Abstract: Bariatric surgery has come to the forefront of weight loss treatment due to its complex interactions via anatomic, physiologic, and neurohormonal changes leading to sustained weight loss. Unlike lifestyle and pharmacologic options, which fail to show long-term sustained weight loss, bariatric surgery has been shown to decrease overall mortality and morbidity. Bariatric surgery can be purely restrictive, such as laparoscopic adjustable gastric band (LAGB) or laparoscopic sleeve gastrectomy (LSG), or restrictive-malabsorptive, such as Roux-en-Y gastric bypass (RYGB). These surgeries cause specific anatomic changes that promote weight loss; however, they also have unintended effects on the esophagus, particularly in terms of gastroesophageal reflux disease (GERD) and esophageal motility. Via restrictive surgery, LAGB has been widely reported to cause significant weight loss, although studies have also shown an increase and worsening of GERD as well as elevated rates of esophageal dilation, aperistalsis, and alterations in lower esophageal sphincter pressure. Along with LAGB, LSG has shown not only a worsening of GERD, but also the formation of de novo GERD in patients who were asymptomatic before the operation. In a restrictive-malabsorptive approach, RYGB has been reported to improve GERD and preserve esophageal motility. Bariatric surgery is a burgeoning field with immense implications on overall mortality. Future randomized, controlled trials are needed to better understand which patients should undergo particular surgeries, with greater emphasis on esophageal health and prevention of GERD and esophageal dysmotility.
obese patients. Weight reduction is vital to alter the course of obesity and its related medical conditions, as well as to decrease the medical and economic burdens.

Lifestyle modifications have been utilized for weight loss, but the results have been disappointing. Despite an initial weight loss of typically 5% to 10% in the first 6 months, most weight is regained. Most lifestyle changes encompass a low-calorie diet and increased physical exercise but lack consistent weight loss, which is needed to decrease metabolic syndrome.6-9

An alternative to diet and exercise is medication, such as orlistat, lorcaserin, and phentermine/topiramate extended-release. Similar to lifestyle changes, there have been limited data on prolonged weight loss and long-term improvements in risk for metabolic syndrome due to a lack of substantial weight loss. Additionally, these medications are not without harm; prior weight loss medications have been implicated in pulmonary disorders (eg, pulmonary hypertension) and cardiac disorders (eg, valvulopathies).10-12

The third and most viable option for weight loss is bariatric surgery, which is the only modality that has shown long-term sustained weight loss, reduction in comorbidities, and improvement in all-cause mortality.6,13 Bariatric surgery is reserved for patients with a BMI greater than 40 or a BMI greater than 35 with comorbidities. For instance, one study examining the effect of Roux-en-Y gastric bypass (RYGB) reported a mean loss of 50% to 70% of excess body weight and a decrease in the rate of metabolic syndrome.14 However, bariatric surgery does have complications, including stenosis at anastomotic sites, stomal ulcers, band erosion, and fistulae, all of which have implications on the esophagus.15-17

This article summarizes the relationship of obesity with esophageal health and the physiologic changes that occur after bariatric surgery. The focus will be on gastroesophageal reflux disease (GERD) and esophageal motility as well as the most common forms of bariatric surgery: laparoscopic adjustable gastric band (LAGB), laparoscopic sleeve gastrectomy (LSG), and RYGB.

The Relationship Between Obesity and Esophageal Health

Obesity is associated with an increase in esophageal disorders, which range from GERD to conditions of the lower esophageal sphincter (LES) and motility dysfunction. GERD, as defined by the Montreal Classification, is the reflux of stomach contents that leads to symptoms of heartburn and regurgitation.18-21 The natural antireflux mechanism is composed of the LES, esophageal hiatus of the diaphragm, phrenoesophageal ligaments, and angle of His. Combined, these parts serve as a unit to prevent reflux of stomach contents.22 Breakdown of this barrier leads to reflux of low pH stomach contents and GERD, which damages the esophageal mucosa.

Obesity has been shown to increase the risk of GERD symptoms by 50% as well as cause a 2-fold increase in esophageal adenocarcinoma.23 Furthermore, obese patients have a 2.5-fold increased risk of developing a hiatal hernia, which is a known risk factor for GERD.24 The physiology of increased GERD with obesity is believed to be multifactorial, including increased abdominal girth leading to high intra-abdominal pressure, increased rate of hiatal hernia, high rate of transient LES relaxations, and slower esophageal acid clearance, all of which favor the development of GERD (Figure 1).24-28 Obesity also leads to an increase in fatty tissue, which produces estrogen; in turn, elevated transient LES relaxations cause increased GERD.29,30

Morbid obesity has been associated with an increase in esophageal dysmotility, ranging in prevalence from 20% to 61%.31,32 Studies have shown that morbidly obese patients have higher rates of hypotensive LES, although a lack of subjective symptoms was attributed to decreased sensation via altered sympathetic and parasympathetic innervation.31,33-36 In one prospective study evaluating obese patients selected for bariatric surgery, the presurgical manometric data showed that patients had varied changes to the esophagus, including defective LES (16%), hypertensive LES (18%), diffuse esophageal spasm (3%), nutcracker esophagus (5%), ineffective esophageal disorder (2%), and nonspecific motility disorder (23%).37 Understanding the pretest probability of esophageal motility disorders is
important, as underlying motility disorders have been shown to be predictors of the need for LAGB reoperation.\textsuperscript{38}

**Overview of Bariatric Surgery**

The 2 main types of bariatric surgery, restrictive and restrictive-malabsorptive, are divided by anatomic and functional differences (Figure 2). Restrictive surgeries, which include LAGB and LSG, decrease the functional capacity of the stomach without a notable change in absorption. Restrictive-malabsorptive surgeries, of which RYGB is the most common, both restrict the carrying capacity of the stomach and lead to anatomic resections that serve to limit calorie and, as a byproduct, nutrient absorption.

Despite anatomic differences, the bariatric surgeries have in common modifications to the digestive tract and anatomic rearrangement. These modifications are known as the BRAVE effects: bile flow alteration, reduction of gastric size, anatomic gut rearrangement and altered flow of nutrients, vagal manipulation, and enteric gut hormone modulation.\textsuperscript{39-47} Weight loss due to bariatric surgery has been shown to decrease all-cause mortality at 10 years with significant morbidity improvements. Growing attention has been placed on neurohormonal changes (such as the alteration of peptide-1 and ghrelin) and their positive effects in sustained weight loss.\textsuperscript{48}

The following sections will discuss LAGB, LSG, and RYGB, along with associated changes in GERD and motility. When determining the appropriate surgical approach, clinicians should consider patient history (eg, preexisting esophageal motility) and understand the physiologic changes that result from the surgery.

**Laparoscopic Adjustable Gastric Band**

**Surgical Approach**

LAGB is a restrictive surgery that involves placing an adjustable gastric band around the proximal stomach to divide it into a small pouch and a larger pouch, the latter of which connects to the remainder of the small bowel (Figure 2A).\textsuperscript{45,49} The inflatable band, and thus the size of the pouches, can be adjusted via a subcutaneous access point as needed. A smaller proximal pouch limits food intake due to decreased stomach size and increased food transit time.
is associated with increases in LES high-pressure zone length, defective propagations, and increased rate of esophageal dilations (Table 2).

There is a lack of randomized, controlled trials for LAGB; one of the largest studies, which evaluated 1232 patients with LAGB over a 9-year period, found anterior and posterior slippage with esophageal dilations in concordance with prior studies’ findings of increased rates of esophageal dilation, acha-lasia, and pouch dilation.58,68,71 However, due to recent changes in surgical approach and band design, the rates of both anterior and posterior prolapses have decreased significantly. When the band is placed suprabursally, the rate of posterior prolapse approaches 0, while the rate of anterior prolapse is also drastically reduced.72,73

Laparoscopic Sleeve Gastrectomy

Surgical Approach

Sleeve gastrectomy is a restrictive surgery that involves removing a large portion of the body and all of the fundus of the stomach to create a smaller gastric pouch (Figure 2B). The remaining portion of the stomach is formed into a narrow sleeve and is stapled closed, with the remainder of the stomach connected to the small bowel. The reduced gastric pouch leads to a decrease in acid production.
Implications With Gastroesophageal Reflux Disease
There have been mixed results in determining the relationship of GERD with LSG, likely owing to decreased literature on this surgical approach (Table 3). Studies show both improvement and worsening of GERD symptoms when using symptom reporting and medication.74-89
Many authors think that reducing the gastric pouch with surgical resection should improve GERD. However, other authors propose that de novo formations of hiatal hernias, sleeve migration, and disruption of the esophagogastric junction lead to worsening, and sometimes de novo formation, of GERD symptoms (Table 3).81,90,91 Hence, despite the surgical resection of a proacidic environment, there are many proregurgitant factors that lead to increased GERD.

Changes in Esophageal Motility
LSG has been shown to cause increased rates of global gastrointestinal motility. There is evidence of ineffective peristalsis after LSG with an increase in LES pressures (Table 3).92,93 Moreover, there are global findings of increased rates of gastric and small bowel transit, which contribute to the excision of the gastric fundus, leading to altered intestinal motility.81,82,94 Two studies by the same group evaluating patients after LSG reported increased gastric emptying, which has been postulated to be due to lack of peristalsis in the sleeve portion.81,82,95 This acceleration of gastric emptying has been utilized by combining LSG and fundoplication for patients with GERD and delayed gastric emptying, with improvement in both areas.96 However, a few studies have shown that there is, conversely, a delay in esophageal and gastric emptying, likely owing to the location of the gastrectomy from the gastroesophageal junction.92 Thus, there is a lack of substantial studies evaluating the effects of LSG, although current studies show a trend toward alteration in gastrointestinal motility with increased ineffective peristalsis. This leads to downstream small bowel motility changes, although the effect on the esophagus has not been fully ascertained.

Roux-en-Y Gastric Bypass

Surgical Approach
RYGB is a restrictive-malabsorptive procedure in which the stomach is transected to form a proximal stomach pouch that is connected to a divided jejunal loop called the Roux limb (Figure 2C). The proximal stomach transection leads to the restrictive component of this surgery; the bypassed small bowel with direct connection to the jejunal loop leads to the malabsorption component. Decreased acid production, as seen in the LSG, leads to faster transit times in the stomach.97 Restrictive-malabsorptive surgery leads to larger weight loss than purely restrictive surgeries, likely due to neurohormonal changes; however, there are associated micronutrient deficiencies in vitamin B12, vitamin D, folate, iron, and calcium, which require lifelong supplementation. Moreover, there are associated complications such as anastomotic leakage and marginal ulcers.98-102

Implications With Gastroesophageal Reflux Disease
In patient questionnaires and manometry that evaluates symptoms, RYGB has been shown to decrease symptoms of GERD, the need for proton pump inhibitor therapy, and time with a pH less than 4 (Table 4).86,88,103-108 The decrease in symptoms is due to the combination of altered stomach anatomy via primary resection and a change in the downstream small bowel loop causing both a decrease in acid production and a lack of formation of a proregurgitant environment. There are several studies that show an increase in GERD after RYGB, but in general, RYGB is thought to be a superior surgery in regard to GERD when compared with LAGB and LSG.61,109,110

Changes in Esophageal Motility
There has been little evidence of esophageal dysmotility after RYGB (Table 4). There are a few retrospective studies with relatively low numbers of patients that have shown a trend toward increased frequency of hypotonic LES, hypertonic upper esophageal sphincter, and esophageal

### Table 3. The Relationship Between Laparoscopic Sleeve Gastrectomy and Esophageal Disease

<table>
<thead>
<tr>
<th>Study</th>
<th>Pathology</th>
<th>Evaluation</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arias et al89</td>
<td>GERD</td>
<td>Symptom reporting</td>
<td>Increased GERD</td>
</tr>
<tr>
<td>Lakdawala et al93</td>
<td>GERD</td>
<td>Symptom reporting</td>
<td>Increased GERD</td>
</tr>
<tr>
<td>Melissas et al94</td>
<td>GERD, gastric emptying</td>
<td>Symptom reporting</td>
<td>Increased GERD, increased gastric emptying</td>
</tr>
<tr>
<td>Melissas et al92</td>
<td>GERD, gastric emptying</td>
<td>Symptom reporting</td>
<td>Reduced GERD, increased gastric emptying</td>
</tr>
<tr>
<td>Howard et al93</td>
<td>GERD</td>
<td>Symptom reporting</td>
<td>Reduced GERD</td>
</tr>
<tr>
<td>Del Genio et al92</td>
<td>Peristalsis</td>
<td>High-resolution impedance manometry</td>
<td>Increased ineffective peristalsis</td>
</tr>
</tbody>
</table>

GERD, gastroesophageal reflux disease.
wave duration and wave amplitude after RYGB. There is also mixed evidence on dysphagia and esophageal contractility; multiple studies report conflicting results. One study reported an improvement in esophageal dysmotility after RYGB. Thus, the lack of evidence supporting overt esophageal dysmotility after RYGB is a large reason why it is the preferred surgery for patients with known esophageal disorders prior to bariatric surgery.

Hernia Repair

In addition to the primary goal of weight loss, the timing of hernia closure in morbidly obese patients is an increasingly important topic. Many studies have shown repair of hernias during bariatric surgery, and some studies have shown no recurrence of hernia. However, there are side effects of hernia repair, including seroma (as high as 18%) and mesh infections (4.4%). The ultimate decision of hernia repair becomes a risk-benefit calculation of the risk of recurrence and perioperative complications and the risk of hernia-associated complications. With improving techniques, recent studies have moved toward concomitant hernia repair, but the literature is still in its infancy, and additional, high-quality studies are needed.

Table 4. The Relationship Between Roux-en-Y Gastric Bypass and Esophage Disease

<table>
<thead>
<tr>
<th>Study</th>
<th>Pathology</th>
<th>Evaluation</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Merrerouche et al61</td>
<td>Esophageal dyskinesia</td>
<td>Symptom scoring, endoscopy, high-resolution manometry, 24-hour pH monitoring</td>
<td>No esophageal dyskinesia</td>
</tr>
<tr>
<td>Peterli et al84</td>
<td>GERD</td>
<td>Symptom reporting</td>
<td>Reduced GERD</td>
</tr>
<tr>
<td>Madalosso et al107</td>
<td>GERD</td>
<td>Symptom reporting, pH monitoring</td>
<td>Reduced GERD</td>
</tr>
<tr>
<td>Cassao et al111</td>
<td>Esophageal sphincter pressure</td>
<td>High-resolution manometry</td>
<td>Increased LES hypotonia</td>
</tr>
<tr>
<td>Valez et al112</td>
<td>LES pressure</td>
<td>High-resolution manometry</td>
<td>Increased LES hypotonia</td>
</tr>
<tr>
<td>Clements et al113</td>
<td>Dysphagia</td>
<td>Symptom scoring</td>
<td>Reduced GERD, worsening of dysphagia</td>
</tr>
<tr>
<td>Foster et al114</td>
<td>Dysphagia</td>
<td>Symptom scoring</td>
<td>Reduced GERD, no change in dysphagia</td>
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</table>

GERD, gastroesophageal reflux disease; LES, lower esophageal sphincter.

Conclusion

Given the limited effectiveness of lifestyle modifications and medications, bariatric surgery has come to the forefront for sustained weight loss therapies. Due to the anatomic, neurohormonal, and microbiota changes associated with these surgeries, weight loss is profound and sustainable, and leads to a reduction in morbidity as a result of a decrease in type 2 diabetes mellitus, hypertension, hyperlipidemia, and mortality.

One study comparing all 3 bariatric procedures found LAGB to be inferior to LSG and RYGB in terms of weight reduction, number of long-term complications, and need for revisional surgery; LSG and RYGB reported similar complication rates, although 9% of LSG patients had to be converted to RYGB due to insufficient weight loss.

RYGB has been shown to improve GERD, whereas restrictive surgeries generally lead to new or worsening GERD through hypotensive LES, decreased gastric compliance and volume, esophageal dilation (via proximal migration in LAGB), or aperistalsis (via surgical resection in LSG). The largest limitation of these findings is that most studies are retrospective reviews or analyses of prospective cohorts; even randomized, controlled trials typically feature a small number of patients and make general statements. Hence, high-quality studies are needed to better elucidate these findings.

In regard to esophageal motility, LAGB is also associated with worsening motility via surrogates such as esophageal stasis, dilation, and esophagitis. Although preoperative manometry is not generally performed, it could be helpful, as preexisting dysmotility would favor RYGB over LAGB. There are limited trials on the effect of LSG, and current studies are focused on the global motility changes of LSG without focusing on the esophagus. Current data show that RYGB is the safest surgery for patients with known esophageal dysmotility, as it has been shown not only to prevent, but also improve, esophageal disorders. LAGB should be avoided in patients with known preoperative esophageal concerns because it can lead to proximal migration of the band, causing esophageal dilation mimicking achalasia.

Therefore, bariatric surgery is an important surgical tool for the treatment of obesity. Each bariatric surgery has key esophageal changes in regard to GERD and esophageal motility; these are important characteristics to understand prior to recommending particular bariatric surgeries and when taking care of these patients postoperatively. LAGB leads to pronounced increases in GERD and esophageal motility issues, whereas RYGB shows...
continued improvement in GERD symptoms without overt effects on the esophagus.\textsuperscript{13,14} LSG is discussed less frequently in the literature, so any conclusions on its effects on GERD and motility are premature. This field needs large-volume, randomized, controlled studies to better characterize the limitations of each surgery; elucidate mechanisms of improvement for the surgical technique; and help understand the neurohormonal changes, which have been vastly underappreciated in the current body of evidence. Such studies can offer better evidence on the role of preoperative manometry, indications and restrictions on each bariatric surgery, and maintenance of the health of the esophagus while still promoting improvements in morbidity and mortality.

The authors have no relevant conflicts of interest to disclose.

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