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REVIEW

Nutrition, Physical Activity, and Prescription of Supplements in Pre- and Post-bariatric Surgery Patients: An Updated Comprehensive Practical Guideline

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Abstract

Only in the USA, 315 billion dollars are spent annually on the medical cost of obesity in adult patients. Till now, bariatric surgery is the most effective method for treating obesity and can play an essential role in reducing the direct and indirect costs of obesity treatment. Nonetheless, there are few comprehensive guidelines which include nutrition, physical activity, and supplements, before and after surgery. The purpose of the present narrative review is to provide an updated and comprehensive practical guideline to help multidisciplinary teams. The core keywords include nutrition, diet, physical activity, exercise, supplements, macronutrients, micronutrients, weight reduction, bariatric surgery, Roux-en-Y Gastric Bypass, Sleeve Gastrostomy, Laparoscopic Adjustable Gastric Banding, and Biliopancreatic diversion with duodenal switch which were searched in databases including PubMed/Medline, Cochrane, and some other sources such as Google Scholar. We answered questions in five important areas: (a) nutritional strategies before bariatric surgery, (b) nutrition after bariatric surgery, (c) physical activity before and after bariatric surgery, (d) weight regain after bariatric surgery, and (e) micronutrient assessments and recommendations before and after bariatric surgery. Some new items were added in this updated guideline including "weight regain" and "pregnancy after bariatric surgery." Other fields were updated based on new evidence and guidelines.

Keywords Nutrition · Physical activity · Supplements · Bariatric surgery

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Nutritional Strategies Before Bariatric Surgery

Is It Beneficial to Lose Weight or Follow a Calorie-Restricted Diet Before Bariatric Surgery?

Bariatric surgery is considered more effective than medical therapy for treating morbid obesity and obesity-related conditions [1–4]. It is usually recommended to have a calorie-restricted diet preoperatively in order to reduce perioperative complications. Nevertheless, there is conflicting evidence on whether using low-energy diets and weight loss before bariatric surgery can effectively improve post-operation outcomes and reduce surgical risks.

Many studies have reported that a low-energy diet is not only recommended to reduce weight and BMI before bariatric surgery but also suggested more for its positive effects on technical challenges of surgery, such as conversion rate to laparotomy and operation time. Up to 85–90% of morbid obese patients have non-alcoholic fatty liver disease

(NAFLD) characterized by an enlarged liver [5, 6], so reducing weight or daily calorie intake can lower the liver volume, especially the left lobe and improve the technical difficulties of bariatric surgery. In addition, perioperative complications (blood loss, anastomotic leak or ulcers) and, subsequently, hospital stay decrease due to the reduction of liver size, intrahepatic and visceral fat content, and abdominal wall thickness [7–13]. Furthermore, dietary management before bariatric surgery may improve weight loss after surgery [14–18] or prepare the patient for post-operative nutrition changes [19]. Authors may also suggest pre-operative weight loss because of its effects on glycemic control, blood pressure, lipid profile, and body composition [19–22]. The benefits of weight loss before surgery are summarized in Table 1.

However, some studies have shown inconsistent results on the protective effects of pre-operative calorie restriction or weight loss on perioperative risks [31, 32] and the successfulness of post-operative weight loss [33–36]. According to some existing evidence, lesser pre-operative weight loss may be associated with more post-operative weight reduction [37], and weight gain before surgery may not be associated with lower weight loss after surgery [38], although there are studies that support patients who lost more weight before surgery can lose more weight after surgery [39, 40].

Despite this conflicting evidence, we recommend that the bariatric surgery multidisciplinary team advise all candidates to follow a low-calorie diet before surgery to achieve its potential benefits, especially people who have enlarged liver, BMI above 50 kg/m^2, greater waist circumference, and thicker abdominal wall or intra-abdominal fat [41–45]. Nevertheless, losing weight is not mandatory because some patients cannot reach the target weight loss or even gain weight during the pre-operative period. Therefore, they should not be prohibited from surgery which is the most effective treatment approach for severely obese patients to get closer to a healthy life. Instead, dietary management before surgery should be suggested by the bariatric surgery team through nutrition counseling and individualized to each patient's condition.

What Is the Target of Successful Pre-operative Weight Loss?

Generally, at least a 10% weight reduction or 5% excess body weight reduction is considered the goal of weight loss within 2 to 12 weeks before surgery. However, the ideal weight loss may vary slightly in different studies. The mentioned amount of weight loss might be associated with liver volume reduction, surgical difficulties, and outcomes improvement [40, 46, 47].

Table 1 The benefits of pre-bariatric weight loss

Effect	Outcomes
Increase	Pre-operative excess weight loss [23]
	Post-operative weight loss [12]
Decrease	Pre-operative BMI [9, 24]
	Liver size or volume [9–11, 13, 25, 26]
	Intrahepatic fat content [11, 25, 26]
	Visceral adipose tissue [8]
	Abdominal wall depth [8]
	Technical challenges of surgery and conversion rate of operation [8, 26]
	Operative time [12, 23, 27]
	Perioperative blood loss [28]
	Post-operative complication rates [7, 8]
	Post-operative hospitalization after lap-GBP [29]
	Anastomotic ulcers in patients treated by LCD, 1 month after lap-GBP [30]
Improvement	Body composition [24]
	Medical comorbidities •Obesity-related comorbidities [25] •Systolic and diastolic blood pressure [10] •Metabolic profile (fasting glucose, fasting insulin, LDL, and TAG) [10]
	Access to the gastro-oesophagal junction and upper stomach and retraction of the left lobe of the liver without damage to it [9, 11, 26] •Facilitation of lap-GBP [16] or LRYGBP [10]
	Body composition [24]

BMI body mass index, *LCD* low-calorie diet, *lap-GBP* laparoscopic gastric bypass, *LRYGBP* laparoscopic Roux-en-Y gastric bypass, *LDL* low-density lipoprotein, *TAG* triacylglycerol

What Is the Best Duration for Pre-operative Diet Therapy?

The duration of a pre-operative diet therapy varies from a few days to a few months in the literature, depending on the diet type and composition and the diet prescription goal, such as weight loss, perioperative risk reduction, or glycemic control [31, 48].

The most significant effect of the pre-surgery regimen in reducing the liver volume usually occurs during the first weeks in most studies [25, 49]. In addition, the weight loss and liver volume reduction in short-term diets have been approximately the same as in longer-term diets, and weight reduction may be slower after the initial weight loss [50]. Also, it should be considered that the decrease in liver volume and fat content is not necessarily related to the duration of diet and daily calorie intake and could be seen in short-term low carbohydrate diets [31, 51]. It seems that the minimum time required for the pre-operative diet to be effective is 2 to 4 weeks, and considering different factors, such as type of diet (amount of calorie restriction and macronutrient content), comorbidities, and patients' compliance, is recommended.

What Are the Most Common and the Best Strategies for Pre-bariatric Weight Loss?

Diet therapy, nutritional supplementation, and intragastric balloon are three different methods recommended for weight loss before bariatric surgery in morbidly obese patients, which are proposed individually or as a complement to each other [13].

Diet Strategies

Many different pre-surgery diets have been used in the studies [48, 50], while there are no standard and agreed-upon dietary characteristics. Low-calorie diets (LCDs) and very-low-calorie diets (VLCDs) are the most common diets that have been used before bariatric surgery, usually known as a diet of 800 to 1200 and 500 to 800 kcal/day, respectively. There are some differences in the daily calorie intake, macronutrients portion size, and food consistency in the studies, but both still cause weight loss and liver volume reduction. The macronutrient composition in these two diets usually includes moderate carbohydrates, at least 20% protein, and less than 30–35% fat [49, 50].

VLCD has more limited daily calorie and carbohydrate intake than LCD, giving faster and more significant weight loss. But it should be noted that it may cause more lean mass loss; have some side effects, such as gallstones, hair loss, volume depletion with electrolyte abnormalities, muscle cramps, and constipation; and may not be well tolerated. So it needs careful medical supervision [31, 49, 52–55]. Furthermore, LCD may reduce liver volume and surgical complications almost the same as a VLCD, besides the better patient toleration, so that can be a better alternative compared to the VLCD [49, 53].

Some types of LCD and VLCD were presented in studies; for example, LCD with a high protein can prevent excess lean mass loss and improve nutritional status. This high-protein dietary method is appropriate for diabetic morbid obese patients preparing for bariatric surgery [53, 56]. One kind of LCD or VLCD is a liquid diet prescribed to patients to lose weight more and adhere better to the diet than to a regular diet [57, 58]. Nonetheless, some evidence has shown that patients may not correctly follow the liquid-based diets [58, 59]; in addition, there are some contraindications in using industrially processed liquid VLCD diets, such as arrhythmias, heart failure, unstable coronary artery disease, and severe chronic kidney disease [19]. Hence, it is better to prescribe an individualized diet according to the patient's condition and preference. One of the recent dietary approaches to pre-operative weight loss is the VLCKD diet (very-low-calorie ketogenic diet) which has fewer carbohydrates (<20–30 g) and a higher percentage of fat than VLCD [60, 61]. It has been shown to increase weight loss while preserving lean body mass, improving glycemic control, lipid profile, and surgical complications due to reducing blood loss and better post-operative hemoglobin level and wound healing [19, 62–65]. VLCKD is becoming more popular due to hunger suppression (because of the ketone body production) and probably more patient satisfaction and tolerance, besides the positive effect on mood [19, 62]. However, there is conflicting evidence regarding the safety of VLCKD. Some studies have reported that VLCKD is a safe diet without side effects on liver and kidney function. Still, some other studies have reported that VLCKD can induce oxidative stress and a catabolic state, which may increase the risk of surgery and cause poor post-operative recovery, so more research is needed to clear the safety of VLCKD prescription [62, 64].

The Mediterranean diet is another dietary method used before surgery to reduce liver volume and viscera fat content and maintain lean body mass [66]. Patients are advised to choose foods wisely, use more fruits and vegetables that have higher fiber and vitamins, and avoid using processed products, sweet drinks, and alcohol. Also, advise patients to drink ≥1.5–2 l water or calorie-free beverages, per day [19, 31]. However, there is insufficient data on this regimen's effectiveness in pre-bariatric patients; therefore, more studies are needed.

Nutritional Supplements

One of the pre-operative dietary plans is nutritional supplements such as omega-3 polyunsaturated fatty acid acids. In people with fatty liver, exceeding intake of omega-6 fatty acids and insufficient intake of polyunsaturated omega-3 fatty acids is seen, so it is expected that by taking omega-3 supplements, liver fat decreases, and serum indicators related to liver damage improve to some extent [67]. Bakker et al. conducted a randomized study to compare the effect of LCD for 2 weeks and a 2000 kcal diet with 2 g of omega-3 fatty acids daily for 4 weeks in obese women before bariatric surgery [68]. Liver volume and visceral fat were reduced in both groups. Although the LCD was associated with a more significant decrease in liver volume, the omega-3 diet had better compliance and lower side effects, such as muscle mass loss. Iannelli et al. also reported the same effect of omega-3 supplementation on liver volume reduction [10].

Other Methods

In addition to diet therapy and the use of formulas, there are other methods that can lead to short-term weight loss before bariatric surgery, such as pharmacological treatment and intragastric balloon. Although some studies showed that using an intragastric balloon is more effective compared to other investigated methods, according to the systematic review of Lee et al., IGB has no significant benefit on greater weight loss before surgery in individuals with BMI greater than 50 [69]. This method is more effective compared to other investigated methods. Due to the invasive nature of the technique, it is mainly advised for patients with greater BMI who need significant weight loss and did not get proper results from the other methods before surgery. Expensive method, invasive nature, and high risk of side effects (in contrast with diet therapy and nutritional supplementation) are its downsides [33]. Using liraglutide is another effective method for short-term weight loss [70]. However, most of the studies that have been done in this area have been for people who have regained weight after bariatric surgery, and there is insufficient evidence on the use of liraglutide before bariatric surgery to reduce weight and liver size. On the other hand, a serious concern regarding the use of liraglutide before surgery is that previous taking can increase the risk of adhesions, especially in people who are going to undergo sleeve gastrectomy surgery [71].

Nutrition After Bariatric Surgery

Anatomical, physiological, and hormonal changes after bariatric surgery (especially on gut–brain hormones) are three critical factors in adjusting the post-surgery diet plan for patients with a history of morbid obesity. During the first 4 weeks after surgery, the patient's diet should be slowly changed from clear liquid to solid liquid and then soft and pureed foods. The reason for this change is to adapt to the reduced stomach size and recover gastric edema caused by the surgery so that the person can gradually return to a solid diet and experience fewer complications during this transition period [33, 72–74].

Different Nutritional Phases After Bariatric Surgery

The key points for different bariatric methods in each stage are summarized in Table 2. In the first 4–6 weeks after bariatric surgery, people need to go through a three-phase diet before returning to solid food. These three steps are respectively included: clear liquid diet, full liquid diet, and puree/soft diet which are explained in Table 2 in detail.

Calorie and Macronutrient Requirements After Bariatric Surgery

In the period of rapid weight loss after bariatric surgery, a negative energy balance is needed. In the first few weeks after the surgery, the intake of calories through the diet is very limited due to the anatomical changes caused by the surgery, and then, it increases over time. In this period, one of the most important nutritional needs of a person is complete protein intake. The key points for calorie and macronutrient requirements after bariatric surgery are summarized in Table 3.

Protein Supplementation After Bariatric Surgery

Protein is one of the most important macronutrients needed after bariatric surgery, and its insufficient intake can affect the process of weight loss and loss of lean mass. Small gastric pouch, change in taste preference, and digestive secretions may lead to low protein intake after bariatric surgery. Previously, Hasannejad et al. reported that during the first 3 months of surgery, protein intake was lower than 40 mg/day, even lower than the minimum recommended daily intake. It seems that receiving protein as a supplement, especially in the first months after surgery, is necessary to meet the minimum daily requirement [76, 79, 80]. Whey (mostly isolated), egg white, casein, milk, and soy are different types of protein powder which are currently available and provide all the essential amino acids needed by the body. Due to the high amounts of branched-chain amino acids, whey protein is the most widely used protein supplement after bariatric surgery. For those with lactose intolerance after surgery, lactose-free supplements are available (ISOPURE Zero Carb whey protein isolate, Optimum Nutrition hydrolyzed whey, etc.).

Table 2 Diet Stages in RYGB, LSG, LAGB, BPD/DS [75]

Diet stages after RYGB, LSG, BPD/DS	Time to begin	Food	Guidelines
1	1st day (immediately after surgery)	Gastric bypass clear liquids, ice chips	• Patients should be encouraged to begin fluid intake after a swallow test for a leak. If there is no problem, sipping water is allowed. • For the first 2 h after surgery, 15 ml of liquid should be drunk every 30 min, and then, it should be increased to 15 ml every 15 min for the rest of the day. • Liquids with no calories are allowed, for example, water and light tea. Carbonated beverages or those with caffeine and sugar should be avoided. • Using straw should be limited.
2	2nd–3rd days	Water, Crystal Light, natural diluted fruit juice without sugar, diluted Gatorade, sugar-free jelly, and broth	• On days 2 and 3, patients should consume 30 ml of no-carbonated and no-sugar liquids every 15 min. • Caffeine should be restricted. • Patients should be encouraged to sip their liquids slowly. • 1/2 cup of fruit juice should be diluted with 1/2 cup of water. • Using straw should be limited. • Recommended total fluid intake is 1500–1800 ml/day.
	Between 4th and 10–14th days	Low or skim milk; soy milk; almond milk; plain or Greek yogurt; whey, isolated whey or soy protein powder; protein shakes; Crystal Light; broth; diluted natural fruit or vegetable juice; sugar-free jelly; smooth vegetable soup with no chunks, mixed with 1% or skim milk or water; sugar-free ice pops	• Patients should be encouraged to consume 120–170 ml of liquids every hour. • Daily intake of protein supplements should be limited to 25–30 g per serving (100–200 calories; < 10 g sugar; < 15 g carbohydrates) • Consumption of plain yogurt with more than 25 g of added sugar should be limited. • Patients should be encouraged to consume salty liquids in moderation. • Carbonated liquids or those with caffeine and sugar should be avoided. • Using straw should be limited. • Recommended total fluid intake is 1500–1800 ml/day. • At least 4 cups of water should be included.
3	Between 10–14th days and end of 3rd week (depending on patient tolerance)	Ground or pureed low-fat meat, poultry, and fish; eggs, egg whites, or egg substitute; low-fat cheese, cottage cheese; soft tofu; strained soups; well-cooked vegetables; unsweetened applesauce; homemade compote without sugar; canned fruit in water; pureed and smooth banana, and non-fibrous, pureed of other fruits	• Soft, pureed food should be started. • Patients should be encouraged to consume 3–5 small meals. • Protein-rich foods should be included. • Patients should be encouraged not to drink water with or immediately after a meal (no problem to drink 15 min before or 30 min after a meal). • As soon as patients can tolerate 1/2 cup of food in one sitting, daily intake should be limited to 3 small meals and 2 snacks. • Since some patients cannot provide their daily nutritional needs for protein through food at this stage, the use of protein powders should be continued.

Table 2 (continued)

4	4th week of post-op and beyond	An advanced diet based on the patient's tolerance	• Patients should be encouraged to stay well hydrated (at least 1500–1800 ml of liquids per day). • New foods should be reintroduced separately to determine which food are intolerable. • Patients should be encouraged not to drink water with or immediately after a meal (no problem to drink 15 min before or 30 min after a meal). • Raw fruits and vegetables should be included slowly due to some problems tolerating their skin or texture. • Intake of rice, bread, and pasta should be limited until patients can tolerate protein-rich food comfortably. • Patients should be informed that as their sense of hunger increases in the following weeks, food intake should increase gradually (Considering recommended daily calorie intake). • Patients should get at least 20 min for every meal and chew every food slowly and adequately in order to prevent blockage.
Diet stages after LAGB	Time to begin	Food	Guidelines
1	1st day (immediately after surgery)	LAGB clear liquids, ice chips	• Patients should be encouraged to begin fluid intake immediately after surgery. • Carbonated liquids or those with caffeine and sugar should be avoided.
2	Between 2nd and 10–14th days	LAGB clear liquids plus LAGB full liquids; low-fat or skim milk; protein shakes; whey, whey isolate or soy protein powder; soy or almond milk, plain or Greek yogurt; Crystal Light; broth; diluted natural fruit or vegetable juice; sugar-free jelly; smooth vegetable soup with no chunks, mixed with 1% or skim milk or water; sugar-free ice pops	• Patients should be encouraged to begin the intake of high-protein liquids. • Recommended total fluid intake is 1500–1800 ml/day. • 700–900 ml of fluid intake should be assigned to clear liquids, and full liquids could provide the rest. • Liquids with more than 25 g sugar per serving and/or 2 g fat should be limited. • Daily intake of protein supplements should be limited to 25–30 g per serving (100–200 calories; < 10 g sugar; < 15 g carbohydrates) • Consumption of plain yogurt with more than 25 g of added sugar should be limited. • Patients should be encouraged to consume salty liquids in moderation. • Carbonated liquids or those with caffeine and sugar should be avoided. • Using straw should be limited.

Table 2 (continued)

3	Between 10–14th days and end of 3rd week (depending on patient tolerance)	LAGB clear liquids plus soft, pureed foods	• Patients should be informed that a sense of hunger is expected at this stage. • Having 3–5 small protein-rich meals increase satiety and prevent high-calorie intake. • Patients should get at least 20 min for every meal and chew every food well. • Patients should be encouraged to stay well hydrated (at least 1500–1800 ml of liquids per day). • Patients should be encouraged not to drink water with or immediately after meal (no problem to drink 15 min before or 30 min after meal). • Carbonated liquids or those with caffeine and sugar should be avoided.
4	4th week of post-op and beyond	An advanced diet based on the patient's tolerance	• Patients should be encouraged to stay well hydrated (at least 1500–1800 ml of liquids per day). • New foods should be reintroduced separately to determine which food are intolerable. • Patients should be encouraged not to drink water with or immediately after a meal (no problem to drink 15 min before or 30 min after a meal). • Raw fruits and vegetables should be included slowly due to some problems tolerating their skin or texture. • Intake of rice, bread, and pasta should be limited until patients can tolerate protein-rich food comfortably. • Patients should be informed that as their sense of hunger increases in the following weeks, food intake should increase gradually (considering recommended daily calorie intake). • Patients should get at least 20 min for every meal and chew every food well. • Patients should be encouraged to include protein in every meal and snakes. • Patients should get at least 20 min for every meal and chew every food slowly and adequately in order to prevent blockage.

(1) There are several types of post-surgical dietary plans that vary in terms of authorized and unauthorized food and the duration of each stage. The patient's food tolerance should be considered at the beginning of each step. (2) Patients should be aware of symptoms of dehydration such as dark-colored urine, nausea, fatigue, hypotension by standing, dizziness, and confusion. Due to various reasons such as rapid weight loss, anatomical changes, drug regimen, reduced intake of fiber and protein, food intolerance (e.g., lactose intolerance), physiological stress of surgery, etc., the occurrence of a series of nutritional issues can be expected in the short term after bariatric surgery. Possible problems include the following: dizziness and lightheadedness, dark urine, constipation, diarrhea, nausea and/or vomiting, bloating, cramping, and acid reflux

RYGB Roux-en-Y gastric bypass, *LSG* laparoscopic sleeve gastrectomy, *LAGB* laparoscopic adjustable gastric banding, *BPD/DS* biliopancreatic diversion with duodenal switch

Table 3 Calorie and macronutrients requirements after bariatric surgery [33, 72, 74, 76–78]

Calorie	No specific number of calories has been defined; nevertheless, calorie deficit (negative energy balance is needed), age, sex, and daily activity level are three essential factors for measuring post-bariatric calorie needs. 400 to 500 calorie intake is recommended within the first days and gradually increases to lower than 900 calories during 6 months post-surgery. The calorie intake should be limited to less than 1000 calories in the first year of surgery.
Carbohydrates	So far, no exact number has been reported for carbohydrate requirements after bariatric surgery. It is recommended that the carbohydrate consumed after bariatric surgery be limited to 35–50% of the total daily calorie intake. 100–130 g/day is needed for a sufficient supply of glucose for the brain and nervous system. The priority is to consume complex or high-fiber carbohydrates.
Protein	60–160 g/day after RYGB and 60–80 g or 1.1 g/kg of ideal weight (i.e., BMI = 25) after SG. In some cases, daily consumption could increase to 2.1 g/kg/day ideal body weight.
Fat	Fat distribution in a post-bariatric diet is not well recognized. Usually, the reported fat intake is 35–42% total daily calorie intake.

Table 4 Calorie intake in pregnancy

First trimester	1385 ± 415 to 1971 ± 430 k
Second trimester	1222 ± 425 to 1978 ± 427
Third trimester	1514 ± 503 to 1881 ± 835 kcal

Protein Malnutrition After Bariatric Surgery

Protein malnutrition, which is defined by serum albumin < 25 g/l, is one of the most important side effects of malabsorptive surgeries (Roux-en-Y gastric bypass (RYGB) and BPD/DS) [81], although people who undergo sleeve gastrectomy surgery are also at risk if they do not get enough protein (60–100 g/day). Inadequate intake, poor digestion, and malabsorption of protein due to converted biliary and pancreatic function lead to protein malnutrition after bariatric surgery [81].

Nutrition in Pregnancy After Bariatric Surgery

Weight loss due to bariatric surgery increases the chances of fertility. Pregnancy after bariatric surgery is a special situation, and not having a proper diet can lead to maternal and fetal malnutrition and pregnancy complications [82–85]. At least 200 extra calories intake during pregnancy is recommended for women with a history of bariatric surgery [82]. According to previous studies, the average intake of calories in the first, second, and third trimesters in pregnant women with a history of bariatric surgery is shown in Table 4 [86–89].

Since the average caloric intake in pregnant women with a history of bariatric surgery has been very different in different studies, it is not possible to propose a definitive number as a reference for caloric intake in different periods of pregnancy. Therefore, to determine the number of calories needed in this period, the decision must be made individually and based on the person's condition. A serious concern in women who have had bariatric surgery is the weight regain during pregnancy, which can lead to insufficient caloric intake, and dietitians should be aware of this concern. As with calories, the ASMBS and IOM guidelines do not provide definitive recommendations on macronutrient intake during pregnancy for women with a history of bariatric surgery. Yet the minimum recommended intake of protein is 60 g/day [90, 91].

Physical Activity Before and After Bariatric Surgery

How Could Exercise Improve Outcomes Before and After Bariatric Surgery?

People who are a candidate for bariatric surgery are most likely physically inactive [92, 93]. However, physical activity has positive cardiovascular and metabolic benefits independent of surgery and its effects [94, 95]. In addition, if these people start exercising before surgery, it will help them learn about changing their lifestyle, which is the cornerstone of obesity treatment [96, 97]. In a clinical trial by Baillot et al., the number of steps per day and time spent on light to moderate-intensity exercise was reported more in patients who started training before surgery. So physical activity before surgery improves physical fitness and activity level [98]. Also, it helps patients to have better diet adherence which is an important part of their treatment plan [99].

Data suggest that exercise before surgery improves weight loss, fat-free mass, body mass index (BMI), muscle strength, and cardiorespiratory fitness in patients undergoing bariatric surgery [100–104]. As mentioned earlier, losing weight and fat helps surgeons access the site of surgery more easily, leads to better surgical results, and decreases the risks of surgery [103]. Also, decreased fat mass and abdominal obesity are associated with improved cardiometabolic and quality of life in patients waiting for bariatric surgery [105]. Cardiometabolic benefits probably are the most important effect of adding physical activity before and after surgery,

especially blood glucose, glycaemic index, and blood pressure control [106].

Bariatric surgery improves physical activity in patients with obesity [107, 108]. After surgery, an active lifestyle improves body composition with fat-mass reduction and fat-free mass preservation. In addition, it increases VO2 max, fat oxidation, and muscle strength. In the long term, it significantly affects the quality of life, preventing weight regain, and, importantly, adherence to diet [99, 102, 109–113]. Furthermore, recent data show that doing exercise during the first year after bariatric surgery decreases bone mass loss [114–116]. Also, some data show beneficial effects on women's hormonal patterns after bariatric surgery [117] and cardiometabolic health [118].

What Assessments Are Needed for Exercise Prescription in this Population?

Although guidelines give thorough information about bariatric surgery and its criteria, they lack evaluations related to physical activity before and after surgery [119, 120]. It seems that lifestyle assessment and functional capacity should be a part of clearance before surgery [119]. As most of this population have comorbidities such as musculoskeletal pain and weight-restricted mobility or even psychological barriers to being active [121, 122], we recommend a checklist to evaluate the patient's activity level and their limitations and then prescribe the exercise in a modified manner for everybody [75]. A complete pre-surgery assessment checklist is shown in supplementary figure 1, based on the previous version of this guideline [75]. As there is a conflict between self-reported physical activity level (questionnaire) and objective measurements (accelerometer/smart watches) [93], we recommend checking physical activity levels, both objective and subjective in order to have an estimation of the functional capacity of patients before and after surgery [75].

Again as there is not enough evidence for pre-surgery assessment, we recommend at least 4 weeks before surgery starting evaluations, in addition to prescribing physical activity. Then, after surgery, we can repeat assessments during follow-ups 1, 3, and 6 months.

What Kinds of Exercise Are Suitable for Patients?

Most articles suggest a combination of aerobic and resistance training for better results [102, 105, 123–126]. A systematic review by Boppre et al. in 2021 suggested that exercise, especially combined exercise, could improve weight loss and BMI [123]. Also, exercise, especially combined exercise, improves cardiometabolic risk factors by decreasing systolic blood pressure and triglyceride [127].

When Should Patients Start Exercise?

There is still no definite time to start exercise after bariatric surgery in existing evidence. Protocols differ from 7 days after surgery to 6 months after that and even later [123, 126]. But patients can begin physical activity from the day of surgery by walking short distances and going out of bed [75]. A structured, individualized exercise program could start a week after surgery when the patient is discharged and does not need medical supervision [126].

During the early phase after surgery, patients should start mobilization in order to decrease the risk of venous thromboembolism and deep vein thrombosis. They should also practice pulmonary hygiene to reduce obstructive respiratory problems and sleep obstructive apnea [119] (supplementary table 1).

How Long After Surgery Should Patients Continue Exercise Protocol?

Although evidence is not enough for this recommendation, it seems that the exercise program should continue for at least 12–16 weeks [125–128]. Nonetheless, the more extended protocol (>16 weeks) will have better results on the reduction of weight, waist circumference, and fat mass and increase in lean mass [123, 127, 129].

When Will Going to the Gym or Returning to Sports be Allowed?

There is no clear evidence in this field, and almost all of the studies are on the general population without specific sport adherence. So, based on all of the existing evidence and considering professional sports risks, the authors suggest starting professional sports in athletes after 6 months; however, an individualized assessment and risk evaluation is required for each athlete. In addition, going to the gym and doing an exercise program at the gym is optional and can be started based on the patient's exercise prescription during the early stage after surgery (supplementary table 1).

Structured Exercise Program

Prescribing exercise is recommended based on the FITT method: frequency, intensity, time, and type (supplementary table 1). Unfortunately, most patients undergoing bariatric surgery do not have enough physical activity afterward. So a structured and detailed supervised exercise program seems necessary [123, 130–132]. However, there are some pros and cons to doing supervised exercise. On the one hand, some research showed that the amount of objective evaluation of physical activity is significantly less than subjective or self-report ones, especially during the first stages after surgery

[93, 107]. Therefore, by supervised exercise, the therapist can ensure that the patients follow the correct protocol and achieve the FITT goals [126]. On the other hand, some suggest doing exercise at home or non-supervised, because a supervised plan is a burden for patients and increases the chance of dropping or non-adherence behaviors [123]. So we can educate patients about their exercise program, give them strict guidelines and still be available in case of any questions (semi-supervised), and even use smart devices [123].

Based on available evidence, there are no side effects in starting exercise acutely after surgery, so we can prescribe exercise protocols as soon as possible. The authors suggest beginning the process by teaching patients to do ankle pumping, concentrating on correct breathing and pulmonary physiotherapy during the first 2–3 days after surgery, and walking as much as possible. The presented exercise protocols (supplementary table 1) are an updated version of our previous guideline based on the most recent systematic reviews, meta-analyses, and best clinical trial protocols in order to improve it to be more practical for physicians in bariatric surgery teams [75, 123, 124, 126, 128, 133, 134]. The most critical point for this protocol is that one can individualize it for each patient based on the tests and assessments accessible in clinics. As lean body mass loss occurs mainly during the first 3 months after surgery [135], it is important to involve patients in a structured exercise program. So the authors recommend teamwork management of these patients, including a surgeon, internal medicine specialist, general physician, psychologist, dietitian, and sports medicine to make the best plan in each field.

Weight Regain After Bariatric Surgery

What Is the Definition of Weight Regain?

The exact definition of this phenomenon may be challenging because of the ambiguity of the transition from inadequate weight loss to weight regain (WR). The distinction between insufficient weight loss (IWL) and weight regain is unclear and under intensive research, although so far, with contradictory outcomes, it is also the primary focus of this article [136, 137].

There are two types of weight loss failure:

(a) Insufficient weight loss (IWL), which is defined as excess weight loss percentage (EWL%) of less than 50% during 18 months post-bariatric surgery (BS).
(b) Weight regain (WR) is defined as progressive weight regain that occurs after the achievement of an initially successful weight loss (defined as EWL>50%) [136, 137].

[EWL% is calculated by this formula: (initial weight−post-operative weight/initial weight−ideal body weight)×100] [138].

Considering the aforementioned criteria, it is important to mention that obesity is a progressive, relapsing chronic disease. Follow-up studies of bariatric patients have revealed that the rate of losing weight tends to decelerate after 2 years postoperatively [137]. Unfortunately, some degree of WR is common after patients reach their nadir weight about 20–25% of them struggle to avoid considerable WR after BS. Likewise, IWL (< 50% EWL) was the most common reason to qualify for revisional BS [137].

What Is the Reported Prevalence of WR and IWL After Bariatric Surgery?

It is reported that WR and IWL prevalence after surgery for a certain period of follow-up time varies by the type of operation performed, whether restrictive and/or malabsorptive [136, 139].

In this context, it is noteworthy to mention that a large prospective multi-center Swedish study found that 10 years after laparoscopic adjustable gastric banding (LAGB), patients regained 38% of the maximal weight which they lost at 1 year [140], and WR after laparoscopic sleeve gastrectomy (LSG) was 27.8% (range 14–37%) at long-term follow-up (≥ 7 years) [141]. Furthermore, a longitudinal assessment of bariatric surgery (LABS) study reported a 3.9% WR 3–7 years after RYGB [142].

In comparison with WR, data on the prevalence of IWL is more limited. For instance, among 17 patients who underwent revision surgery after LSG, 40% were indicated for conversion to biliopancreatic diversion/duodenal switch (BPD/DS) and RYGB because of IWL [143], and other investigators reported that 32% of patients underwent revisional RYGB because of the same reason [144].

What Are the Mechanisms of Weight Regain After Bariatric Surgery?

There are some mechanisms for WR and IWL, such as hormonal factors, nutritional non-adherence, physical inactivity, mental health issues, and maladaptive eating behaviors [136, 137, 139, 145, 146]. Hormonal factors of WR and IWL after bariatric surgery are due to an increase in ghrelin, a decrease in peptide YY and GLP-1, and post-bariatric hypoglycemia. The role of leptin is still unclear and debatable in this context. Nutritional causes are a gradual increase in calorie intake with time, dietary non-adherence/food indiscretion, grazing, and lack of nutritional care follow-ups [136, 137, 139, 140, 145–148]. Physical inactivity mechanisms include non-compliance, sedentary behavior, and certain barriers to exercise [149]. Mental

health causes are due to depression, multiple psychiatric conditions, binge eating disorder, and loss of control over eating [145, 146, 148, 149]. Finally, some surgical method failures involved for WR and IWL after BS consist of pouch distension for LAGB, dilatation of gastric pouch for LSG, dilatation of gastrojejunostomy stoma outlet, and gastro-gastric fistula for RYGB [136, 137, 139, 149].

Is Alcohol Consumption Related to Weight Regain After Bariatric Surgery?

It seems that alcohol consumption is higher among people with bariatric surgery, in comparison to the general population [150]. Alcohol is a source of liquid calories which significantly increases one's caloric intake, and some studies have found an association between weight regain and alcohol intake after bariatric surgery [145, 150–153]. For example, in a study in 2016, alcohol consumption was reported significantly higher among weight regainers (18.5 ± 30.9 g) compared to maintainers (2.6 ± 6.5 g) [152].

Alcohol is an energy-dense substance whose caloric value per gram is 6.9 kcal/g, so by consuming alcohol per day, regainers are ingesting high amounts of calories with little to no nutritional [152].

According to the mentioned study, although the volume of alcohol drunk by regainers (1.32 standard drinks per day) and maintainers (0.19 standard drinks per day) was within the recommended low-risk level (0–2 standard drinks per day), alcohol metabolism is different post-RYGB and causing a greater peak blood alcohol level [152, 154]. On the other hand, we have an acceleration in alcohol absorption after a gastric bypass, a shorter time to reach a maximum concentration, and a longer time to fully metabolize and eliminate [152]. These data suggest that this additional volume of alcohol consumption may cause weight regain after bariatric surgery [152–154].

Because of changes in alcohol metabolism, patients should be educated on the effects of alcohol consumption after malabsorptive bariatric procedures such as gastric bypass and should be more closely assessed and monitored [152, 154].

What Are the Predictors of Weight Regain After Bariatric Surgery?

There are some predictors for WR and IWL after surgery, such as older age, male gender, higher pre-operative BMI, mental health issues, and presence of comorbidities, including type 2 DM, hypertension, and obstructive sleep apnea [139, 149].

What Are the Treatment Options for Weight Regain After Bariatric Surgery?

The prevention and management strategies are essentially similar for WR and IWL, except that prevention does not include a surgical component. The management options for WR include behavioral interventions, pharmacotherapy, endoscopic interventions, and last-chance surgical revision [136].

Some strategies for behavioral therapy are cognitive behavioral therapy (CBT), remote acceptance-based behavioral intervention, and lifestyle counseling [136, 155–158]. Dietary treatment consists of counseling with a dietitian and structured nutritional intervention and correction of macronutrient and micronutrient intake such as iron deficiency [136, 159, 160].

For low physical activity problems, maintaining a moderate physical activity practice will predict lower weight regain, which emphasizes the importance of an active lifestyle promotion integrated intervention as part of the approach to obesity treatment after bariatric surgery [136, 149]. Several antiobesity medications (pharmacologically FDA approved) have been utilized in conjunction with lifestyle modifications, such as phentermine, phentermine–topiramate extended release, liraglutide, and bupropion/naltrexone [136, 161, 162]. The recommended alternatives in surgical management after failed LAGB are conversion to LSG, RYGB, and BPD/DS [136, 163]. After failed LSG, conversion to RYGB and BPD/DS [143] is recommended. After failed RYGB conversion to DRYGB (distal RYGB) or BPD/DS, revision of the gastric pouch and anastomosis and revision with the gastric band are recommended [164].

In summary, patients with weight regain should extensively be assessed by the multidisciplinary team with all important aspects, and also, an individualized management strategy should be established under the guidance of scientific evidence.

Micronutrient Assessments and Recommendations Before and After Bariatric Surgery

In order to perform a pre-surgery evaluation, the practitioners should consider nutrient screening, besides routine and endocrine tests, including iron studies, B12 and folic acid (RBC folate, homocysteine, methylmalonic acid are optional), and 25-vitamin D (vitamins A and E are optional); considering more extensive testing in patients undergoing malabsorptive procedures based on symptoms and risks was recommended [119].

Supplementary Table 2 provides a summarized practical guideline for micronutrient assessments after surgery including vitamins and minerals. It also includes the recommended dose of micronutrient supplementation for preventing and treating deficiency. These recommendations are based on the "American Society for Metabolic and Bariatric Surgery" guideline in 2016–2017 [165] and our previous guideline [75]; in addition, the last update of the ASMBS guideline in 2020 was added [119]. In the new version of the table, we removed the level of evidence in order to simplify using it; however, the level of evidence is available in the previous version of our guideline and the main reference article [75, 119].

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Declarations

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