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Revisional bariatric surgery for chronic complications necessitates custom surgical solutions

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Abstract

Bariatric surgery continues to grow as a treatment modality for obesity and weight-related comorbidities. The anatomic rearrangement can produce unique anatomic complications, as well as functional problems that are correctible with revisional operations. Understanding the unique subset of complications and the options available for correction can allow surgical solutions to be tailored to both the patient's anatomy, and the symptoms or pathologies they are targeting. Revisional operations are becoming increasingly common, as the proportion of the general population who have previously undergone bariatric surgery continues to increase. Revisional bariatric operations are associated with an increased risk of complications and longer hospital stays, but in experienced centers can be performed safely, and often using minimally invasive approaches.

Keywords: Bariatric surgery, Roux-en-Y gastric bypass, sleeve gastrectomy, one anastomosis gastric bypass, single anastomosis duodeno-ileostomy

INTRODUCTION

Bariatric surgery introduces a permanent alteration to the gastrointestinal tract, which in turn results in a myriad of alterations in gut physiology. There are effects on transit, absorption, microarchitecture, microbiome, hormone signaling, and the tightly controlled mechanisms affecting nearly every macro and

micronutrient in the body. While these alterations are highly effective at producing weight loss and reversing many comorbid conditions, these operations also introduce a unique set of complications and a unique set of surgical procedures to rectify them. This review addresses minimally invasive approaches to surgical correction of chronic complications of bariatric operations. This review will not discuss surgery for acute complications which are reviewed elsewhere. Terminology in this review will follow the nomenclature established to discuss re-operative bariatric surgery. The term *conversion* refers to an operation that changes an index bariatric operation; *corrective procedures* address complications or incomplete treatment effects of an index bariatric operation; *reversal* restores normal or near normal anatomy[1].

Classifying complications from bariatric operations could be done in various ways. We have chosen to divide these broadly into categories of anatomic problems and functional problems, with a focus on the unique aspects as applied to the most popular bariatric operations: sleeve gastrectomy (SG), Roux-en-Y gastric bypass (RYGB), biliopancreatic diversion and duodenal switch (BPD-DS), and one anastomosis procedures including the one anastomosis gastric bypass (OAGB), and the single anastomosis variations of the duodenal switch.

Incidence of re-operative bariatric surgery

While the exact number of operations performed to correct chronic complications from prior bariatric surgeries is unknown, re-operative surgeries are becoming increasingly common. Recent data from the American Society of Metabolic and Bariatric Surgeons (ASMBS) shows that from 2011 to 2019, the proportion of revisional bariatric surgeries performed in the United States increased from 6% to 16.7%. Over the same time, the overall volume of surgeries also increased by 62%[2]. Moreover, the increase in annual total bariatric surgeries contributes to an expanding pool of patients with a potential need for future corrective surgeries.

METHODS FOR REVIEW

The authors searched PubMed and Medline for articles pertaining to revisional bariatric surgery from 2000 to the present. Keywords included the named index procedures and their variations, in addition to "conversion", "revision", and "re-operative". Titles and abstracts were reviewed for inclusion, with particular attention to minimally invasive techniques. Additional papers were identified by the authors if they did not appear in search results using the methods above. Given the heterogeneous nature of both index operations, potential complications, and corrective surgeries, a systematic review is not possible. Studies included are not likely to be comprehensive but representative of extant literature. Where possible, guideline documents from professional societies were included.

GENERAL MINIMALLY-INVASIVE SURGICAL PRINCIPLES

A detailed discussion of the operative techniques discussed is outside the scope of this review. We do share, however, some generalizable key points. Revisional surgery ensures a re-operative field with non-native tissue planes, though laparoscopy still offers an advantage and offers good outcomes among centers with high volumes[3,4]. The same advantages proffered by laparoscopy at an index bariatric operation are realized in the re-operative setting as well. This includes earlier ambulation and a shorter length of stay, with the caveat that surgeons must have the requisite technical skills to accomplish similar outcomes. Anecdotally, the robotic platform offers advantages in terms of surgeon ergonomics and visualization, which can be invaluable in a re-operative field. Studies reported on robotic platforms for revisional bariatric surgery have been mixed. Single-center series compared to conventional laparoscopic approaches have shown favorable results in terms of length of stay and similar complication profiles[5,6]. However, studies utilizing data from the Metabolic and Bariatric Surgery Quality Improvement Project public data files have not universally

shown these same advantages[7,8].

Patients are generally positioned supine on the operating room table with their arms supported on arm boards. Initial abdominal entry is placed away from any prior surgical incisions. Depending upon the burden of adhesive disease, remaining trocars are placed right away, or in the case of significant adhesions, additional 5mm trocars are placed liberally to lyse adhesions and delimit existing anatomy. The left lobe of the liver is often adherent to an existing gastric pouch or sleeve. Taking these adhesions down early facilitates the insertion of a liver retractor. In mobilizing these adhesions, the gastrohepatic ligament can be divided in order to identify the caudate lobe of the liver, and thus the location of the sub-hepatic inferior vena cava. The inferior vena cava can be pulled in a more anterior and leftward position in the presence of significant inflammation. Our preferred port set up once adhesions are lysed is similar to that of a primary bariatric operation. A gentle U configuration, typically positioned supra-umbilical, is utilized. The surgeon is on the patient's right side. The surgeon's right hand should be at least a 12 mm port to give the flexibility to use suturing devices, laparoscopic linear staplers, or other instruments. It is worth noting that some commercially available staplers require a 15mm trocar for their tallest staple heights, and this port may need to be upsized if using of those loads is anticipated. Upper endoscopy is liberally used intraoperatively by the authors, and can be a helpful tool to identify the esophagus and esophago-gastric junction in the presence of obscuring inflammation. Endoscopy may also be useful to identify the location of prior staple lines, eroded foreign bodies, fistula tracts, strictures, and perform an air leak test once reconstruction is completed. If intraoperative endoscopy is not available, then a detailed upper endoscopy should be performed prior to pursuing a proximal revision, preferably by the surgeon[9,10].

COMPLICATIONS AT THE DIAPHRAGM

Hiatal hernias

Repair of hiatal hernias at the same time as a bariatric operation remains a topic of considerable debate, and is outside the scope of this review. However, increasing attention is being paid to trans-hiatal migration of the proximal portion of a gastric sleeve or gastric pouch after bariatric surgery. Defining the incidence of this is difficult. Intra-operative recognition of a hiatal hernia at the time of an index bariatric operation varies among even experienced surgeons[11]. However, it appears that trans-hiatal migration of the gastric pouch or proximal sleeve may occur in up to 7% of patients[12,13]. The presence of a de-novo or recurrent hiatal hernia after a bariatric operation produces symptoms similar to that of a patient without a prior bariatric operation[14]. Operative repair with reduction of the gastric pouch or sleeve pouch into the abdominal cavity and closure of the hiatus leads to a reduction in reflux symptoms for most patients[14,15]. The size of the hiatus defect is often not very large, and these operations can be difficult given the re-operative field and small space. In addition to a posterior hiatoplasty, a *ligamentum teres* wrap may be a useful adjunct to prevent re-migration into the thorax and bolster the antireflux mechanism[15].

CHRONIC COMPLICATIONS OF SLEEVE GASTRECTOMY

From its origination, SG has fundamentally been a revisable operation[16]. The conversion from SG to BPD-DS was historically the obvious option, since SG emerged from BPD-DS as a standalone procedure. Conversion to RYGB is an option, particularly in centers where other providers are unfamiliar with BPD-DS anatomy and the attendant potential complications. In parallel with the growing interest in single anastomosis primary bariatric procedures, including the OAGB, and the single anastomosis duodeno-ileostomy (SADI-S), these are emerging as options for sleeve revision as well[17-19]. Given the current prevalence of SG in the United States, there is likely to be a growth in these types of conversions over the next one to two decades.

Sleeve dilation

A wide range of bougie sizes are used to form a gastric sleeve, ranging from a standard upper endoscope (roughly 33 French) to 54 French. Reality is even more opaque, as some surgeons will encroach tightly to the bougie and others prefer a margin of the stomach around the bougie, making bougie size an imprecise gauge of final sleeve pouch diameter. Re-sleeve was introduced as an option by Iannelli and colleagues, wherein a new vertical staple creates or restores conventional sleeve anatomy as an option when a dilated sleeve pouch was noted, so long as gastroesophageal reflux disease is not present[20-22].

Consideration of re-sleeve has been based on radiographic criteria where evidence of persistent gastric fundus or diffuse dilation on an upper gastrointestinal series is present[21]. In addition, prior reports have set criteria for re-sleeve as either weight regain or less than < 50% excess weight loss at 1 year after initial sleeve gastrectomy[23]. Dilation of the gastric sleeve is classified into primary and secondary dilation. Primary dilation is not true dilation but rather the persistence of an upper posterior gastric pouch indicating incomplete dissection at the index operation and technical failure to resect the fundus. Secondary dilation is defined as a homogenously dilated gastric tube > 250 cc and is measured using a standardized computed tomography volumetry technique[20,24]. In the presence of proximal dilation (type I), careful attention should be paid to rule out twists or strictures of the midbody of the stomach. Re-sleeve in these situations can lead to a higher risk of leak as a narrower lumen leads to greater intraluminal pressure, and conversion to RYGB, or duodenal switch may be a better option. In the published series, the re-sleeve is performed laparoscopically with port placement similar to a primary SG operation. A 34 French bougie is used to size the pouch, and a new vertical staple line is created[20,22]. Complications have been uncommon in reported literature, though this is likely because this procedure is currently only performed in a few select centers. In general additional weight loss occurs, though the degree varies[20-26].

Sleeve revision to treat mechanical complications of the sleeve

A number of mechanical problems of the sleeve pouch have been described, including stenosis, twist, and altered motility contributing to gastroesophageal reflux disease. Stenoses can be fixed stenosis due to a narrowing at the incisura, or functional stenosis resulting from a helical twist longitudinally along the staple line. Functional stenosis from helical twisting is most often identified weeks to months following the index operation, at the point when more solid food is introduced. Estimates of the incidence of sleeve stenosis range from 0.6%-4% in the reported series[27,28]. Risk factors for sleeve stenoses include younger age, use of staple line reinforcement, and segmental imbrication of the staple line.[28] Fixed mechanical stenosis most commonly occurs at the incisura. Retraction of the greater curvature stretches the stomach before and during stapled division. Once the bougie is removed, the tissue recoils, creating a fixed narrowing[28]. The incidence of fixed stenoses does not vary as a function of bougie size. A twisted or spiral sleeve is generated from a progressive rotation of the staple line traveling from an anterior position at the inferior sleeve to a more posterior lie as the staple line progresses toward the hiatus, often as a result of retraction. Differentiating fixed and functional obstructions is possible with endoscopy if the endoscopist is keyed into this as a possibility. In the case of a sleeve twist, twisting the endoscope with the curve of the staple line allows easy passage to the pylorus, compared to fixed mechanical narrowing that typically occurs at the incisura, where such passage is difficult or impossible[28,29]. A helical twist can be easily missed, as there is a natural tendency to rotate the endoscope clockwise as it progresses, which is the typical direction of the twist, and insufflation tends to straighten the twist.

The First International Consensus conference convened for sleeve gastrectomy described a step-wise approach for sleeve strictures and stenoses: observation, endoscopic balloon dilation and/or endoluminal stenting, seromyotomy, and finally conversion to RYGB[30]. Success rates for endoscopic therapy for sleeve stenosis have been reported as high as 88%-94%, though this is heavily weighted toward the early

postoperative period, and success may be less likely further out from surgery[29,31].

Conversion to RYGB is considered a definitive therapy for stenosis of the mid-body of the gastric sleeve, in particular when stenosis is diagnosed more than a few weeks after the index operation. Sleeve stenosis is also a strong risk factor for proximal sleeve leak, which should be ruled out prior to attempting conversion. Conversion to RYGB can be performed laparoscopically in most cases. Port placement should mirror port sites utilized for primary RYGB. Separation of the sleeve from the liver is typically the most difficult part of the operation. Following this, the sleeve pouch is transected with a linear stapler proximal to the stenosis, while preserving the left gastric pedicle as blood supply to the new gastric pouch[32]. The gastro-jejunal anastomosis may be formed using an end-to-end circular stapled technique, and linear stapled or hand-sewn depending on surgeon preference. Typically, resection of the distal stomach is unnecessary and should be maintained if possible as a potential future conduit for a feeding tube if necessary.

Late or chronic sleeve leak

Sleeve leaks identified 6-12 weeks after the index operations are categorized as late leaks, and chronic leaks are identified 12 or more weeks after an index operation. Late and chronic sleeve leaks follow a separate management paradigm compared to early leaks, as endoscopic therapies are much less likely to be successful, and surgical correction is almost always necessary. To that end, preoperative nutritional optimization is essential, whether achieved by distal enteral feeding or parenteral routes[33]. There cannot be too many modalities used to investigate a chronic leak and to define its anatomy. Upper gastrointestinal series are necessary, but bronchoscopy, endoscopy, computed tomography scans, or endoscopically guided contrast injection should be used to fully delineate anatomy and assess the extent of the fistulae or abscess cavities. This will help determine the need for esophago-jejunostomy both for preoperative planning and preoperative patient education.

In some cases, proximal leaks can be isolated and completely resected while preserving a small cuff of gastric tissue; however, *en bloc* fistulectomy and Roux-en-Y esophago-jejunostomy reconstruction are often necessary[33,34]. As many as one-third of these patients will need a total gastrectomy due to the lack of remaining blood supply to the distal stomach[35]. In the best case, a chronic leak communicates only with an abscess cavity, allowing resection of the stomach alone and reconstruction with a roux-en-y esophago-jejunostomy[36-40]. Operative management is more complicated when chronic leaks develop into fistulas to other cavities or organs and may involve multiple surgical specialties.

The general principles of treating chronic sleeve leaks, whether fistulae are present or not, are to control sepsis with drainage and antimicrobial therapy, optimize nutritional status, and physical condition prior to attempted surgery. Interventional radiology and advanced endoluminal procedures are often complementary in preparing these patients for surgical intervention. Waiting 3-6 months or more after adequate control of sepsis allows the scar tissue to stabilize and become less inflamed. The goal of the operative intervention is to resect the entire fistulous tract, leaving healthy tissue for reconstruction. For some fistulae into the thoracic cavity, esophagectomy has been described as a final, definitive operation[41]. Published series generally have favorable results; however, they are in general the product of a single center and/or single surgeon with substantial experience and institutional resources to support preoperative optimization and postoperative recovery. As such, generalizability is limited, and such operations should be undertaken at centers with the existing framework for such multidisciplinary care.

Functional problems of the sleeve: intractable nausea and vomiting, refractory reflux disease

The relationship between sleeve gastrectomy obesity, weight loss, and symptomatic gastroesophageal reflux disease is a complex interplay of sometimes opposing, sometimes corroborating factors. While discussion of

this relationship is outside the scope of this review, that reflux disease can have a debilitating effect on postoperative quality of life is not controversial and may be a reason for revision. Reflux symptoms, especially if developing *de novo* after sleeve, should have a comprehensive evaluation. An upper gastrointestinal series is a prudent first step, as this will highlight any of the potential anatomic problems discussed above that are correctable with operations that target correction of that abnormality. In the presence of an otherwise normal sleeve, endoscopy with attention to esophagitis, and pH probe may allow correlation between symptoms and pathologic acid or base (bile) exposure. Esophageal manometry may be considered as well.

For patients post SG with medically refractory gastroesophageal reflux disease, conversion to RYGB is the preferred approach at most centers[32,42]. The presence of Roux-en-Y anatomy both separates the bulk of the parietal cell mass from direct connection to the esophagus, and prevents bile reflux if it was also contributory to reflux symptoms[43,44]. Conversion from SG to RYBG for gastroesophgeal reflux disease can typically be performed laparoscopically. Whether to retain an excluded portion of the stomach, or resect to reduce parietal cell mass has not been well studied; however, it should be noted that the distal stomach is left without vagal input. As in the case of SG to RYGB conversion for stenosis, retaining the distal stomach provides an access point for enteral access should this be necessary at a later time point.

Recent literature has introduced additional options for sleeve revision to treat refractory gastroesophageal reflux disease. Small series of magnetic sphincter augmentation have been reported[45,46]. Radio frequency to augment the smooth muscle and enhance the antireflux barrier of the distal esophagus also have favorable results in small series[47,48]. Finally, the *ligamentum teres* wrap, wherein a portion of the falciform ligament is mobilized and wrapped around the proximal sleeve, is emerging as an option that does not involve the introduction of a foreign body[15,49].

CHRONIC COMPLICATIONS OF ROUX EN-Y-GASTRIC BYPASS

Operations for dilation of the gastric pouch

The size of the gastric pouch and its relationship to various outcomes post gastric bypass has been a controversial topic in the past decade. There is no doubt that variations in pouch size exist. The size of the gastric pouch varies, even by the same surgeon, for a variety of reasons. Pouch size may vary due to the thickness of the gastric wall, the insertion point of the left gastric artery or its descending branch, the reach of the small bowel, the angle of the initial staple fire, and others. Some studies have correlated larger pouch sizes with lesser degrees of weight loss, or as a corollary, later pouch dilation to weight regain[50]. The gastric pouch size has also been demonstrated to play a role in satiety[51]. Others have correlated larger pouch size to increased marginal ulcer risk[52]. While there may be merit to these associations, underlying them is an assumption that pouch size can be accurately measured, which has historically been difficult and is not standardized. Accepted literature definitions for pouch dilation are a pouch > 6 cm in length, > 5 cm in width, or the presence of gastric fundus on retroflexed view during upper endoscopy or on upper gastrointestinal series[53]. However, resection and revision of a large gastric pouch or dilated gastro-jejunal anastomosis have been shown to slow food transit into the small intestine, improve feelings of satiety and thus produce greater weight loss.

A number of series have described techniques to laparoscopically revise a dilated gastric pouch. Most series describe using a laparoscopic linear stapler to divide the lateral aspect of a wide gastric pouch to create a new vertical staple line. This technique is similar to the formation of the vertical staple line in a sleeve gastrectomy. Once adhesions are divided, a vertical staple line is formed over a 36-40 French bougie, including resection of the candy cane or blind limb of gastro-jejunostomy and proceeding through the

gastric pouch toward the left crus of the diaphragm[54,55]. This resulted in a mean additional excess weight loss of 12%-21%[54,55]. This technique has the advantage of avoiding the left gastric along the lesser curve of the stomach, from which the gastric pouch derives the majority of its blood supply. This technique has an unpredictable effect on gastro-jejunal anastomosis, and may not alter it at all. Dilated gastro-jejunal anastomosis most often benefits from complete revision, which generally occurs with a reduction in pouch size. This can be thought of as a revision of both the vertical and horizontal staple lines of the gastric pouch.

The diameter of the gastro-jejunal anastomosis has also been correlated to weight loss outcomes and as such a target for revision. In one study, evaluating patients referred for weight recurrence after gastric bypass compared to patients with adequate weight loss at the same time period after surgery, found that dilated gastro-jejunal anastomosis > 2 cm was more frequent in the group of patients with weight recurrence[56]. While the gastro-jejunal anastomosis could be resected and re-fashioned, per-oral or endoscopic reduction of gastro-jejunal anastomosis has been described using multiple modalities[57,58]. Most commonly, argon plasma coagulation is used to ablate a 1 cm rim of tissue circumferentially around the gastro-jejunal anastomosis. Endoscopic suturing devices are then used to plicate the anastomosis and reduce aperture diameter. These technologies require great facility with the endoscope, have limited evidence, especially in terms of weight loss produced, and have yet to reach mainstream adoption outside of a few centers that have published the majority of the existing evidence for the technique. However, medium-term follow-up demonstrates successful arrest of weight regain, and additional excess weight loss of 19.2% at three years[59].

Operations for marginal ulceration and stricture of the gastro-jejunal anastomosis

Marginal ulceration at the gastro-jejunal anastomosis is one of the more common chronic complications of RYGB. In one large, single-center experience, the marginal ulcer rate was 2.3%, despite the routine use of postoperative proton pump inhibitor therapy for 90 days. Of the patients in that series who experienced marginal ulcers, 44.1% eventually needed operative intervention[60]. In an international survey of bariatric surgeons, the reported rate of operative intervention for marginal ulceration was 16%[61]. The risk of ulcer formation is not just in the early postoperative period, but persists lifelong. The underlying pathology is not well understood, though alteration in blood flow, anastomotic tension, smoking, use of non-steroidal anti-inflammatory medications or corticosteroids, *Helicobacter pylori* infection, and larger gastric pouch size have all been associated with increased risk of marginal ulcer formation. In our center, marginal ulcers are medically treated with sucralfate, proton pump inhibitor, and misoprostol in addition to mitigation of modifiable risk factors such as smoking cessation[61,62]. Controversy exists as to whether the technique used to fashion the gastro-jejunal anastomosis (circular stapled, linear stapled, or fully hand-sewn) plays a role in the development of later strictures[63-66]. Marginal ulcers can present with acute perforation. Often these perforations are contained in the retrogastric space, with the roux limb mesentery preventing the free flow of gastric contents. These contained perforations can be managed non-operatively with *nil per os* measures, the medical therapy mentioned above, and followed clinically. Oral diet can be resumed with clear liquids as the pain improves. In the case that operative intervention is needed for acute perforation, repair can be approached similarly to perforated peptic ulcers in a patient with native anatomy, and can be oversewn and reinforced with a pedicled omental patch[67]. We do not often attempt to revise a gastro-jejunal anastomosis in the acute setting, as the dense inflammation makes injury to the splenic vasculature, left gastric artery, pancreas, colon, and remnant stomach increasingly likely.

Recalcitrant or recurrent marginal ulcers can eventually become medically refractory and associated with chronic gastrodynia, intractable nausea and vomiting, and resultant macro- and micro-nutrient deficiencies. This is an important consideration as patients should be replete from a nutritional standpoint prior to attempting elective revisional surgery. Sequelae of chronic ulcers include gastro-jejunal stricture, gastro-gastric fistula, as well as fistulae to various other hollow and solid organs. There are no standard criteria to

denote gastro-jejunal stricture; however, published literature supports the inability to traverse the anastomosis with a pediatric (10mm) endoscope[65]. The published incidence of gastro-jejunal stricture ranges from 2.9%-23.0%[64,65,68]. The initial therapy for gastro-jejunal stricture is endoscopic pneumatic dilation which is associated with a high initial success rate[63,69,70]. For some patients, periodic dilation is sufficient to maintain anastomotic patency; however, these patients may have decreasing degrees of improvement over time. Risk factors for failure of endoscopic dilation have been identified as ischemic segments and the concomitant presence of fistula, longer time from index operation, and failure to resolve at the first dilation[71,72]. Patients with severe strictures such that a guidewire cannot be safely passed to facilitate pneumatic dilation or become non-responsive to repeated dilation are candidates for surgical revision of their gastro-jejunostomy. Candidates for revision of the gastro-jejunostomy alone must not have an additional fistula, such as a gastro-gastric fistula. For roughly one-third of patients, gastro-jejunostomy revision may cure their marginal ulcer disease[61,73,74]. In the absence of a concomitant gastro-gastric fistula, revision can generally be accomplished by revision of the gastro-jejunostomy alone.

The objective of gastro-jejunal anastomosis revision is to isolate and resect the gastro-jejunostomy while identifying and preserving adequately perfused tissue that can be used to re-fashion a tension-free anastomosis. The surgical approach begins as described above. Dense inflammatory tissue is often present and may be posterior or anterior to the gastric pouch. The posterior dissection involves freeing the gastric pouch and the roux limb mesentery from the pancreas. The splenic vasculature can easily be injured in this dissection, and the surgeon should take care to identify it during the dissection. The left gastric artery must also be identified and preserved. We often divide the roux limb early in the dissection, as retraction in an anterior and cephalad direction aids in the identification of these vascular structures. The gastro-jejunostomy may also be adherent to the remnant stomach, even in the absence of a gastro-gastric fistula. A partial gastrectomy of the remnant is often more prudent than risking missed injury to the gastric remnant and having an undrained gastric leak adjacent to a new anastomosis. The gastric pouch is typically the last part divided and is again typically accomplished with a linear stapler. Fibrosis associated with chronic inflammation often mandates increased staple heights compared to a primary operation. Following the division of the pouch, the use of an immunofluorescent dye such as indocyanine green is a useful adjunct to ensure tissue perfusion prior to planning a new anastomosis. If perfusion is compromised, strong consideration should be made to divide at the esophagogastric junction and to perform an esophagojejunostomy.

Reconstruction can be approached in a manner similar to a primary operation. Options for re-anastomosis include fully hand-sewn, linear stapled, and circular end-to-end stapled techniques. Foreign body reaction may play a role in some cases of marginal ulceration, which can be minimized by utilizing absorbable sutures and a fully hand-sewn technique. In some cases, a truncal vagotomy may be added as an adjunct to gastro-jejunal revision for chronic marginal ulceration, though data on this technique is limited[75].

Prior to reconstruction, limb lengths should be measured. A roux limb of at least 75cm is recommended to minimize the risk of bile reflux, which may contribute to chronic ulceration in some cases. Surgical drains are used selectively, but are useful if there has been the potential of trauma to the pancreas as a means of diagnosing and managing a pancreatic fistula. Patients with significant degrees of malnutrition preoperatively may additionally benefit from the placement of a gastrostomy tube in the remnant stomach.

Revision for chronic leaks of the gastric pouch, gastro-jejunal anastomosis, or gastric fistulae

Leaks and fistulae following gastric bypass are uncommon occurrences. As a result, most published reports group both acute leaks and chronic fistulae together[34]. Consistent with prior literature, fistulae describe an

abnormal connection because two tubular, epithelialized structures > 12 weeks after an index operation[30]. Traditionally the term fistula refers to an abnormal connection between two tubular epithelialized structures[76,77]. A simple fistula generally refers to a single outlet, whereas a complex fistula contains multiple outlets[78]. There have been case reports and short series that detail gastro-bronchial, gastro-pleural, gastro-pericardial, gastro-colonic, and gastro-cutaneous fistulae following RYGB. These are unique cases that often involve solutions customized to the anatomy of the fistulae and may involve surgical teams from multiple specialties.

The most common fistula after RYGB is the gastro-gastric fistula (GGF), which may arise from the vertical staple line, or the gastro-jejunal anastomosis. Incomplete division of the stomach is the strongest predictor for GGF, and indeed much of the early experience was adapted from the era of non-divided stomach operations. In the presence of incomplete division, the incidence of GGF approaches 50%, while complete division reduces this risk to 1%-6%[77,78]. Additional risk factors for GGF include foreign body erosions of sutures, staples, or various types of bands placed around the pouch, ischemia usually related to perforations of marginal ulcers, and acute or chronic staple line leak[78]. Some have divided GGF into two distinct subclasses: type I involving the proximal gastric pouch and type 2 when located near the gastro-jejunostomy. Upper endoscopy and upper gastrointestinal series should both be performed in all patients with a suspected GGF, and complement each other in terms of identifying anatomy[10]. A CT scan is also sensible to identify the location of staple lines, clips, and other foreign bodies, which should be avoided when creating new staple lines. GGF that arise from marginal ulcers or leaks at the gastro-jejunostomy typically necessitates concomitant revision of the gastro-jejunostomy, while fistulae arising from the vertical staple line may be amenable to partial resection of the pouch and partial remnant gastrectomy, leaving the gastro-jejunostomy intact.

The operative objective when attempt to resolve a GGF is to remove the GGF *en bloc* and then reconstruct it with uninflamed/non-fibrotic tissue without tension[79,80]. Gastrostomy tubes are placed in the remaining excluded stomach on an elective basis, based on preoperative nutritive indices. In the event a gastrostomy is not placed, care should be taken to preserve sufficient distal stomach such that one could be placed in the future if necessary. Surgical drains are generally placed along the neo-anastomoses and/or to potentially drain pancreatic fluid in the event of trauma to the pancreas in the course of dissecting the GGF complex.

Revision of the gastro-jejunostomy for excess weight loss or malnutrition: gastric bypass reversal

The same alterations in gastrointestinal anatomy that alters absorption, insulin regulation, and hormone signaling put individuals at risk for malnutrition and certain vitamin deficiencies. While this is uncommon after gastric bypass, it does occur in a subset of patients. In the short term, this can be treated with dietary supplementation or occasionally parenteral nutrition; while malnutrition is far and away from the most common reason for gastric bypass reversal, in some patients, intractable nausea and vomiting, recurrent postprandial hypoglycemia, or dumping syndrome may be the reason for reversal[81,82]. In some cases, these symptoms are representative of underlying issues with the gastro-jejunostomy, such as recurrent or chronic marginal ulceration.

The key concept in the reversal of RYGB is to re-establish a normal or near-normal stomach volume and passage of food from the stomach to the duodenum. To accomplish this, a gastro-gastrostomy is formed, reconnecting the gastric pouch and the excluded stomach. The dissection is similar to that of a gastro-jejunal anastomosis revision, and we find it easiest to completely resect the gastro-jejunal complex. The distal stomach is then mobilized in order to create a tension-free gastro-gastrostomy. The anastomosis is typically hand-sewn, which allows for more flexibility in terms of the position of the enterotomies and the

length of the anastomosis[82,83]. The roux limb may be left in position, or resected just above the jejuno-jejunostomy. If it is left *in situ*, it can be used as a conduit for enteral feeding if needed in the future. The complete restoration of the roux limb to its native position has also been described, but involves creating two new anastomoses, which may introduce undue risk and little additional benefit. Consideration can be made to a pyloroplasty to be performed in conjunction with the gastro-gastrostomy, as the distal stomach is functionally vagotomized[83]. Intraoperative, endoscopically guided placement of a post-pyloric feeding tube in Gastric bypass reversal, even in experienced centers, has a significant risk of complications and often requires cooperation among an experienced multidisciplinary team for success.

Revision of the jejuno-jejunostomy for intussusception

The jejuno-jejunostomy formed during RYGB is a potential location for intussusception. This is estimated to occur in 0.4%-0.64% of patients following RYGB[84,85]. This typically happens in the retrograde fashion, with the common channel as the intussuscipient traveling proximally through the jejuno-jejunostomy, though it may also occur antegrade[84,86]. Intussusception typically presents with pain, nausea, and vomiting, and it is diagnosed typically with a CT scan. Management can be done by laparoscopic reduction alone in roughly 60% of patients, or resection and reconstruction in the remainder[85]. Intervention should be expeditious to avoid the risk of bowel ischemia. We suggest that all limbs be evaluated, and marked with colored sutures or various tail lengths prior to attempting resection, to ensure reconstruction re-establishes enteric flow in the correct orientation.

Revisions of the jejuno-jejunostomy for inadequate weight loss: limb lengthening

Fundamentally, revision of the jejuno-jejunostomy for inadequate weight loss is an attempt to manipulate the lengths of the alimentary limb, biliopancreatic limb, and common channel. The first description was drafted by Fobi *et al.,* which included 65 patients[87]. This involved the division of the roux limb just proximal to the jejuno-jejunostomy and the creation of a neo-jejuno-jejunostomy at one half the distance from the initial anastomosis and the terminal ileum. This created a much longer biliopancreatic limb and a must shorter common channel. Revision resulted in a mean weight loss of an additional 20kg, which corresponded to an average decrease of an additional 7 points in body mass index[87]. Perioperative complications were acceptable, with wound complications being the most common at 9.2%; however, over the longer term, 23.1% had malnutrition[87]. Other case series followed, with similar profiles in terms of additional weight loss and perioperative complications[88-90]. Malnutrition affected many patients, with many of these patients needing re-revision to decrease the amount of bypassed intestine. A careful review of the existing literature for distalization procedures notes heterogeneity in terms of technique and the resultant lengths (or ratios) of the limbs involved. The various reported techniques were categorized in a recent meta-analysis and introduced a standardized terminology for the various distalization approaches[91]. Based on this analysis, when pursuing distalization procedures, the total alimentary limb length, which is a sum of the roux limb and the common channel length, should be 350cm or more to reduce the risk of later protein-calorie malnutrition[91]. Distalization procedures are best approached laparoscopically, given the need to operate in multiple quadrants of the abdomen. Careful measurement and marking of the limbs with various colored sutures, clips, or other techniques are essential to ensure the intended reconstruction is achieved.

Operations for internal hernia after gastric bypass

Internal hernia is one of the most feared complications of anastomotic bariatric procedures. Internal hernias are best described after roux-en-y gastric bypass, since this is a more common operation than OAGB, or BPD-DS, though similar presentations can follow those operations as well. As the intestinal limbs are re-arranged, potential spaces are created at the intersection of the mesenteries where loops of the small intestine may slide and cause impairments to vascular supply or drainage. Prompt identification offers the best opportunity for intervention without needing to resect lengthy portions of the small intestine.

Computed tomography has been demonstrated to be 82% sensitive for identifying internal hernias after RYGB[92]. Internal hernias are more common when mesenteric defects are not closed. Unfortunately, computed tomography is also less accurate for the identification of internal hernias when the mesenteric defects are not closed compared to when they are closed[93,94]. Diagnostic laparoscopy is more accurate in general, and patients who present with crampy abdominal pain and/or obstruction should be offered laparoscopy[94]. Even in this setting, a computed tomography scan can diagnose a dilated gastric remnant which may be indicative of an obstructed biliopancreatic limb. Consideration should be given for gastrostomy tube placement into the remnant stomach if it is dilated.

While internal hernias are typically closed-loop obstructions, they may also produce secondary upstream dilation. Nasogastric and/or endoscopic decompression may aid in decompression of the proximal aspect of the bowel and allow a laparoscopic approach to attempted reduction. Attempted reduction of internal hernia can be attempted laparoscopically, as prior laparoscopic surgery tends to minimize adhesions. Initial port placement should be triangulated to assess the distal bowel first. Typically, there is much less bowel present in the right lower quadrant, particularly in the presence of internal hernias, when the bulk of the small intestine often lays on the left[95]. This also allows handling of non-distended bowel, reducing the risk of accidental injury to the fragile and distended small bowel. Often by running the bowel backward from the terminal ileum, the internal hernia is reduced in the process. The bowel should be inspected for viability. The most important step, however, is the closure of the mesenteric defects. In some cases, old sutures have pulled through, or weight loss has been sufficient to allow large gaps between the sutures. Non-absorbable sutures should be used to close mesenteric defects both in this setting and at the time of index operation. The management of internal hernia after OAGB follows the same principles, except that there is no jejunal-jejunostomy defect to close[96].

REVISION OF SINGLE ANASTOMOSIS BARIATRIC OPERATIONS

Single anastomosis variations of bariatric operations are becoming increasingly popular, particularly outside of the United States. In many countries, OAGB is the predominant operation performed over its roux en y variation. In the case of OAGB, the gastric pouch is typically longer, and a looped gastro-enteric anastomosis is formed, creating an afferent biliopancreatic limb and an efferent common channel. Single anastomosis variations of the duodenal switch, known as the single anastomosis duodeno-ileostomy (SADI) or, in another variant, the stomach intestinal pylorus preserving surgery (SIPS)[97,98]. In these cases, a sleeve gastrectomy is formed, and the proximal duodenum is divided. A looped duodeno-enterostomy is then fashioned, creating a similar afferent biliopancreatic limb and an efferent common channel. These two techniques (SADI *vs.* SIPS) vary in terms of the bougie size and length of the efferent limb, but are anatomically very similar.

OAGB has a side effect profile that is unique compared to RYGB. The larger pouch size does increase the risk of marginal ulceration over RYGB[99]. The presence of the looped anatomy also allows bile to enter the gastric pouch. While this is likely asymptomatic much of the time, scintigraphic evidence demonstrates bile reflux into the esophagus in 2.6% of patients[100]. Bile reflux into the esophagus has been shown to be a strong driver toward metaplasia in the distal esophagus and has been implicated in the progression of precancerous and cancerous lesions. At least annual endoscopic surveillance is recommended for patients undergoing OAGB to evaluate for both marginal ulceration and bile reflux esophagitis. Most surgeons offering OAGB will either reverse the OAGB, or convert to an RYGB in the presence of medically refractory marginal ulcers or bile reflux[96,100,101]. The surgical approach to conversion of OAGB to RYGB follows similar steps to that of a gastro-jejunal anastomosis revision after RYGB, except that a roux limb must be constructed as well.

Single anastomosis variations of the duodenal switch have been demonstrated to be safe and effective over the short term though medium- and long-term data to detail the effects of eliminating biliary diversion are not yet available[102]. Within the published series, there has been a reoperation rate of around 5%[103]. At least a portion of these operations was to correct malnutrition and/or intractable diarrhea. The initial series used a 200cm common channel, while more recent series have extended this to 250cm, 300cm, or 400cm, which is likely to result in a lower incidence of intractable diarrhea[102]. These reoperations were typically undertaken to lengthen the common channel. Due to the preservation of the pylorus, bile reflux does not appear to be as problematic as with OAGB.

CONCLUSION

Bariatric surgery continues to grow as a primary treatment modality for obesity and weight-related comorbidities. As the number of patients who have undergone primary bariatric operations continues to increase, so also does the proportion of revisional bariatric operations performed. Operations performed to correct chronic complications are tailored to the patient's anatomy, and the symptoms or pathologies they are meant to correct. Revisional operations are associated with an increased risk of complications and longer hospital stays, but in experienced centers can be performed safely.

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Authors' contributions

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