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Chapter

Do All Bariatric Surgery Methods Have the Same Effects on the Gut Microbiota?

Elham Foroudi Pourdeh and Izzet Ulker

Abstract

Despite the various treatment methods that exist for obesity, the most effective treatment for long-term weight control is bariatric surgery. Different surgical methods affect different mechanisms, such as appetite change, restriction of intake, and control of hunger. Divert food from the proximal part of the small intestine, food aversion, increased energy expenditure, malabsorption of macronutrients, and modifications of bile aside profiles and the gut microbiota. Gut microbiota plays an important role in maintaining human health. Dysbiosis usually has detrimental effects and may also have long-term consequences that lead to diseases or disorders, such as diabetes, obesity, and inflammatory bowel disease. While Firmicutes are abundant in the gut microbiota of obese individuals, Bacteroidetes are more abundant in individuals with normal weight. Thus, specific changes in the gut microbial composition are associated with obesity. The suggestion of growing evidence of bariatric surgery’s success is because of the procedure’s effect on the gut microbiota. Bariatric surgery changes the short-chain fatty acids composition by certain changes in the gut microbiota, thus affecting host metabolism, including intestinal hormone secretion and insulin sensitivity. Different methods of bariatric surgery alter the gut microbiota differently.

Keywords: bariatric surgery, gut microbiota

1. Introduction

Bariatric surgery is the name given to surgical methods to control obesity [1]. There are varying treatment methods for obesity, such as lifestyle modification (which includes behavioral modification, increased physical activity, and caloric restriction), pharmacotherapy, and bariatric surgery [2]. The main obesity treatment method is weight loss through lifestyle interventions. These interventions include diet and exercise. However, in most cases, with these measures, sufficient weight loss is not achieved, and gaining weight is common and does not lead to a significant and lasting solution. The use of medications is another possible approach, although their effectiveness may seem limited [3]. There are few effective treatment options for severe obesity. For severe obesity, the most effective treatment for long-term weight control in adults is bariatric surgery [3, 4]. Bariatric surgery methods in general are considered safe. The average preoperative mortality is less than 3% [5]. Bariatric surgery is recommended for
adults with excessive obesity (BMI ≥ 40 kg/m²) or those obese with BMI ≥ 35 kg/m² in attendance of at least one significant comorbidity caused by obesity. The health risks that interact with obesity are hypertension, type 2 diabetes mellitus, stroke, coronary heart disease, asthma, obstructive sleep apnea, and osteoarthritis, among other health complications [2]. The different surgeries methods effects assorted mechanisms, including change of appetite, restriction of intake, control of hunger, divert food from the proximal part of the small intestine, food aversion, increased energy expenditure, malabsorption of macronutrients, and modifications of bile aside profiles and the gut microbiota. Choosing the surgical methods depends on the surgeon or patient preference, permanent anatomical change, and accessibility for proper aftercare. Nowadays, bariatric surgery contains three main types of methods. They are categorized according to their mechanism: A) Restrictive methods, aimed at reducing the size of the stomach to restrict solids consumption include gastric imbrication, sleeve gastrectomy (SG), and adjustable gastric banding (LAGB) B) Malabsorptive methods, by shortening the small intestine, thus surface area exposed to food is reduced and the absorption of nutrients is reduced, include jejunooileal bypass (JIB) C) Combined malabsorptive and respective methods include the Biliopancreatic diversion (BPD) [3]. The most common bariatric surgery methods are laparoscopic, which include sleeve gastrectomy (SG) and Roux-en-Y gastric bypass (RYGB). In terms of popularity, sleeve gastrectomy has surpassed Roux-en-Y gastric bypass in the last few years [2].

2. Bariatric surgery methods

2.1 Roux-en-Y gastric bypass (RYGB)

The surgical treatment that is still considered a standard technique and widely used for the treatment of morbid obesity is RYGB [6, 7]. In RYGB, a small gastric pouch attaches to the small intestine and bypasses the stomach, duodenum, and proximal jejunum [8]. Recently, RYGB is the second most common operation worldwide, sleeve gastrectomy (SG) preceded that [9]. Although RYGB frequency is surpassed worldwide by sleeve gastrectomy (SG), long-term results in weight reduction, remission of comorbidities also changing quality of life, are well documented and make the RYGB a common bariatric procedure [6, 7, 10]. For these good results, identifiable factors are mostly a combination of mechanisms of action, which include mild malabsorption by bypassing a reasonable part of the jejunum, mechanical restriction of calorie intake due to the small gastric pouch, and hormonal changes like a decrease in the production of ghrelin, early secretion of PYY and changes in various incretin levels, such as GLP1 [11]. For patients with gastroesophageal reflux disease, many are seen as the gold standard treatment and it is recommended as the first method of choice for patients with type 2 diabetes mellitus [12]. Hepatic hypersensitivity to insulin has been shown to improve within a week after RYGB, and after months, after major weight loss, insulin sensitivity in adipose tissue and skeletal muscle also improves [13]. However, due to changes in intestinal anatomy after LRYGB, the internal hernia can occur through the Petersen space mesenteric defect or the mesenteric jejunojunostomy defect during follow-up [10]. After LRYGB, a frequent complication is small bowel obstruction [14]. Fasting bile acid levels increase after RYGB but do not increase after SG [15]. Long-term complications may occur. Re-interventions are sometimes needed. In very rare cases, a return to normal anatomy may be due to severe dumping syndrome, gastric bypass malnutrition, excessive
weight loss, postprandial hypoglycemia, or recurrent marginal ulcers [9]. Long-term complications, such as anemia, may not be diagnosed by non-bariatric specialists. Anemia causes include folate, iron, and B12 deficiency. Bleeding marginal ulcers, and selenium, copper, and vitamin A deficiency are the less common causes [16].

2.2 Laparoscopic sleeve gastrectomy (LSG)

The most common bariatric surgery, which is performed is sleeve gastrectomy (SG) [17]. Some advantages include intact and normal intestinal absorption, preservation of pylorus preventing dumping syndrome, technical efficiency, and the first appropriate step for extremely obese patients [18]. Additional benefits, such as maintaining gastrointestinal integrity and preventing malabsorption [19]. The extreme objective of the method is to evacuate between 60 and 70% of the stomach, counting the fundus, leaving a long, thin banana-shaped stomach [17,18]. Narrowing of the gastric leads to significant limitations of stomach capacity also in other metabolic modifications. Ghrelin is one of the hormones that increments and stimulates the patient’s appetite. It is produced by cells found within the fundus. Resection of the fundus significantly diminished the basal level of ghrelin, diminishing appetite in patients who experienced LSG [18]. PYY increased postoperatively and leptin, insulin and ghrelin decreased. Probably due to improved beta-cell function and improved insulin sensitivity, insulin levels decreased following LSG. Also, decreased postoperative leptin levels may be related to decreased leptin resistance or improved leptin sensitivity [20]. LSG has illustrated its effectiveness in accomplishing weight loss and determination of obesity-related comorbidities; the concept of SG is simple, but performing incorrectly some components can cause serious complications [18]. Bleeding, staple line leak, stenosis, venous thromboembolism, intra-abdominal abscess, gastroesophageal reflux, and strictures are complications associated with LSG [17]. Staple line leakage and bleeding are the major complications in the early postoperative period. The most common complication, which occurs in about 1.1–8.7% of cases, is staple line bleeding. The most life-threatening and dangerous complication is leakage of staple line with 0.5%-2.7 incidence ranging [21]. The potential causes of leakage are a technical failure, a stapler’s mechanical failure, functionality and the shape of the sleeve, high intraluminal pressure, incisura angularis obstruction, or poor wound healing [19]. Primary subphrenic abscess and secondary rupture of the diaphragm, which can rarely be caused by gastric leakage, eventually will lead to gastrobronchial fistula. Gastrobronchial fistula is a chronic gastric leakage late complication located above the staple line [22]. Compared to laparoscopic adjustable gastric banding (LAGB), a very popular method over a decade before, sleeve gastrectomy is a simple yet powerful metabolic operation that changes the eating behavior, gut functions, and glycemic control by activating hormonal pathways, and the procedure needs no foreign implant. And compared to RYGB, it is technically easier and does not require intestinal anastomosis. The LSG is limited to the stomach and prevents the presence of an internal hernia in postoperative follow-up [23].

2.3 Laparoscopic adjustable gastric banding (LAGB)

One of the most secure surgical methods used to treat obesity is LAGB [24]. Firstly, in 1993, laparoscopic adjustable gastric banding was described by Belachew. Since then, the LAGB has undergone many changes, revisions, and corrections to become the way it is now defined. These changes influenced both surgical and technological techniques, but most importantly, the management of pre-and postoperative [25].
In LAGB, a silicone ring is placed around the gastric to create a little upper stomach pouch under the esophagus. Within the 1970s, this method was introduced and remains secure, well endured, and effective with a relatively low risk of complications. Increasing the effect of weight loss without compromising safety by adjusting the band is another benefit of this method. An option that makes LAGB attractive to most patients is that it is a reversible form of laparoscopic surgery, although it is not touted as a temporary method due to the considerable risk of regaining weight after removal [24]. LAGB at first accounted for most methods and affected weight loss by a restrictive mechanism [26]. And indeed even though its popularity has been diminishing over time, it remains a choice for a specific group of patients, creating significant weight loss and improving obesity-associated comorbidities [24]. Due to the lack of any resection or anastomosis, reversibility, low life-threatening complications, and a minimally invasive intervention, LAGB surgical procedure seems to be useful [27]. Obesity to a lower degree, at a younger age, and at the time of surgery, the lesser severity of comorbidities for successful weight loss can be an important indicator, making these patients the perfect candidate for LAGB [24]. LAGB is the simplest form of minimally invasive or surgical method performed for obesity, but it is less commonly used due to the high rate of secondary revision to complications and late weight gain. Weight loss was promising in the initial results but in the long-term, the result is less encouraging [28]. LAGB has some minor complications, such as port slippage, port tube separation, and port infection, and major complications, such as band intolerance, band erosion, band migration, pouch enlargement, band slippage, and band opening [27]. One of the less common late-onset complications is digestive lumen band erosion/migration, which occurs after LAGB. Late complications after LAGB are more than the initial complications and include band slippage, device-related complications, band erosion, and pouch dilation. Major life-threatening complications, manifesting as severe gastrointestinal hemorrhage, perforation, or obstruction are rare and require immediate surgical intervention [28].

2.4 Biliopancreatic diversion (BPD)

One of the most effective surgical methods for obesity is BPD, which generally loses more than 72% of excess body weight in 5 years. Firstly, Scopinaro described BPD, done over the past 25 years, and lead to sustainable and effective long-term weight loss [29]. Among the existing bariatric methods, biliopancreatic diversion (BPD) was common in prior decades. It is a combination of a Roux-en-Y construction with a distal gastrectomy [30]. Biliary and pancreatic juices are transported by the biliopancreatic limb to the common limb, while ingested food is transferred to the common limb by the alimentary limb [30]. One of the most effective methods in decreasing comorbidities of obesity and weight loss with minimal long-term weight regain is biliopancreatic diversion (BPD) [30, 31]. Patients lose weight because of the reduction in the area of absorption by bypassing most of the intestines with nutrients, also because of reduced absorption and digestion by the attachment of nutrients to the biliopancreatic enzymes and secretions distally [32]. BPD leads to many metabolic syndrome complications remission [29]. BPD has a positive effect on T2DM and other complications of metabolic disorder in the short-term and long-term. After surgery, triglycerides, total cholesterol, and LDL decrease, while HDL levels increase. HTN improvement or resolution is observed. Before surgery, the HTN incidence was 56.7%. After surgery, approximately 50% of hypertensive patients improved or recovered after a one-year follow-up [31]. Signaling of bile acid, increased secretion of intestinal
hormones (oxyntomodulin, PYY, and GLP-1), Gut microbiota changing and intestinal glucose transport reduction through circulating branched-chain amino acids and SGLT1, improved initial sensitivity and secretion of insulin, and increased satiety, is thought to cause these effects [29]. However, BPD is not widespread due to it is associated with long-term side effects, such as vitamin deficiency and protein malnutrition due to malabsorption [29, 31]. BPD anatomical late complications were reported to be less frequent [29]. Protein malnutrition is a common and frightening aspect of bariatric surgery [31]. In 7.7–11.9% of patients with BPD, protein malnutrition can occur; when the gastric pouch is less than 200 MLS, this reaches even in 17.8%. To minimize this risk, the common limb's length and the gastric pouch's size can be adapted (increase from 50 cm to 100 cm). In 60% of BPD patients, iron deficiency anemia will occur due to exclusion of the proximal jejunum and duodenum and decreased gastric acid secretion [29]. Especially, according to the fat-soluble vitamins in malabsorptive bariatric methods, multiple vitamin supplements will be required. Calcium metabolism changes significantly, usually due to vitamin D deficiency. Weight loss, even before surgery, reduces bone density because of mechanical disorders of load on bones and usually, secondary hyperparathyroidism is established. Vitamin D and calcium deficiency occur more often after malabsorptive methods than in restrictive methods [31]. BPD, which is surgically challenging, is rarely performed today due to the high risk of lifelong needs and nutritional complications for follow-up [29]. Presently, late complications are frequently observed in elderly patients [30].

3. Gut microbiota

There are trillions of microorganisms in the human body and the coordinated function of these microorganisms is important for the host life. The population of microorganisms in the intestine reaches its highest density. This complex microbial community that forms in the intestinal is the gut microbiota [33]. There are 100 trillion microorganisms in the human intestine. The gut microbiota is mainly formed by five phyla and populations, while the intestine is dominated by bacterial species (phyla Firmicutes and Bacteriodetes). There are also viruses, bacteria, archaea, fungi, phages, nematodes, and protists. There is a symbiotic relationship between microorganisms and their human hosts. Through this symbiotic relationship, microorganisms protect and support the structure of the intestinal mucosa during their evolution. There are at least 150 times more genes in the gut microbiota than in the human genome. And it weighs approximately 1 to 2 kg [34–36]. After birth, the ecosystem of gut microbiota is created by the transfer of maternal bacteria and environmental bacteria and continues to expand until adulthood [36]. Bacteria's quantity in the gastrointestinal tract increases from the proximal part to the distal parts. More than 70% of all body microorganisms are located in the large intestine, which is usually associated with host health and disease. In addition, the lumen has a higher bacterial diversity and the mucosal layer has a lower bacterial diversity [35]. Some environmental parameters that may affect the composition of the gastrointestinal microbiota are water activity, PH, availability of nutrients, oxygen levels, and temperature. The diverse and abundant members of the gut microbiota play an important role in maintaining human health by promoting host cell differentiation, by breaking down food to release nutrients that otherwise would be inaccessible to the host, modulating/stimulating the immune system, and preventing colonization by pathogens they protect the host [33]. The presence of large numbers of bacteria in the gastrointestinal
tract causes metabolic activity and biochemical diversity that have interactions with the host physiology [35]. Many factors can shift the balance of gut microbiota, and thus, disrupt gut microbial homeostasis and cause dysbiosis. Dysbiosis usually has detrimental effects and may also have long-term consequences that lead to diseases or disorders, such as diabetes, obesity, and inflammatory bowel disease [33]. Dysbiosis is associated with three different phenomena that can occur simultaneously: losing beneficial organisms, potentially harmful bacteria overgrowth, and losing overall microbial diversity [34]. Bacteriocins, which inhibit the bacterial pathogens growing that cause dysbiosis by their antibacterial action are produced by Lactobacillus Plantarum and Lactobacillus para case [37]. For homeostasis and proper metabolic function gut microbiota’s health is crucial. Changes in microbiota composition may lead to diabetes and obesity by affecting homeostasis and substantially altering host metabolism and affecting central appetite mechanisms [36]. Proteobacteria lead to metabolic diseases, such as obesity, because it is associated with dysbiosis [37]. Therefore, potentially new anti-obesity strategies may be proposed by modulating intestinal microbiota with fecal microbiota transplantation or dietary interventions, including probiotics and prebiotics. The suggestion of growing evidence of bariatric surgery’s success is because of the procedure’s effect on the gut microbiota. Bariatric surgery changes the short-chain fatty acids composition by particular changes in the gut microbiota. Thus, affecting host metabolism, including intestinal hormone secretion and sensitivity of insulin. While Firmicutes are abundant in the gut microbiota of obese individuals. Bacteroidetes are more abundant in individuals with normal BMI, which break down plant starches and plant fibers for energy, thus specific changes in the gut microbial composition are associated with obesity [36]. The increase in the genus Lactobacillus, which belongs to the Firmicutes phylum was associated with obesity [37]. For metabolic syndrome and obesity, the gut microbiota is an effective and potential factor. Gut microbiota can also affect insulin resistance and hyperglycemia, which are associated with obesity. The effect of intestinal microbiota on insulin and glucose homeostasis may be due to its effect on changing the relative abundance and composition of bile acid species [36]. Bacteria can produce major neurotransmitters. The microbiota also has the potential to affect other levels of neurotransmitters, including gasotransmitters, steroids, neuropeptides, endocannabinoids, and histamine among others [38]. Gut bacteria are involved in the production of neuroactive metabolites, including γ-aminobutyric acid (GABA) and serotonin, thereby affecting central appetite control. And by the effect on serotonin metabolism, which might also influence glucose homeostasis. The gut microbiota also may affect hepatic lipid metabolism, fat storage, and hepatic triglyceride storage. Some bacterial strains affect satiety and appetite by altering the secretion of gut hormones, including ghrelin, leptin, GLP-1, and PYY, through the hypothalamic neuroendocrine pathways. Gut microbiota by altering mood and modulating reward pathways might also affect feeding behavior. The main factor affecting the activity and composition of the microbiota is diet. The gut microbiota is directly shaped by the various components of the diet [36].

4. Effects of bariatric surgery methods on gut microbiota

4.1 Roux-en-Y gastric bypass (RYGB)-gut microbiota

Bariatric surgery modifies the gut microbiota. Bariatric surgery also affects the physiology of the distal intestine and has a great influence on activity and the
composition of the gut microbiota. Different methods of bariatric surgery alter the intestinal microbiota differently [39]. Bacterial diversity and richness are restored by RYGB surgery, and the frequency of several groups of bacteria is significantly altered [40]. These changes after surgery may affect weight loss, weight maintenance, and metabolic improvement. They may also cause weight gain [40, 41]. Patients who lost weight successfully after RYGB surgery had a significant difference in gut microbiota compared to patients who showed weight regain [41]. Patient preferences for high-fat and high-carbohydrate foods decrease after RYGB surgery. Patients have reportedly lost motivation to eat. Another common effect of RYGB surgery is to alter the gut microbiota and its related metabolites. *Escherichia Coli, Streptococcus, pneumonia, Klebsiella, Akkermansia muciniphila, Dentium,* and *Bifidobacterium* in the feces of patients increased after RYGB surgery [42]. After RYGB surgery, there is a decrease in *Firmicutes* and an increase in the frequency of *Verrucomicrobia (Akkermansia)* and *proteobacteria* in patients. After surgery, the *phylum Bacteroidetes* abundance decreases. Also, there is a decrease in the genus *Clostridium* and abundance of the *Fusobacteriaceae* family, *Gammaproteobacteria* (including *Enterobacteriaceae*), and the genus *Succinivibrio* increased following RYGB. Also, after surgery in animals and humans, an increase in *Enterococcus* was observed. This genus competes for intestinal epithelium adherence, and hereby, prevents the colonization of pathogenic bacteria and also has anti-inflammatory effects by producing butyrate [41]. After RYGB, the pH of the intestinal is lower compared to SG. Excluded parts of digestive transit in RYGB are the distal stomach and small intestine. Therefore, avoided stomach acidity and in the intestine, hydrochloric acid is reduced. Some studies have shown the pH reduction effect in inhibiting *Bacteroidetes* growth in bacterial culture. pH is important in the distribution of fermentation end-products [39]. After RYGB, a decrease in gastric acid secretion causes the incompletely digested proteins to increment in the gut and this results in the production of putrescine. Bacteria of the genus *Klebsiella* that has increased after RYGB. Also, can produce putrescine. This polyamine is metabolized to GABA, which stimulates the GLP-1 levels increments and improves insulin resistance. Similarly, the genus *Lachnobacterium*, which increased after RYGB improves glucose homeostasis and insulin resistance via short-chain fatty acids [41]. Metabolites like short-chain fatty acids produced by the intestinal microbiota have a beneficial effect on health and they have been linked to glycemic improvement, food intake regulation, and weight loss [43]. When the obese diabetic patients' fecal microbiota is evaluated before and after RYGB surgery, and preoperatively increase in *desulfovibrio* levels is seen in patients who have no postoperative T2DM remission compared with patients who have metabolic improvement [44]. Species, such as *pneumonia, Klebsiella, Alistipes, muciniphila,* and *Akkermansia,* are species that are augmented after RYGB and their relative abundance is associated with reduced adiposity [45]. There is *Streptococcus* and *villanelle* increment and *Claudia decrement* (all belong to the *Firmicutes phylum*). These changes can have important clinical consequences after surgery. For example, *Streptococcus* and *Veillonella* metabolize lactate, which in turn affects butyrate metabolism and epithelial barrier integrity. Increasing the integrity of the intestinal epithelium can improve metabolic disorders and reduce low-grade systemic inflammation. *Akkermansia* contains mucin-destroying microbes and in several studies has been shown increment after bariatric surgery. According to previous animal studies, *Akkermansia muciniphila* has been shown to protect against diabetes and obesity by potentially reducing low-grade inflammation and endotoxemia, as well as enhancing the barrier of the intestinal epithelium. *Akkermansia muciniphila* in humans also was associated with improved insulin sensitivity markers.
A negative correlation has previously been reported between serum leptin and *E. Coli* after RYGB [43]. Reducing stomach volume, which is included in RYGMB, dramatically reduces the amount of food intake. Individual changes in diet can alter gut microbiota and it should be considered when considering changes in gut microbiota after bariatric surgery procedures [44]. Hospital-associated pathogens, such as *pneumonia, Klebsiella*, and *clostridium, perfringens* have also been shown to increase after RYGMB. After surgery, one of the reasons for opportunistic pathogens increments is the routine administration of operative prophylactic antibiotics and alternation of the gastrointestinal environment [43]. RYGB surgery procedure resulted in a significant reduction in estimated and observed fungal diversity and richness. This contradicts many reports of bacterial alpha diversity increments. Despite the unidirectional changes observed in bacterial microbiota, changes in fungal microbiota after RYGMB are individual [40].

### 4.2 Laparoscopic sleeve gastrectomy (LSG)-gut microbiota

Changes in the composition of the gut microbial community after surgery can affect metabolic outcomes. In particular, SG alters certain gut bacteria’s relative abundance. It leads to increases in the species that improve the phenotypes of diabetes and obesity, abundance. For obese mice, fecal transplantation from mice and human patients post-bariatric surgery has metabolic benefits, such as improved insulin sensitivity, glucose tolerance, and weight loss. Importantly, in mice, antibiotics abolish the SG effectiveness due to gut microbiota disruption. These findings increase the possibility that after SG in metabolic changes gut bacteria are involved. Gut bacteria communicate through the portal vein by transporting a bacterial-derived molecule from the intestine to the liver [46]. SG leads to persistent changes in the intestinal microbiome by decreasing dysbiosis due to an increase in *Bacteroidetes* and a decrease in *Firmicutes*. SG improves diurnal oscillation and dysbiosis and increases microbial richness [47]. Compared to before LSG the percentage of *Phylum Verrucomicrobia* significantly increased after 1 month and 6 months. Percentages for the *Streptococcaceae* family also significantly increased. Also, *Christensenellaceae* increased after 1 month and 3 months, *Verrucomicrobiaceae* increased after 1 month and 6 months, *Rikenellaceae* increased after 6 months, and *Fusobacteriaceae* increased after 2 weeks, *A. muciniphila* significantly increased after 1 month and 6 months. For gut microbiota, the diversity indices OS, PD, and Chao1 were significantly increased after 6 months. The percentage of *Mogibacteriaceae* family after 3 months and 6 months were significantly decreased than before LSG [48]. SG surgery does not affect the presence of *F. Prausnitzii*, a butyrate producer in feces. LRYGB resulted in a greater increase in oral colonizers (genus *Veillonela* and *Streptococcus*) than in SG. *A. Muciniphila*, which negatively correlated with inflammation, increases in a similar proportion in patients after LRYGB or SG. *E. Coli* increment may reflect gut and host adaptation to energy harvest maximization in the post-bariatric surgery starvation-like condition [49]. In a rodent model, it was shown that *A. Muciniphila* inhibited metabolic abnormalities and body fat accumulation. However, with decreasing biological parameters related to obesity, increasing diversity of *α* and other taxa like the *Rikenellaceae* family is more associated. Although not much attention has been paid to *Rikenellaceae*, the results suggest that the *Rikenellaceae* taxon may play a role in the metabolic benefits of LSG and weight loss [48]. Changes in the microbiome after SG, particularly the reduction of *Clostridia*, lead to a decrease in lithocholic acid (LCA) production, which ultimately
leads to increased glucregulatory compound CA7S production. Lithocolicacid (LCA) by inducing CA7S synthesis in murine liver and human hepatocytes affects host metabolism. After SG, the amount of lithocholic acid (LCA) that is transported from the intestine to the liver through the portal vein increases. LCA induces colonic acid sulfonation and activates vitamin D receptors both \textit{in vivo} in mice and \textit{in vitro} in human hepatocytes. CA7S synthesized by LCA in human hepatocytes can induce the secretion of GLP-1 in enteroendocrine cells and provides a link between the changes in BA observed after SG and the surgery’s metabolic benefits [46]. After LSG, \textit{Fusobacteriaceae} and \textit{Streptococcaceae} families relative abundance increased. These species are thought to have a pathogenic property, such as colorectal carcinogenic risk. They may be high due to reduced gastric passage time and decreased gastric juice secretion by LSG. After LSG, although the $\alpha$ diversity index is restored, the total number of gut microbiota remains lower than in healthy individuals. Disorders, such as Parkinson’s disease, colorectal cancer, and inflammatory bowel disease, are associated with decreased total microbiota [48]. \textit{Pseudobutyricivibrio} and \textit{Prevotella sp.} increase after SG, they can inhibit colon cancer cell formation [50]. \textit{Clostridium} species became enriched after SG, while LRYGB harmed them, which suggests the intestine is still largely anaerobic after SG. In this regard, a higher ferredoxin oxidoreductase relative abundance was observed post-LRYGB compared to SG, which is associated generally with aerobic respiration [49]. After SG Microbiome changes may protect from progressive hypertension related to multiple strains of \textit{Lactobacillus} [51]. After 9 years postoperatively, changes in gut microbiota are less pronounced in LSG patients versus RYGB patients [52].

4.3 Laparoscopic adjustable gastric banding (LAGB)-gut microbiota

To our knowledge gut microbiota changes, have not been studied after LAGB surgery [53].

4.4 Biliopancreatic diversion (BPD)-gut microbiota

BPD/DS rats have significantly different microbiota than SHAM animals. Decreased gut microbiota richness and diversity were observed in BPD/DS rats. Microbial profile analysis showed a major shift from presurgical Clostridiales-dominated microbiota to high-concentration microbiota in \textit{Bifidobacteriales} soon after surgery. After BPD/SD, the gut is divided into three functional segments: the alimentary limb, biliopancreatic limb, and common limb. \textit{Bifidobacteriales} have a high content in the alimentary limb and common limb. But because the biliopancreatic limb contains a significant amount of \textit{Actinomycetales}, it is different from the other two limbs. In BPD/DS, unlike RYGB, it was shown that \textit{Bifidobacteriales} elevated significantly as represented by the increasing abundance of the \textit{Bifidobacterium} genus. In the lower part of the intestine, the presence of nutrients, which is digestible, but undigested can change the microbiota. In BPD/SD rats, changes in the gut microbiota were associated with the beneficial influence of malabsorption procedures. Increasing the proportion of \textit{Bifidobacteriales} bacteria associated with the genus \textit{Bifidobacterium} may have health benefits for the host. \textit{Bifidobacterium} predominance in the microbiota can reduce low-grade inflammation. The positive outcomes of surgery may be because of gut microbiota modulation and more specifically increase in \textit{Bifidobacterium} abundance throughout the gastrointestinal tract [54].
5. Conclusions

Although various surgical methods may have long-term side effects, they can lead to the improvement of obesity and its related disorders, and changes in the microbiota and related metabolites are effective in this matter. For example, bacteria of the genus Klebsiella, which has increased after RYGB, by producing putrescine and metabolizing this polyamine into GABA can increase the GLP-1 levels and improve insulin resistance. Similarly, the genus Lachnobacterium, which increased after RYGB improves glucose homeostasis and insulin resistance via short-chain fatty acids. Species, such as pneumonia, Klebsiella, Alistipes, muciniphila, and Akkermansia, are species that are augmented after RYGB and their relative abundance is associated with reduced adiposity. Also, SG leads to persistent changes in the intestinal microbiome by decreasing dysbiosis due to an increase in Bacteroidetes and a decrease in Firmicutes. Changes in gut microbiota are less pronounced in LSG patients versus RYGB patients. Also, The positive outcomes of BPD/SD surgery may be because of gut microbiota modulation and more specifically increase in Bifidobacterium abundance throughout the gastrointestinal tract. In BPD/DS, unlike RYGB, it was shown that Bifidobacteriales elevated significantly as represented by the increasing abundance of the Bifidobacterium genus.

Conflict of interest

The authors declare no conflict of interest.

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