrition, such as surgery or a pre-existing health problem, as this will have economic consequences and an influence for related public health recommendations.

In conclusion, bariatric patients need routine follow-ups after surgery and individual treatment with specific dietary supplements to manage their deficiency of vitamins, minerals, and trace elements. International practice guidelines generally agree that multivitamin and calcium supplementation with added vitamin D is required for all post-bariatric patients and is best administered orally, while intravenous administration should only be applied in situations when oral supplementation is insufficient. Furthermore, healthy nutrition with a targeted diet is recommended for preventing the deficiency of specific micronutrients.

Author contributions AG, PKM, and AD contributed to the acquisition of data. AG wrote the first version of the manuscript. All authors, AG, PKM, AD, GB, SP, AGB, MP, and DOC, supported the conception. AG, GB, and MP contributed to the drafting and revised the manuscript for essential intellectual content. GB coordinated the project. All authors approved the final version of the manuscript.

Funding The authors received no financial support for the research, authorship, and/or publication of this article.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Bluher M (2019) Obesity: global epidemiology and pathogenesis. Nat Rev Endocrinol 15(5):288–298. https://doi.org/10.1038/s41574-019-0176-8
2. Casimiro I, Sam S, Brady MJ (2019) Endocrine implications of bariatric surgery: a review on the intersection between incretins, bone, and sex hormones. Physiol Rep 7(10):e14111–e14111. https://doi.org/10.14814/phy2.14111
3. Purnell JQ, Wolfe BM (2019) Bariatric/metabolic surgery for diabetes: lessons from the past and present. Diabetes Care 42(2):186–188. https://doi.org/10.2337/dci18-0031
4. Bjørklund G, Semenova Y, Pivina L, Costea DO (2020) Follow-up after bariatric surgery: a review. Nutrition 78:110831. https://doi.org/10.1016/j.nut.2020.110831
5. Dixon JB, Zimmet P, Alberti KG, Rubino F (2011) Bariatric surgery: an IDF statement for obese type 2 diabetes. Diabet Med 28(6):628–642. https://doi.org/10.1111/j.1464-5491.2011.03306.x
6. McCracken J, Steinbeisser M, Kharbutli B (2018) Does size matter? correlation of excised gastric specimen size in sleeve gastrectomy to postoperative weight loss and comorbidities. Obes Surg 28(4):1002–1006. https://doi.org/10.1007/s11695-017-2975-0
7. Lupoli R, Lembo E, Saldalamacchia G, Avola CK, Angrisani L, Capaldo B (2017) Bariatric surgery and long-term nutritional issues. World J Diabetes 8(11):464–474. https://doi.org/10.4239/wjd.v8.i11.464
8. Lim CH, Jahansouz C, Abraham AA, Leslie DB, Ikramuddin S (2016) The future of the Roux-en-Y gastric bypass. Expert Rev Gastroenterol Hepatol 10(7):777–784. https://doi.org/10.1586/17474124.2016.1169921
9. Franco JV, Ruiz PA, Palermo M, Gagner M (2011) A review of studies comparing three laparoscopic procedures in bariatric surgery: sleeve gastrectomy, Roux-en-Y gastric bypass and adjustable gastric banding. Obes Surg 21(9):1458–1468. https://doi.org/10.1007/s11695-011-0390-5
10. Justice A, Keilani Z, Tribble J (2018) A unique case report of jejunoileal bypass reversal with review of the literature. Int J Surg Case Rep 50:88–91. https://doi.org/10.1016/j.ijscr.2018.07.028
11. Colquitt JL, Pickett K, Loveman E, Frampton GK (2014) Surgery for weight loss in adults. Cochrane Database Syst Rev 8:3641. https://doi.org/10.1002/14651858.CD003641.pub4
12. Mechanick JI, Apovian C, Brethauer S, Garvey WT, Joffe AM, Kim J, Kushner RF, Lindquist R, Pessah-Pollack R, Seger J, Urman RD, Adams S, Cleek JB, Correa R, Figaro MK, Flanders K, Grams J, Hurley DL, Kothari S, Seger MV, Still CD (2019) Clinical practice guidelines for the perioperative nutrition, metabolic, and nonsurgical support of patients undergoing bariatric procedures—2019 update: cosponsored by American Association of Clinical Endocrinologists/American College of Endocrinology, the Obesity Society, American Society for Metabolic & Bariatric Surgery, Obesity Medicine Association, and American Society of Anesthesiologists, Executive Summary. Endocr Pract 25(12):1346–1359. https://doi.org/10.4158/GL-2019-0406
13. Poitou Bernert C, Ciangura C, Coupaye M, Czernichow S, Bouillot JL, Basdevant A (2007) Nutritional deficiency after gastric bypass: diagnosis, prevention and treatment. Diabetes Metab 33(1):13–24. https://doi.org/10.1016/j.diabet.2006.11.004
14. Mahawar KK, Reid A, Graham Y, Callejas-Diaz L, Parmar C, Carr WR, Jennings N, Singhal R, Small PK (2018) Oral Vitamin B12 supplementation after Roux-en-Y gastric bypass: a systematic review. Obes Surg 28(7):1916–1923. https://doi.org/10.1007/s11695-017-3102-y
15. Homan J, Schijns W, Janssen IMC, Berends FJ, Aarts EO (2019) Adequate multivitamin supplementation after Roux-En-Y gastric bypass results in a decrease of national health care costs: a cost-effectiveness analysis. Obes Surg 29(5):1638–1643. https://doi.org/10.1007/s11695-019-03750-6
16. Gletsu-Miller N, Wright BN (2013) Mineral malnutrition following bariatric surgery. Adv Nutr 4(5):506–517. https://doi.org/10.3945/an.113.004341
17. Weng TC, Chang CH, Dong YH, Chang YC, Chuang LM (2015) Anaemia and related nutrient deficiencies after Roux-en-Y gastric bypass surgery: a systematic review and meta-analysis. BMJ Open 5(7):e006964. https://doi.org/10.1136/bmjopen-2014-006964
18. O'Keefe SJD, Rakitt T, Ou J, El H II, Blaney E, Vipperla K, Holst JJ, Rehlfeld J (2017) Pancreatic and intestinal function post Roux-en-Y gastric bypass surgery for obesity. Clin Transl Gastroenterol 8(8):e112. https://doi.org/10.1038/ctg.2017.39
19. Emile SH, Elfeki H, Elalfy K, Abdallah E (2017) Laparoscopic sleeve gastrectomy then and now: an updated systematic review of the progress and short-term outcomes over the last 5 years. Surg Laparosc Endosc Percutaneous Tech 27(5):307–315
20. El Ansari W, Elhag W (2021) Weight regain and insufficient weight loss after bariatric surgery: definitions, prevalence, mechanisms, predictors, prevention and management strategies, and knowledge gaps—a scoping review. Obes Surg 31(4):1755–1766. https://doi.org/10.1007/s11695-020-05160-5
21. Saad R, Habli D, El Sabbagh R, Chakhtoura M (2020) Bone health following bariatric surgery: an update. J Clin Densitom 23(2):165–181. https://doi.org/10.1016/j.jocd.2019.08.002
22. Homan J, Betzel B, Aarts EO, Dogan K, van Laarhoven KJ, Janssen IM, Berends FJ (2015) Vitamin and mineral deficiencies after biliopancreatic diversion and biliopancreatic diversion with duodenal switch—the rule rather than the exception. Obes Surg 25(9):1626–1632. https://doi.org/10.1007/s11695-015-1570-5
23. Nett PC (2016) Answer to: micronutrient supplementation after biliopancreatic diversion with duodenal switch in the long term: using refill bypass is the solution. Obes Surg 26(8):1939. https://doi.org/10.1007/s11695-016-2241-x
24. Pech N, Meyer F, Lippert H, Manger T, Stroh C (2012) Complications and nutrient deficiencies two years after sleeve gastrectomy. BMC Surg 12:13. https://doi.org/10.1186/1471-2482-12-13
25. Ormanji MS, Rodrigues FG, Heilberg IP (2020) Dietary recommendations for bariatric patients to prevent kidney stone formation. Nutrients. https://doi.org/10.3390/nu12051442
26. Chakravartty S, Sarma DR, Patel AG (2013) Rhabdomyolysis in bariatric surgery: a systematic review. Obes Surg 23(8):1333–1340. https://doi.org/10.1007/s11695-013-0913-3
27. Xanthakos SA (2009) Nutritional deficiencies in obesity and after bariatric surgery. Pediatr Clin North Am 56(5):1105–1121. https://doi.org/10.1016/j.pcl.2009.07.002
28. Verma S, Hussain ME (2017) Obesity and diabetes: an update. Diabetes Metab Syndr 11(1):73–79. https://doi.org/10.1016/j.dsx.2016.06.017
29. Paschou SA, Kosmopoulos M, Nikas IP, Spartalis M, Kassi E, Goulis DG, Lambrinoudaki I, Siasos G (2019) The impact of obesity on the association between vitamin D deficiency and cardiovascular disease. Nutrients 11(10):2458. https://doi.org/10.3390/nu11102458
30. Cepeda-Lopez AC, Aeberli I, Zimmermann MB (2010) Does obesity increase risk for iron deficiency? A review of the literature and the potential mechanisms. Int J Vitam Nutr Res 80(45):263–270. https://doi.org/10.1024/0300-9831/a000033
31. Gasmi A, Mujawdiya PK, Shanaida M, Ongenae A, Lysiuk R, Dosa MD, Tsal O, Piscopo S, Chirumbolo S, Bjørklund G (2020) Calanus oil in the treatment of obesity-related low-grade inflammation, insulin resistance, and atherosclerosis. Appl Microbiol Biotechnol 104(3):967–979. https://doi.org/10.1007/s00253-019-10293-4

32. Bjørklund G, Peana M, Pivina L, Dosa A, Aaseth J, Semenova Y, Chirumbolo S, Medici S, Dadar M, Costea DO (2021) Iron deficiency in obesity and after bariatric surgery. Biomolecules. https://doi.org/10.3390/biom11050613
33. Hampl JS, Betts NM (1995) Comparisons of dietary intake and sources of fat in low- and high-fat diets of 18- to 24-year-olds. J Am Diet Assoc 95(8):893–897. https://doi.org/10.1016/s0002-8223(95)00247-2
34. Thomas-Valdés S, Tostes MdGV, Anunciação PC, da Silva BP, Sant'Ana HMP (2017) Association between vitamin deficiency and metabolic disorders related to obesity. Crit Rev Food Sci Nutr 57(15):3332–3343. https://doi.org/10.1080/10408398.2015.1117413
35. Gillis L, Gillis A (2005) Nutrient inadequacy in obese and non-obese youth. Can J Diet Pract Res 66(4):237–242. https://doi.org/10.3148/66.4.2005.237
36. Dennis EA, Flack KD, Davy BM (2009) Beverage consumption and adult weight management: a review. Eat Behav 10(4):237–246. https://doi.org/10.1016/j.eatbeh.2009.07.006
37. Bettencourt A, Boleixa D, Reis J, Oliveira JC, Mendonca D, Costa PP, Silva BMD, Marinho A, Silva AMD (2018) Serum 25-hydroxyvitamin D levels in a healthy population from the North of Portugal. J Steroid Biochem Mol Biol 175:97–101. https://doi.org/10.1016/j.jsbmb.2016.11.005
38. Gromova O, Doschanova A, Lokshin V, Tuletova A, Grebennikova G, Daniyarova L, Kaishibayeva G, Nurpeissov T, Khan V, Semenova Y, Chibisova A, Suzdalskaya N, Aitaly Z, Glushkova N (2020) Vitamin D deficiency in Kazakhstan: cross-sectional study. J Steroid Biochem Mol Biol 199:105565. https://doi.org/10.1016/j.jsbmb.2019.105565
39. Ernst B, Thurnheer M, Schmid SM, Schultes B (2009) Evidence for the necessity to systematically assess micronutrient status prior to bariatric surgery. Obes Surg 19(1):66–73. https://doi.org/10.1007/s11695-008-9545-4
40. World Health Organization (2011) Haemoglobin concentrations for the diagnosis of anaemia and assessment of severity. Vitamin and Mineral Nutrition Information System. http://www.who.int/vmnis/indicators/haemoglobin.pdf. Accessed 1 May 2021
41. Schweiger C, Weiss R, Berry E, Keidar A (2010) Nutritional deficiencies in bariatric surgery candidates. Obes Surg 20(2):193–197. https://doi.org/10.1007/s11695-009-0008-3
42. de Luis DA, Pacheco D, Izaola O, Terroba MC, Cuellar L, Cabezas G (2013) Micronutrient status in morbidly obese women before bariatric surgery. Surg Obes Relat Dis 9(2):323–327. https://doi.org/10.1016/j.soard.2011.09.015
43. Astrup A, Bugel S (2019) Overfed but undernourished: recognizing nutritional inadequacies/deficiencies in patients with overweight or obesity. Int J Obes (Lond) 43(2):219–232. https://doi.org/10.1038/s41366-018-0143-9
44. Nilsson E, Matte A, Perfilyev A, de Mello VD, Kakela P, Pihlajamaki J, Ling C (2015) Epigenetic alterations in human liver from subjects with type 2 diabetes in parallel with reduced folate levels. J Clin Endocrinol Metab 100(11):E1491-1501. https://doi.org/10.1210/jc.2015-3204
45. Tardy AL, Pouteau E, Marquez D, Yilmaz C, Scholey A (2020) Vitamins and minerals for energy, fatigue and cognition: a narrative review of the biochemical and clinical evidence. Nutrients. https://doi.org/10.3390/nu12010228
46. Berridge MJ (2017) Vitamin D deficiency and diabetes. Biochem J 474(8):1321–1332. https://doi.org/10.1042/BCJ20170042
47. Levin M, Katz A, Padayatty SJ (2006) Vitamin C. In: Shils ME, Shike M, Ross AC, Caballero B, Cousins RJ (eds) Modern nutrition in health and disease. Lippincott Williams & Wilkins, Philadelphia
48. Bloomberg RD, Fleishman A, Nalle JE, Herron DM, Kini S (2005) Nutritional deficiencies following bariatric surgery: what have we learned? Obes Surg 15(2):145–154. https://doi.org/10.1381/0960892053268264
49. Lewis CA, de Jersey S, Seymour M, Hopkins G, Hickman I, Osland E (2020) Iron, Vitamin B12, folate and copper deficiency after bariatric surgery and the impact on anaemia: a systematic review. Obes Surg 30(11):4542–4591. https://doi.org/10.1007/s11695-020-04872-y
50. Komorniak N, Szczuko M, Kowalewski B, Stachowska E (2019) Nutritional deficiencies, bariatric surgery, and serum homocysteine level: review of current literature. Obes Surg 29(11):3735–3742. https://doi.org/10.1007/s11695-019-04100-2
51. Alexandrou A, Armeni E, Kouskouni E, Tsoka E, Diamantis T, Lambrinoudaki I (2014) Cross-sectional long-term micronutrient deficiencies after sleeve gastrectomy versus Roux-en-Y gastric bypass: a pilot study. Surg Obes Relat Dis 10(2):262–268. https://doi.org/10.1016/j.soard.2013.07.014
52. Al-Jafar H, Al-Zamil K, Al Ageeli M, Alhaifi M, Al-Sabah S (2018) Potential hematology and nutritional complications of bariatric surgery. Ann Hematol Oncol. https://doi.org/10.26420/annhematoloncol.2018.1209
53. Mahmood L (2014) The metabolic processes of folic acid and Vitamin B12 deficiency. J Health Res Rev 1(1):5
54. Chakhtoura MT, Nakhoul NN, Shawwa K, Mantzoros C, El Hajj Fuleihan GA (2016) Hypovitaminosis D in bariatric surgery: a systematic review of observational studies. Metabolism 65(4):574–585. https://doi.org/10.1016/j.metabol.2015.12.004
55. Shah M, Sharma A, Wermers RA, Kennel KA, Kellogg TA, Mundi MS (2017) Hypocalcemia after bariatric surgery: prevalence and associated risk factors. Obes Surg 27(11):2905–2911. https://doi.org/10.1007/s11695-017-2705-7
56. Lespessailles E, Toumi H (2017) Vitamin D alteration associated with obesity and bariatric surgery. Exp Biol Med (Maywood) 242(10):1086–1094. https://doi.org/10.1177/1535370216688567
57. Manzoni AP, Weber MB (2015) Skin changes after bariatric surgery. An Bras Dermatol 90(2):157–166. https://doi.org/10.1590/abd1806-4841.20153139
58. Bartholomay LM, Berlin K, McInerney M, Garcia L (2019) Vitamin K status in women of childbearing years before or after bariatric surgery. Curr Dev Nutr. https://doi.org/10.1093/cdn/nzz056
59. Sherf-Dagan S, Goldenshluger A, Azran C, Sakran N, Sinai T, Ben-Porat T (2019) Vitamin K—what is known regarding bariatric surgery patients: a systematic review. Surg Obes Relat Dis 15(8):1402–1413. https://doi.org/10.1016/j.soard.2019.05.031
60. Homan J, Ruinemans-Koerts J, Aarts EO, Janssen IMC, Berends FJ, de Boer H (2016) Management of vitamin K deficiency after biliopancreatic diversion with or without duodenal switch. Surg Obes Relat Dis 12(2):338–344. https://doi.org/10.1016/j.soard.2015.09.021
61. Pardo-Aranda F, Perez-Romero N, Osorio J, Rodriguez-Santiago J, Munoz E, Puertolas N, Veloso E (2016) Wernicke's encephalopathy after sleeve gastrectomy: literature review. Int J Surg Case Rep 20:92–95. https://doi.org/10.1016/j.ijscr.2016.01.016
62. Klick BH (2013) Thiamine deficiency in the bariatric surgery patient—a multidisciplinary challenge in the clinic and the community. Bariatr Times 10(1):20–21
63. Oudman E, Wijnia JW, van Dam M, Biter LU, Postma A (2018) Preventing Wernicke encephalopathy after bariatric surgery. Obes Surg 28(7):2060–2068. https://doi.org/10.1007/s11695-018-3262-4
64. Hansen EP, Metzsche C, Henningsen E, Toft P (2012) Severe scurvy after gastric bypass surgery and a poor postoperative diet. J Clin Med Res 4(2):135–137. https://doi.org/10.4021/jocmr726w
65. Concors SJ, Ecker BL, Maduka R, Furukawa A, Raper SE, Dempsey DD, Williams NN, Dumon KR (2016) Complications

and surveillance after bariatric surgery. Curr Treat Options Neurol 18(1):5. https://doi.org/10.1007/s11940-015-0383-0
66. Freeland-Graves JH, Lee JJ, Mousa TY, Elizondo JJ (2014) Patients at risk for trace element deficiencies: bariatric surgery. J Trace Elem Med Biol 28(4):495–503. https://doi.org/10.1016/j.jtemb.2014.06.015
67. Corbeels K, Verlinden L, Lannoo M, Simoens C, Matthys C, Verstuyf A, Meulemans A, Carmeliet G, Van der Schueren B (2018) Thin bones: Vitamin D and calcium handling after bariatric surgery. Bone Rep 8:57–63. https://doi.org/10.1016/j.bonr.2018.02.002
68. Freeth A, Prajuabpansri P, Victory JM, Jenkins P (2012) Assessment of selenium in Roux-en-Y gastric bypass and gastric banding surgery. Obes Surg 22(11):1660–1665. https://doi.org/10.1007/s11695-012-0680-6
69. Ems T, St Lucia K, Huecker MR (2020) Biochemistry, iron absorption. StatPearls, Treasure Island
70. Mischler RA, Armah SM, Craig BA, Rosen AD, Banerjee A, Selzer DJ, Choi JN, Gletsu-Miller N (2018) Comparison of oral iron supplement formulations for normalization of iron status following Roux-EN-y gastric bypass surgery: a randomized trial. Obes Surg 28(2):369–377. https://doi.org/10.1007/s11695-017-2858-4
71. Diniz Mde F, Diniz MT, Sanches SR, Salgado PP, Valadao MM, Araujo FC, Martins DS, Rocha AL (2004) Elevated serum parathormone after Roux-en-Y gastric bypass. Obes Surg 14(9):1222–1226. https://doi.org/10.1381/0960892042386959
72. Johnson JM, Maher JW, Samuel I, Heitshusen D, Doherty C, Downs RW (2005) Effects of gastric bypass procedures on bone mineral density, calcium, parathyroid hormone, and vitamin D. J Gastrointest Surg 9(8):1106–1110. https://doi.org/10.1016/j.gassur.2005.07.012 (**discussion 1110-1101**)
73. Carafoli E, Krebs J (2016) Why calcium? How calcium became the best communicator. J Biol Chem 291(40):20849–20857. https://doi.org/10.1074/jbc.R116.735894
74. Khazai N, Judd SE, Tangpricha V (2008) Calcium and vitamin D: skeletal and extraskeletal health. Curr Rheumatol Rep 10(2):110–117. https://doi.org/10.1007/s11926-008-0020-y
75. Gasmi A, Bjorklund G, Peana M, Mujawdiya PK, Pivina L, Ongenae A, Piscopo S, Severin B (2021) Phosphocalcic metabolism and the role of vitamin D, vitamin K2, and nattokinase supplementation. Crit Rev Food Sci Nutr. https://doi.org/10.1080/10408398.2021.1910481
76. Ernst B, Thurnheer M, Schultes B (2009) Copper deficiency after gastric bypass surgery. Obesity (Silver Spring) 17(11):1980–1981. https://doi.org/10.1038/oby.2009.237
77. Salle A, Demarsy D, Poirier AL, Lelievre B, Topart P, Guilloteau G, Becouarn G, Rohmer V (2010) Zinc deficiency: a frequent and underestimated complication after bariatric surgery. Obes Surg 20(12):1660–1670. https://doi.org/10.1007/s11695-010-0237-5
78. Yahalom M, Koren O, Rozner E, Turgeman Y (2019) Cardiomyopathy associated with zinc deficiency after bariatric surgery. Int J Angiol 28(2):145–146. https://doi.org/10.1055/s-0038-1666848
79. Papamargaritis D, Aasheim ET, Sampson B, le Roux CW (2015) Copper, selenium and zinc levels after bariatric surgery in patients recommended to take multivitamin-mineral supplementation. J Trace Elem Med Biol 31:167–172. https://doi.org/10.1016/j.jtemb.2014.09.005
80. Shankar P, Boylan M, Sriram K (2010) Micronutrient deficiencies after bariatric surgery. Nutrition 26(11–12):1031–1037. https://doi.org/10.1016/j.nut.2009.12.003
81. Billeter AT, Probst P, Fischer L, Senft J, Kenngott HG, Schulte T, Clemens G, Zech U, Büchler MW, Nawroth PP, Müller-Stich BP (2015) Risk of malnutrition, trace metal, and vitamin deficiency post Roux-en-Y gastric bypass—a prospective study of 20 patients with BMI <35 kg/m^2. Obes Surg 25(11):2125–2134. https://doi.org/10.1007/s11695-015-1676-9
82. Mohapatra S, Gangadharan K, Pitchumoni CS (2020) Malnutrition in obesity before and after bariatric surgery. Dis Mon 66(2):100866. https://doi.org/10.1016/j.disamonth.2019.06.008
83. Zoroddu MA, Aaseth J, Crisponi G, Medici S, Peana M, Nurchi VM (2019) The essential metals for humans: a brief overview. J Inorg Biochem 195:120–129. https://doi.org/10.1016/j.jinorgbio.2019.03.013
84. Hassan Zadeh M, Mohammadi Farsani G, Zamaninour N (2019) Selenium status after Roux-en-Y Gastric bypass: interventions and recommendations. Obes Surg 29(11):3743–3748. https://doi.org/10.1007/s11695-019-04148-0
85. Riess KP, Farnen JP, Lambert PJ, Mathiason MA, Kothari SN (2009) Ascorbic acid deficiency in bariatric surgical population. Surg Obes Relat Dis 5(1):81–86. https://doi.org/10.1016/j.soard.2008.06.007
86. Gowanlock Z, Lezhanska A, Conroy M, Crowther M, Tiboni M, Mbuagbaw L, Siegal DM (2020) Iron deficiency following bariatric surgery: a retrospective cohort study. Blood Adv 4(15):3639–3647. https://doi.org/10.1182/bloodadvances.2020001880
87. von Drygalski A, Andris DA (2009) Anemia after bariatric surgery: more than just iron deficiency. Nutr Clin Pract 24(2):217–226. https://doi.org/10.1177/0884533609332174
88. Velazquez A, Apovian CM, Istfan NW (2017) The complexities of iron deficiency in patients after bariatric surgery. Am J Med 130(7):e293–e294. https://doi.org/10.1016/j.amjmed.2017.01.040
89. Knight T, D'Sylva L, Moore B, Barish CF (2015) Burden of iron deficiency anemia in a bariatric surgery population in the United States. J Manag Care Spec Pharm 21(10):946–954. https://doi.org/10.18553/jmcp.2015.21.10.946
90. Majumder S, Soriano J, Louie Cruz A, Dasanu CA (2013) Vitamin B12 deficiency in patients undergoing bariatric surgery: preventive strategies and key recommendations. Surg Obes Relat Dis 9(6):1013–1019. https://doi.org/10.1016/j.soard.2013.04.017
91. Shil RSK, Alomar AF, Farooqui MR (2015) Ataxia and weakness after sleeve gastrectomy. Saudi J Obesity 3(1):26
92. Ruiz-Tovar J, Oller I, Llavero C, Zubiaga L, Diez M, Arroyo A, Calero A, Calpena R (2014) Hair loss in females after sleeve gastrectomy: predictive value of serum zinc and iron levels. Am Surg 80(5):466–471
93. Ledoux S, Flamant M, Calabrese D, Bogard C, Sami O, Coupaye M (2020) What are the micronutrient deficiencies responsible for the most common nutritional symptoms after bariatric surgery? Obes Surg 30(5):1891–1897. https://doi.org/10.1007/s11695-020-04412-8
94. Ciangura C, Coupaye M, Deruelle P, Gascoin G, Calabrese D, Cosson E, Ducarme G, Gaborit B, Lelievre B, Mandelbrot L, Petrucciani N, Quilliot D, Ritz P, Robin G, Salle A, Gugenheim J, Nizard J (2019) Clinical practice guidelines for childbearing female candidates for bariatric surgery, pregnancy, and post-partum management after bariatric surgery. Obes Surg 29(11):3722–3734. https://doi.org/10.1007/s11695-019-04093-y
95. Kominiarek MA (2011) Preparing for and managing a pregnancy after bariatric surgery. Semin Perinatol 35(6):356–361. https://doi.org/10.1053/j.semperi.2011.05.022
96. Bronnimann A, Jung MK, Niclauss N, Hagen ME, Toso C, Buchs NC (2020) The impact of pregnancy on outcomes after bariatric surgery. Obes Surg 30(8):3001–3009. https://doi.org/10.1007/s11695-020-04643-9
97. Shawe J, Ceulemans D, Akhter Z, Neff K, Hart K, Heslehurst N, Stotl I, Agrawal S, Steegers-Theunissen R, Taheri S, Greenslade B, Rankin J, Huda B, Douek I, Galjaard S, Blumenfeld O, Robinson A, Whyte M, Mathews E, Devlieger R (2019) Pregnancy

after bariatric surgery: consensus recommendations for periconception, antenatal and postnatal care. Obes Rev 20(11):1507–1522. https://doi.org/10.1111/obr.12927
98. Harreiter J, Schindler K, Bancher-Todesca D, Gobl C, Langer F, Prager G, Gessl A, Leutner M, Ludvik B, Luger A, Kautzky-Willer A, Krebs M (2018) Management of pregnant women after bariatric surgery. J Obes 2018:4587064. https://doi.org/10.1155/2018/4587064
99. Armstrong C (2010) ACOG guidelines on pregnancy after bariatric surgery. Am Fam Physician 81(7):905
100. Mechanick JI, Kushner RF, Sugerman HJ, Gonzalez-Campoy JM, Collazo-Clavell ML, Spitz AF, Apovian CM, Livingston EH, Brolin R, Sarwer DB, Anderson WA, Dixon J, Guven S (2009) American Association of Clinical Endocrinologists, The Obesity Society, and American Society for Metabolic and Bariatric Surgery medical guidelines for clinical practice for the perioperative nutritional, metabolic, and nonsurgical support of the bariatric surgery patient. Obesity (Silver Spring) 17(Suppl 1):S1–S70. https://doi.org/10.1038/oby.2009.28
101. Lapolla A, Marangon M, Dalfra MG, Segato G, De Luca M, Fedele D, Favretti F, Enzi G, Busetto L (2010) Pregnancy outcome in morbidly obese women before and after laparoscopic gastric banding. Obes Surg 20(9):1251–1257. https://doi.org/10.1007/s11695-010-0199-7
102. ACOG (2009) Practice bulletin no. 105: bariatric surgery and pregnancy. Obstet Gynecol 113(6):1405–1413. https://doi.org/10.1097/AOG.0b013e3181ac0544