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Review Article

Potential Hematology and Nutritional Complications of Bariatric Surgery

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Abstract

Bariatrics is a specialized field of medicine that deals with the etiology, prevention and management of patients with morbid obesity. Surgical and nutritional complications are two adverse effects associated with bariatric surgery. For patients in recovery, post-bariatric surgical treatment and management often involves the care of a hematologist. Long term nutritional problems may develop following bariatic surgery and should be considered by physicians, although long-term nutritional complications are often rare or just temporary. Multivitamin and iron supplementation are required as part of a patient's prophylactic post-bariatric surgical management protocol; therefore, the patient's adherence to vitamin supplementation should be checked during follow up appointments. This review aims to emphasize the potential multi systemic hematological and nutritional complications of bariatric surgery. Vitamin deficiencies such as iron and vitamin B12 sometimes affect patients and therefore physicians should be aware of this in the treatment of patients with a history bariatric surgery. Inquiring about a patient's history of bariatric surgery needs to be one of the first questions to ask a patient who is presenting with vitamin deficiencies as this can cause multi system abnormalities. Many patients are lost to follow up after bariatric surgery and come back with complications. Therefore, the importance of maintaining follow up appointments should be emphasized.

Keywords: Bariatric; Hematology; Nutrition; Vitamins

Introduction

The term "bariatric" was used for the first time on 1965 [1]. Bariatrics in medicine deals with the etiology, prevention and management of morbid obesity. Body Mass Index (BMI) is derived from a patient's weight and height to assess the degree of obesity [2]. The BMI is widely applicable in various clinical fields as it is necessary to assess the dose of many drugs [3]. Bariatric surgery is currently the most used and effective measure to treat patients with morbid obesity and to help reduce metabolic disorders such as Diabetes mellitus, dyslipidemia and hypertension [4]. The U.S. National Institutes of Health recommends bariatric surgery for obese people with a BMI of 40 kg/m^2 [5]. Indication for bariatric surgery could be appropriate for those individuals with a BMI of 35-40 kg/m^2 without comorbidities or a BMI of 30-35 kg/m^2 with significant comorbidities [6]. Obesity is associated with severe fat deposition in many organs that may cause serious, adverse effects on health [7] and individuals with BMIs exceeding the healthy range have a much greater risk for medical issues [8]. Usually, exercise, diet and behavior therapy should be the first-line of treatment for individuals with obesity [9], as medical therapy for severe obesity has limited short and long-term success [10]. Bariatric surgery often leads to improvements in a patient's quality of life and obesity-related diseases [11]; moreover, improvements in psychological health have also been observed [12]. Major complications due to bariatric surgery have been reported in 3.3% of patients [13]. Surgical complications may occur as adverse events early in the post-operative period, especially in those excessively overweight [14]. Nutritional complications are considered late side effects and require attention by the treating surgeon. These complications are often associated with gastrointestinal malabsorption which needs to be addressed to prevent chronic health conditions such as neurological complications associated with long-standing severe vitamin B_{12} deficiency [15].

I-Potential Surgical Complications

Bleeding

Bleeding is an adverse outcome in many types of surgical procedures. However, the amount of bleeding can be reduced by adequate pre-operative assessment to identify and correct disorders due to other comorbidities. Surgical bleeding can arise from technical causes as well as the presence of a bleeding disorder [16]. The onset of early bleeding is usually ≤ 24 hours after the end of the surgery, the location is either intraluminal or extra luminal, and the severity of the bleeding may be either mild or severe [17]. Bleeding due to a disorder can be categorized into three groups: disorders of platelet function or number, disorders of clotting factors, or a combination of these, and thirdly, the bleeding could be due to vascular or pathological localized lesions [18]. The incidence of bleeding ranges between 0% and 4.4% and varies according to the different procedures performed. However, bleeding remains a known and limited complication in bariatric surgery [19].

Thrombosis

Deep Vein Thrombosis (DVT) is one of the serious complications of bariatric surgery in patients with morbid obesity. Patients with postoperative DVT could be asymptomatic [20] or DVT could simply manifest as chronic venous hypertension, which subsequently develops into varicose veins. Factors that could influence thrombus

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Table 1: The effect of trace elements deficiency on hematology aspect.

Trace Element deficiency	Hematological manifestations
Thiamine (B_1)	Megaloblastic anemia [39]
Riboflavin (B_2)	normochromic normocytic anemia, megaloblastic anemia [43]
Niacin (B_3)	Anemia [46]
Pantothenic (B_5)	Anemia [46,51]
Pyridoxine (B_6)	sideroblastic microcytic anemia [53].
Biotin (B_7)	Anemia [56]
Folate (B_9)	Macrocytic, megaloblastic anemia [46], hemorrhage [59]
Vitamin B_{12}	Megaloblastic anemia, microcytic and hypochromic anemia. [59,64]
Vitamin A	Normocytic and normochromic anemia [70,71]
Vitamin C	Bleeding disorder and anemia [74]
Vitamin D	Anemia [76]
Vitamin E	Anemia· Hemolysis of RBC [48,74,83]
Vitamin K	Bleeding disorder [84,87]
Iron	Microcytic and hypochromicanemia, mild thrombocytosis, chronic bleeding [29,91,93]
Copper	Microcytic, macrocytic and neutropenia [104], Thrombocytopenia is unusual [105]
Magnesium	Iron deficiency anemia [112]
Selenium	Anemia [115]
Chromium	Iron deficiency anemia [117]
Calcium	Iron deficiency anemia [91]
Phosphorus	Anemia [102]
Zinc	Anemia [70]

formation are alterations in blood flow, changes in the vessel wall, alterations in blood constituents and viscosity, and inhibition of the fibrinolysis system. Once DVT occurs, the fate of the thrombus depends on the persistence of factors involved in its formation. Many thrombi will spontaneously lyse or will shrink, but others may extend and embolize, posing a threat to the patient [21]. The reported incidence of DVT after bariatric surgery varies widely, from 0.2% to1.3% at 30 days [22] and to 0.42% at 90 days [23].

Embolism

All patients who undergo surgery are at risk for Pulmonary Embolism (PE). During surgery, PE often initially manifests as hemodynamic instability [24]. PE occurs in approximately 0.3% to 1.6% of the general population that undergoes surgery [25]. The initial hemodynamic insult in PE is the obstruction of blood flow, which causes emboli in the pulmonary vasculature that disrupt pulmonary outflow, cause an acute increase in right ventricular impedance, and initiate neural reflexes and the release of pulmonary vasoconstrictors into the circutation [26]. The reported incidence of PE in patients undergoing open bariatric surgery with prophylaxis measures ranges from 0.36% to 3.0% [27].

II-Potential Nutritional Complications

A-Vitamin Deficiencies

Micronutrients, including trace elements, water, and fat-soluble vitamins can become depleted in patients during the post-bariatric surgical recovery period, and such elements are essential factors that mainly serve as enzymatic cofactors in biochemical pathways and metabolic processes [28]. Micronutrient deficiencies vary in frequency according to the type of surgery performed [29,30]. Adverse events after bariatric surgery can lead to a wide range of symptoms, most commonly anemia (10%-74%) and neurological dysfunction (5%-9%) [31,32]. Determining the exact risk for developing micronutrient deficiencies is challenging as there is no consensus on the appropriate amount of vitamin and mineral supplementation required across bariatric surgery programs, and therefore, supplementation practices vary widely [33]. It is clear that micronutrient deficiencies are relatively common in patients before and after all types of bariatric surgery; therefore, it is important to screen patients at baseline and at least annually [34].

Thiamine (vitamin B_1) deficiency

Thiamine deficiency is common after bariatric surgery lead to the combination of a reduction in acid production by the gastric pouch, restriction of food intake, and frequent episodes of vomiting [35,36]. Thiamine deficiency accompanied by peripheral neuropathy is characterized by polyneuropathy with paresthesia of the extremities, especially the legs, reduced knee-jerk and other tendon reflexes, severe progressive weakness, muscle wasting, and increased susceptibility to infections [37]. Thiamine deficiency is associated with a condition called Beriberi syndrome, which presents as mental confusion, anorexia, muscular weakness, ataxia, peripheral paralysis, tachycardia; thiamine deficiency associated with edema is known as wet beriberi [38]. Red blood cell megaloblastic changes in thiamine deficiency could cause megaloblastic anemia [39], which is reversible and could be corrected with pharmacologic doses of thiamine

(vitamin B1) [40] (Table 1).

Riboflavin (vitaminB_2)

Riboflavin deficiency can cause neurodegenerative disorders [41,42]. Owing to its effects on iron, mild to moderate riboflavin deficiency results in anemia despite average cell sizes and normal intra corpuscular hemoglobin content (normochromic normocytic anemia). This type of anemia caused by the combined deficiency of riboflavin (vitamin B_2) and folic acid (B_9) or cyanocobalamin (B_{12}), usually causes megaloblastic anemia [43].

Niacin (vitamin B_3) deficiency

Niacin deficiency can cause pellagra and alterations in protein metabolism, and eventually malnutrition. Symptoms include eczema, intestinal and stomach distress, depression, headache, and thinning of the hair [44,45]. Additional possible symptoms of mild vitamin B_3 deficiency include anemia, skin lesions, diarrhea, insomnia, forgetfulness, irritability, nervousness, and other psychological symptoms [46].

Pantothenic acid (vitamin B_5) deficiency

Pantothenic acid is an essential component of the coenzyme A, which is a cofactor in many enzymatic reactions crucial to the metabolism of carbohydrates, fats, corticosteroids, and sex hormones. Pantothenic acid deficiency is rare in humans and depends on the proper functioning of the adrenal glands and nervous system. Nevertheless, this vitamin is important for healthy growth and development throughout life [47,48]. Symptoms of deficiency are similar to those observed in other vitamin B deficiencies: irritability, fatigue, apathy, and hypoglycemia or increased sensitivity to insulin. In cases of pantothenic acid deficiency, more insulin will bind to receptors, thus causing hypoglycemia [49]. Additional symptoms could include restlessness, malaise, sleep disturbances, nausea, vomiting, abdominal cramps, insomnia, anemia, vomiting, muscle contractions, and abnormal skin features. Deficiency of pantothenic acid is also associated with a condition called burning feet syndrome [50,51].

Pyridoxine (vitamin B_6)

Pyridoxine acts as a coenzyme in many reactions including fatty acid and amino acid metabolism [52]. Therefore, it is important for the blood, central nervous system, and skin metabolism. Vitamin B_6 deficiency could lead to seborrheic dermatitis, glossitis, cheilosis, peripheral neuropathy, and lymphopenia [48]. Severe vitamin B6 deficiency may cause sideroblastic microcytic anemia due to decreased hemoglobin synthesis, seizures that are refractory to conventional medications, convulsions, and peripheral neuropathy [53].

Biotin (vitamin B_7) deficiency

Biotin deficiency typically occurs due to the dietary absence of the vitamin or malabsorption but can be addressed via nutritional supplementation [54,55]. Lack of vitamin B_7 may cause symptoms of anemia [56]; brittle and thin fingernails; hair loss; conjunctivitis; dermatitis; and red rashes around the eyes, nose, mouth, and genital area. In adults, neurological defects manifest as depression, lethargy, numbness, hallucinations, and tingling of the extremities [55].

Folate (vitamin B_9) deficiency

The prevalence of folate deficiency after bariatric surgery has been reported to be 9%-39% and is often reported in women who become pregnant after bariatric surgery [57,58]. Folate deficiency may be a consequence of vitamin B_{12} deficiency since the latter plays a vital role in the conversion of the inactive methyltetrahydrofolic acid to active tetrahydrofolic acid [59]. The deficiency of folic acid can lead to megaloblastic anemia. Folate is essential for the prevention of neural tube defects in infants; therefore, women considering pregnancy following bariatric surgery to treat obesity should receive counseling before conception and prophylactic supplementation of folate and vitamin B_{12} [60]. Folate deficiency can easily be corrected via oral vitamin supplementation [61].

Cobalamin (vitamin B_{12}) deficiency

Cobalamin deficiency could occur after bariatric surgery procedures that bypass the lower stomach [62,63]. Potential complications from vitamin B_{12} deficiency include megaloblastic anemia, generalized weakness, neuropathy, and cognitive difficulties [64]. Bariatric surgery patients are at increased risk of developing vitamin B12 deficiency because their digestive tracts have been altered in such way that it interferes with the natural absorption of this vitamin [65]. In healthy adults, an intrinsic factor released by the parietal cells in the stomach binds with vitamin B_{12} in the duodenum. The bound vitamin B_{12} is absorbed in the ileum [66]. The daily recommended oral supplementation dose is 350-600 ug per day, which has shown to correct the deficiency in 81%-95% of patients [67]. Intramuscular vitamin B_{12} injections are another option for patients who have trouble adhering to daily oral supplements [28].

Vitamin A deficiency

Vitamin A deficiency after bariatric surgery to manage obesity can be observed in 61%-69% of patients [68,69]. Being a fat-soluble vitamin, an approximately one year's supply of vitamin A can be stored in the liver, resulting in deficiencies to manifest much later; this is also true for other fat-soluble vitamins, proteins, and zinc. Vitamin A appears to be involved in the pathogenesis of anemia through diverse biological mechanisms such as enhancement of growth, differentiation of erythrocyte progenitor cells, potentiation of immunity to infection, and reduction of iron reserves in tissues [70]. Symptoms of vitamin A deficiency include pathological manifestations affecting the eye, skin problems, mucous membranes, dry hair, broken nails, and increased risk for infections. Exophthalmia is a condition characterized by abnormal dryness of the conjunctiva and cornea of the eye with inflammation and ridge formation, which is typically associated with vitamin A deficiency. Vitamin A deficiency also may contribute to iron deficiency [71].

Vitamin C deficiency

Vitamin C or ascorbic acid is essential for the hydroxylation of proline and lysine in collagen [72,73]. Vitamin C deficiency results in scurvy, which is characterized by the degeneration of capillaries, bone, and connective tissue, leading to perifollicular petechial rash, poor wound healing, and bleeding of the gums. Early symptoms of vitamin C deficiency, occurring within 1 to 3 months, include fatigue and myalgia, weakness, anemia, gum disease, and skin hemorrhage. This condition usually occurs in malnourished adults [74]. Biochemical evidence of vitamin C deficiency is common, it reported prevalence 10%-50% after bariatric surgery [65]. Vitamin C deficiency can be successfully treated with supplementation of 500 mg once daily and

complete remission can be achieved after one month [28]. However, a significant adverse effect due to vitamin C deficiency after bariatric surgery is rare [74].

Vitamin D deficiency

Vitamin D is mainly responsible for the formation and health of red blood cells. Since vitamin D is needed for iron metabolism a deficiency of vitamin D may cause anemia [75,76]. Severe vitamin D deficiency can lead to fatigue, weakness, general muscle pain, joint pain, muscle cramps, chronic pain, restless sleep, headaches, poor concentration, bladder problems, and gastrointestinal problems [77]. Vitamin D deficiency is common following bariatric surgery and has been reported to occur in 50%-80% of patients [78]. Coates, et al. studied bone metabolism in 25 patients at 9 months following bariatric surgery and found that bone mineral density and content were significantly diminished when the patients were compared to 30 obese control patients [79]. Brolin, et al. found that 51% of post-bariatric surgery patients had significant vitamin D deficiencies at the 2-year follow-up [80].

Vitamin E deficiency

Vitamin E is involved in several processes including antioxidant immunomodulation [81,82]. Vitamin E deficiency has been reported in up to 22% of bariatric surgery patients. Post-bariatric surgery neurological symptoms could manifest in the form of ataxia, muscle weakness, peripheral neuropathy, or unexplained anemia [83]. Vitamin E deficiency also may hemolysis red blood cells, defective embryogenesis, and capillary permeability disorders [48].

Vitamin K deficiency

Vitamin K acts as a critical cofactor in the carboxylation of glutamic acid residues in several proteins as well as proteins involved in bone homeostasis (e.g., osteocalcin) [84]. Vitamin K has a rapid turnover and minimal body reservoirs [85]. Traditionally, vitamin K status is accessed via functional assays such as prothrombin time [86]. Symptoms of vitamin K deficiency include bleeding, arteriosclerosis, and osteoporosis [87]. Bleeding is a primary manifestation of vitamin K deficiency. Easy mucosal bleeding especially epistaxis, gastrointestinal hemorrhage, menorrhagia, and hematuria could occur [48]. Vitamin K deficiency should be treated with 10 mg injection supplements, followed by 1-2 mg/week administered parenterally or orally [88].

B-Mineral Deficiencies

Iron deficiency

Iron deficiency is common and the earliest nutritional deficiency to occur following bariatric surgery, occurring in up to 12%-47% of patients [89,90]. Symptoms of iron deficiency anemia include fatigue, palpitations, anxiety, hair loss, feeling cold [29]. Laboratory tests for determining iron deficiency should include serum ferritin levels, serum iron, transferrin saturation, total iron binding capacity, mean corpuscular hemoglobin, and hemoglobin level. The typical presentation of iron deficiency with anemia is elevated total iron binding capacity, with low values for all other hematological parameters [91]. Iron deficiency has been reported in up to 44% of adults before bariatric surgery, which may contribute to the persistence of iron deficiency post-operatively if not identified and treated [92]. Hypoferritinemia without Anemia (HWA) seen in many post-bariatric patients is a disorder that requires correction of serum ferritin levels [93]. Post-bariatric surgery iron supplementation is necessary in most cases [30,94]. Refractory responses to oral iron supplementation might necessitate parenteral iron therapy or even blood transfusions [95].

Calcium deficiency

Calcium is a necessary element for human life; 99% of the calcium in the body is stored in teeth and bones [96,97]. Calcium helps the heart, brain, nerves, and muscles, and promotes blood clotting. Calcium deficiency develops in up to 48% of patients that undergo malabsorptive bariatric surgery. Common manifestations include muscle spasms, back and leg cramps, depression, aching joints, eczema, insomnia, cognitive impairment, and convulsions. If calcium deficiency is severe or acute, it can cause muscle spasm or cramping, tingling, burning sensation around the mouth and fingertips, seizures, and tremors [98]. The chances of osteoporosis in older patient's post- bariatric surgery are higher [99]. Iron deficiency anemia could also be related to calcium intake in such patients. Treatment includes ensuring a balanced phosphorous to calcium ratio. Products containing phosphoric acid may worsen the calcium deficiency, as it increases calcium excretion, such as dark colas, bottled teas, and flavored waters [91].

Phosphorus deficiency

Phosphorus has several functions in the human body. It is a major component of bones, DNA-RNA, ATP (the primary energy producer in the body), and phospholipids. Phosphorus is also essential for maintaining the acid-base balance in the body [100]. Deficiency is rare because phosphorus is widely available in food. However, bariatric surgery, alcoholism, and certain medicines can cause low levels of phosphorus, known as hypophosphatemia [101]. Symptoms of deficiency include anorexia, anemia, muscle weakness, bone pain, confusion, increased susceptibility to infection, difficulty walking and, in severe cases, death [102].

Copper deficiency

Copper deficiency is a well-documented cause of hematologic abnormalities, including anemia with neutropenia [103,104]. Copper is required for iron mobilization in the body; thus, copper deficiency manifests as iron deficiency, which results in low concentrations of red blood cells and white blood cells [105]. Studies have shown that the level of serum copper decreases following bariatric surgery [106]. The prevalence of copper deficiency ranges from 4%-18% [107]. Another concern is that anemia due to copper deficiency is often misdiagnosed as iron and vitamin B_{12} deficiency. The neurological symptoms such as unsteady gait, extremity numbness, tingling in the hands and feet [108], leukopenia, pain, impaired wound healing, paresthesia, or paralysis may be irreversible [109].

Magnesium deficiency

Magnesium is an important element that activates more than 300 enzymes in the human body [110] and is often found to be deficient in patients after bariatric surgery. Magnesium assists in maintaining the muscle and nerve function in the human body. People with magnesium deficiency are often tired, irritable, nervous, experience muscle stiffness and difficulty in concentrating. Magnesium deficiency is linked to various pathological conditions such as those

affecting bones, heart, muscular system, emotional and dental health, as well as stroke, diabetes, stress, depression, and anxiety. Therefore, magnesium deficiency disrupts biochemical functions in the human body, especially in the nervous system [111]. Magnesium deficiency could lead to anemia, as low magnesium levels cause the red blood cell membranes to become more fragile and easily damaged. Heaton, et al. revealed that anemia could develop during magnesium deficiency due to changes in the red blood cell membrane, which is the primary reason for the underlying disturbances in cellular metabolism [112].

Selenium deficiency

Selenium is a component of the glutathione peroxidase enzyme. It helps prevent cell damage caused by free radicals. The prevalence of selenium deficiency following bariatric surgery has been estimated at up to 20% [113]. Currently, no sufficient evidence supports the need for routine selenium screening or supplementation after bariatric surgery to treat selenium deficiency [114]. Selenium levels need to be checked in patients who have undergone malabsorptive surgical procedures who develop anemia, fatigue, cardiomyopathy, heart palpitations, impaired immunity, infertility, and myalgia [115].

Chromium deficiency

Patients who undergo bariatric surgery are at risk for low chromium intake. Even a mild chromium deficiency could generate problems in blood sugar metabolism and contribute to other symptoms such as anxiety or fatigue [116]. Chromium is considered to work synergistically with iron, and its deficiency can thus lead to iron deficiency [117].

Zinc deficiency

Zinc is a trace mineral co-factor used in various enzymes involved in protein synthesis, digestion, and regulation of gene transcription [118]. Zinc is also essential to maintain immune function. Specifically, zinc is vital for T-cell growth, differentiation, and apoptosis, which kill dangerous bacteria, viruses, and cancer cells. It is also a critical structural component of hormone receptors and proteins that contribute to a healthy, balanced mood [119]. Manifestations of zinc deficiency include respiratory, gastrointestinal symptoms and bacterial infections due to low immunity [120], skin lesions, poor wound healing, dermatitis, hair loss, alopecia, and glossitis - symptoms similar to vitamin B_{12} deficiency [121]. During inflammation, there is an increased cellular demand for zinc [122]. Zinc deficiency has been reported in 36%-51% of patients who underwent bariatric surgery [123,124].

Other micronutrients such as proteins are vehicles for the functions of metabolism, digestion, and DNA replication [125,126]. They frame the structure of cells such as those of the hair, skin, and nails. Proteins also help the body combat infection by strengthening the immune system [127]. Low intake of protein during post-bariatric surgical recovery may lead to mild to moderate anemia [128]. Anemia-like symptoms of protein deficiency include lethargy, easy fatigue, headaches, and muscle wasting. Following bariatric surgery, women require 60-80 g of protein daily, and men 70-90 g per day Measurement of albumin levels is a useful approach for assessing the protein status [91,125].

Prophylactic and Supplementary Measures

A prophylactic anticoagulants protocol for post-bariatric surgery could be a useful tool to prevent thrombosis in such morbid obesity patients; also a supplementary protocol with mega doses of micronutrients should be implemented before bariatric surgery especially for patients with nutritional deficiencies [129]. Multi-vitamin supplementation is recommended after bariatric procedures [130]. The importance of postoperative dietary supplementation for bariatric surgery has been widely recognized by researchers and clinicians [131]. Recent studies continue to report nutrient deficiencies after bariatric surgery, which should always be monitored and treated [132]. Difficulties in swallowing pills were identified as a primary barrier to adherence to multivitamins and other trace elements besides malabsorption [61]. Such patients could benefit from intravenous administration of multivitamins [133].

Conclusion

Bariatric surgery is a new approach for management of diabetes mellitus, various metabolic disorders and psychological problems due to morbid obesity. Over the past three decades, a substantial amount of research has been conducted regarding the complications associated with bariatric surgery; however, the authors think it is a safe procedure when the hematological and nutritional precautions are put into place and the necessary investigations and prophylactic measures are performed. As this type of surgery has become very popular, it is important that physicians perform thorough medical history for the possiblety that the patient with obsecure complains may have history of bariatric surgery because some patient forget to mention that in their medical history and being aware of the potiential complications will help to ensure safe and effective outcomes.

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