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Review

Effects of Bariatric Surgery on Energy Homeostasis

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ABSTRACT

Bariatric surgery represents the most efficient therapy for severe obesity. It reduces the size of fat stores or the amount of body fat gain. The bariatric surgery procedures currently used include Roux-en-Y gastric bypass and sleeve gastrectomy, which are the most commonly performed procedures. Other procedures are laparoscopic adjustable gastric banding and biliopancreatic diversion. The latter represents the most effective surgery for treatment of severe obesity as well as type 2 diabetes. Bariatric surgery reduces energy intake by restricting the size of the stomach reservoir and causing malabsorption, as in the case of biliopancreatic diversion. The present article provides an overview of the literature on the effects of bariatric surgery on energy homeostasis. Accumulated evidence has indicated that the effects of bariatric surgery on energy balance can encompass complex components including effects on the corticolimbic appetitive network, with modulatory effects exerted through changes in gastrointestinal hormones, bile acid production and microbiota composition. The reorganization of the gastrointestinal tract has been shown to reduce the rewarding effects of palatable food and impulsive eating, while elevating anorexigenic hormones glucagon-like peptide 1 and peptide tyrosine tyrosine to stimulate the production of bile acids and normalize the obesogenic gut microbiota. Bariatric surgery could also increase energy expenditure, which represents, like energy intake, a key component of the energy balance equation.

RÉSUMÉ

La chirurgie bariatrique représente le traitement le plus efficace de l'obésité sévère. Elle réduit les réserves de graisse ou l'accumulation de tissu adipeux. Parmi les interventions chirurgicales courantes de l'obésité, le pontage gastrique avec anse en Y de Roux et la gastrectomie longitudinale sont les interventions les plus fréquemment effectuées. Les autres interventions sont l'anneau de gastroplastie ajustable implanté par laparoscopie et la dérivation biliopancréatique. Cette dernière représente l'intervention chirurgicale la plus efficace pour le traitement de l'obésité ainsi que pour le diabète de type 2. La chirurgie bariatrique réduit l'apport énergétique en réduisant la taille de l'estomac et, dans le cas de la dérivation biliopancréatique, en provoquant une malabsorption. Le présent article donne un aperçu de la littérature sur les effets de la chirurgie bariatrique sur l'homéostasie énergétique. Les données probantes accumulées ont indiqué que les effets de la chirurgie bariatrique sur le bilan énergétique peut englober des éléments complexes, à savoir les effets sur le réseau corticolimbique impliqué dans l'appétit et les effets modulateurs exercés par les changements dans les hormones gastro-intestinales, la production des acides biliaires et la composition du microbiote. Il a été démontré que la réorganisation du tractus gastro-intestinal réduit les effets de récompense des aliments palatables et de l'alimentation impulsive, alors que l'élévation de l'hormone GLP–1 (*glucagon-like peptide–1*) à effet anorexigène et du peptide tyrosine-tyrosine stimule la production des acides biliaires et normalise le microbiote intestinal obésogène. La chirurgie bariatrique pourrait également augmenter la dépense énergétique, qui représente, comme l'apport énergétique, un élément essentiel de l'équation du bilan énergétique.

Introduction

The prevalence of obesity (body mass index [BMI]≥30 kg/m^2) has considerably increased over the last decades. Globally, more than 1 of 10 adults is now obese (http://www.who.int/mediacentre/factsheets/fs311/en/). Even though a slowing of the increase in

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obesity prevalence has been reported (1), obesity remains a significant health issue. In fact, the prevalence of excess weight remains very high in most industrialized countries, and the prevalence of morbid, or severe, obesity (BMI >40 kg/m^2) continues to rise. Obesity, in particular in its severe forms (morbid and visceral), is associated with a plethora of sequelae (https://www.nhlbi.nih.gov/health/health-topics/topics/obe/risks), leading to a major socioeconomic burden.

Complex gene-environment interactions underlie obesity (2); the obesogenic environment in which we live, which facilitates a sedentary lifestyle and overeating through marketing and the availability of energy-dense foodstuffs, proves to be particularly obesity inducing in individuals who are genetically predisposed to a positive energy balance. The heritability of excess fat deposition, which is estimated to be between 40% and 70 % from most biometric studies (e.g. family, adoption and twin studies), is noticeable (3). Predisposition to obesity is admittedly polygenic, and genetic variations that promote obesity are likely to be associated with obesogenic genes. Those genes are involved in modern lifestyle–induced obesity by contributing to overeating, sedentary lifestyle and other obesity-promoting behaviours (4). The modern lifestyle is also responsible for producing epigenetic effects that could contribute to obesity (5–7). Obesity-related epigenetic effects cannot only be induced or reversed during life but can also be passed through generations (8). The environment in which we live is also likely to alter the gut microbiota, rendering it obesogenic (9).

The high prevalence of obesity, together with the awareness of its detrimental health effects and its socioeconomic burden, has stimulated research on obesity. Part of this research has involved the medical treatment of the condition, in particular, the effects of bariatric surgery, which is recognized as the most efficient treatment for severe obesity (10). Bariatric surgery has also been shown to cure several obesity-related comorbidities, including type 2 diabetes, dyslipidemia, hypertension and sleep apnea, and to improve mental health. Noticeable progress has been made in better understanding of how this surgery cures obesity. There is growing evidence that bariatric surgery influences energy balance regulation in various ways (11–14). This short article provides an overview of the effects of bariatric surgery on energy homeostasis.

Bariatric Surgery and Obesity

The bariatric surgery procedures that are used to treat severe obesity include gastric banding procedures, mainly laparoscopic adjustable gastric banding, Roux-en-Y gastric bypass (RYGB), sleeve gastrectomy (SG) and biliopancreatic diversion (BPD) (15). Currently, the most commonly performed procedures are RYGB and SG (15), which have been described as restrictive obesity procedures because they limit the amount of food that can be eaten. RYGB restricts the stomach to a small (generally less than 30 mL) and vertically oriented gastric pouch, which is joined to the proximal jejunum. The proximal small bowel is, therefore, bypassed. However, this surgery apparently causes only slight malabsorption. SG is a procedure that consists of the surgical removal of a substantial portion of the stomach, transforming it to a tube-like assembly. The size of the stomach is restricted to about a quarter of its original volume. It is noteworthy that SG was originally performed as 1 step of another bariatric procedure, BPD with duodenal switch (DS) (16). BPD-DS includes a vertical SG and the re-engineering of the intestine, which brings the biliopancreatic secretion to the level of the distal ileum, essentially 100 cm from the ileocaecal junction (16). This procedure causes malabsorption in addition to restriction. It is a modification of the original BPD procedure (17), which included a distal antral gastrectomy.

Bariatric procedures have proven to be more efficient in treating obesity than conventional medical therapy based mostly on behavioural interventions (18). Among the bariatric procedures, the BPD seems to be the most efficacious, followed by RYGB, SG and banding procedures. Notably, weight loss (or the absence of weight gain) after bariatric surgery primarily results from a reduction in fat mass or fat mass gain (19,20). It is also noteworthy that SG has been increasingly used as a stand-alone procedure worldwide, likely because of its high feasibility compared with RYGB and BPD and its effectiveness in treating both obesity and type 2 diabetes (21–23). SG has overtaken banding procedures, which are also relatively simple interventions but which apparently produce mitigated long-term outcomes, in the treatment of obesity (24). Additionally, SG has been successfully used as a first step of BPD-DS when the surgery is performed in 2 stages. SG produces an initial body weight reduction, which facilitates subsequent gut reorganization (DS) as part of the BPD-DS (25). The DS component of the BPD-DS intervention likely contributes the most to excess body weight loss and the remission rate of type 2 diabetes (26). Apparently, patients who undergo SG regain weight faster than patients who undergo DS (27). Our own findings in rats suggest that DS represents an essential component of the long-term weight-reducing effects of BPD-DS (28,29). The significance of DS in reducing excess weight loss has also been reported by Pata et al (30) in a group of patients in whom a permanent DS coupled to a transient (6–8 months) gastroplasty produced a reduced BMI after 10 to 15 years. Despite its efficacy, BPD is performed much less often than RYGB and SG, possibly because BPD is believed to cause more complications and side effects than SG and RYGB.

Bariatric Surgery and Energy Balance

As stated previously, bariatric surgery constitutes the most efficacious treatment for severe obesity. The BPD-DS has proven to be particularly efficacious, with a loss of 83%±14% of excess body weight observed at 36 months (31). Furthermore, a loss of 40.7%±10.8% of excess body weight has been observed 10 years after laparoscopic BPD-DS in patients with a BMI>50 kg/m^2 (32). As mentioned previously, weight loss after bariatric surgery primarily consists of fat mass loss. In high-fat–fed obese rats, RYGB reversed high-fat diet–induced fat mass accumulation without fat-free mass (FFM) loss (33). Similarly, in humans (34), RYGB-induced weight loss mainly occurs as a consequence of a reduction in the fat mass with less impact on FFM. In 1 study (34), the percentage of fat mass decreased from 47.7±5.1 (before surgery) to 28.8±8 (1 year after surgery), whereas the percentage of FFM decreased from 66.5±16.5 to 58.3±13. (The loss of FFM was nonetheless statistically significant.) Apparently, bariatric surgery leads to a preferential loss of visceral fat versus subcutaneous fat (35).

The various bariatric procedures have been reported to treat obesity by acting on the 2 inescapable components of the energy balance equation, namely energy intake and energy expenditure. They cause fat loss by reducing energy intake while also increasing or maintaining energy expenditure through mechanisms that have yet to be fully distinguished.

Bariatric surgery and energy intake

Most bariatric procedures cause a decrease in digestible energy intake (gross energy intake minus energy loss in feces) by either reducing gross energy intake (heat of combustion of food) or causing energy malabsorption ("undigestibility" of nutrients) as in the case of BPD-DS (28,29,36). Animal studies have clearly demonstrated that procedures restricting the volume of the stomach reduce meal size (28,29). Also, patients with restrictive bariatric procedures exhibit a diminished amount of ingested food compared with subjects who have not undergone such procedures (37). Similarly, rats that had