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From the Knife to the Endoscope—a History of Bariatric Surgery

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Abstract
Purpose of Review Current bariatric surgical practice has developed from early procedures, some of which are no longer routinely performed. This review highlights how surgical practice in this area has developed over time.
Recent Findings This review outlines early procedures including jejuno-colic and jejuno-ileal bypass, initial experience with gastric bypass, vertical banded gastroplasty and biliopancreatic diversion with or without duodenal switch. The role laparoscopy has played in the widespread utilization of surgery for treatment of obesity will be described, as will the development of procedures which form the mainstay of current bariatric surgical practice including gastric bypass, sleeve gastrectomy and adjustable gastric banding. Endoscopic therapies for the treatment of obesity will be described.
Summary By outlining how bariatric surgical practice has developed over time, this review will help practicing surgeons understand how individual procedures have evolved and also provide insight into potential future developments in this field.

Keywords Bariatric surgery · Metabolic surgery · Gastric bypass · Sleeve gastrectomy · Gastric band · Bariatric endoscopy

Introduction

Sleeve gastrectomy and Roux-en-Y gastric bypass (RYGB) represent the most commonly performed bariatric procedures in present-day surgical practice [1]. One anastomosis gastric bypass (OAGB) has gained popularity in recent years and although the rates of adjustable gastric band insertion have reduced over time, this procedure still represents around 5% of all procedures performed internationally [1]. Endoscopic procedures for the treatment of obesity and metabolic syndrome have also been developed [2].

Each of these surgical techniques has evolved over time and represents an adaptation of other forms of bariatric and metabolic surgical intervention which have been utilized previously in clinical practice. This review will discuss the history of the development of bariatric and metabolic surgery and how this form of surgical intervention has evolved over time into the procedures that now represent the mainstay of present-day surgical practice in this field. Potential future developments in the field of bariatric and metabolic surgery will also be discussed.

Early Malabsorptive Procedures

Following observations of significant weight loss in patients undergoing extensive small bowel resection, the first attempt of surgical management for obesity was performed in 1952 by Henriksen in Gothenburg who resected 105 cm of small intestine from an obese patient [3, 4] (Table 1). In 1954, Kremen went on to identify that in canines, resection of the distal small bowel produced fat malabsorption and weight loss, whereas similar effects were not seen with proximal small bowel resection [5]. Kremen discussed the potential of small bowel resection for treatment of severe obesity in humans and described the utilization of this technique in one case, although further details were not provided [5].

In 1963, Payne reported a series of ten patients with uncontrolled obesity who underwent jejuno-colic shunts, bypassing a portion of the jejunum, the entire ileum and right colon [6]. During this procedure, the small intestine was divided 35–50 cm from the ligament of Treitz, with the proximal segment anastomosed to the transverse colon in an end-to-side orientation. The distal end was simply closed blindly to produce a long blind-ending loop of intestine. This was a purely

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Table 1 Details of each form of bariatric procedure developed over time, including whether this technique constitutes part of present-day surgical practice

Procedure	Year described	Initial describing surgeon	Current-day practice
Small bowel resection	1952	Henriksen [3, 4] &Kremen [5]	No—Limited patient numbers and considered unnecessary to resect bowel length.
Jejuno-colic shunt	1963	Payne [6]	No—Complications of malabsorption with diarrhoea, dehydration, micronutrient and electrolyte deficiencies.
Jejuno-ileal bypass	1969	Payne [7]	No—Less malabsorptive issues than jejuno-colic shunt but still present.
Loop gastric bypass	1966	Mason [8]	No—Superseded by procedures involving vertical gastric pouch such as Roux en-Y gastric bypass and one-anastomosis gastric bypass.
Roux en-Y gastric bypass	1977	Griffen [9]	Yes—Considered as 'gold-standard' bariatric procedure. Now performed routinely as laparoscopic operation (described by Wittgrove in 1993 [10]).
Biliopancreatic diversion	1979	Scopinaro [11]	Now performed with associated duodenal switch procedure as detailed below.
Vertical banded gastroplasty	1980	Mason [12]	No—Issues with long-term weight regain and intolerance.
Biliopancreatic diversion with duodenal switch	1988	Hess [13]	Yes—Developed from biliopancreatic diversion with sleeve gastrectomy and duodenojejunostomy. Generally reserved for super-obese patients due to issues with malabsorption with diarrhoea and micronutrient deficiencies.
Banded gastric bypass	1991	Fobi [14]	Yes—Role of use of non-adjustable band with gastric bypass remains controversial.
Adjustable gastric band	1991	Kuzmak [15], Forsell [16]	Yes—Developed as laparoscopic procedure from 1993 [17, 18].
One-anastomosis gastric bypass	1997	Rutledge [19]	Yes—Increasing in popularity worldwide.
Sleeve gastrectomy	Early 2000s	Johnston [20]/McMahon [21], Gagner [22], Anthone [23]	Yes—Now the most common form of bariatric procedure performed worldwide.
Single anastomosis duodeno-ileal bypass	2010	A. Torres [24]	Yes—Developed from principles of duodenal switch but only single anastomosis performed around 200 cm from ileocaecal valve.

malabsorptive procedure, and in all subjects, there was decreased fat absorption with decrease in serum cholesterol and lipoproteins. However, steatorrhea, diarrhoea and anal complications were significant issues in all patients. Significant dehydration, micronutrient and electrolyte deficiencies and liver fibrosis were also commonly encountered in these cases [6]. Payne planned to re-establish partial or complete intestinal continuity for these patients once the required weight loss had been achieved. In a proportion of these patients, a jejuno-ileal bypass was fashioned at re-operation and Payne went on to recommend this as the procedure of choice for treatment of obesity (Fig. 1) [7]. This procedure involved leaving the patient with 35 cm of jejunum anastomosed in an end-to-side fashion to the distal ileum 10 cm from the ileocaecal valve. There were various modifications of this form of jejuno-ileal bypass including Scott recommending an end-to-end anastomosis, or others recommending valve formation in order to prevent retrograde reflux [25, 26].

Initial Experience with Gastric Bypass

The principle of gastric bypass was developed by Edward Mason and results were presented in 1966 [8]. He had identified that patients undergoing gastric resection with gastroenterostomy had noticeable weight loss following surgery but appreciated that such a resectional operation would be too radical and irreversible to be considered appropriate for the treatment of obesity. He therefore proposed a loop horizontal divided gastric bypass, with approximately 20% of the fundus anastomosed to a jejunal loop around 60 cm from the ligament of Treitz (Fig. 1b) [8]. The distal closed segment of the stomach was sutured to the anterior surface of the fundic segment. Mason presented a total of eight initial cases and reported good initial outcomes [8]. Alden then produced a modification of the gastric bypass with partitioning of the bypassed portion of the stomach without division [27]. A Roux-en-Y configuration for the purposes of gastric bypass was first reported by Griffen in 1977 [9]. This procedure involved the addition of a jejuno-jejunostomy in addition to the gastro-jejunostomy. This alteration was made in order to reduce tension upon the gastro-jejunal anastomosis, and also due to issues relating to bilious vomiting in patients undergoing the initial Mason form of gastric bypass [9]. A representative diagram of a Roux-en-Y gastric bypass (RYGB) is provided in Fig. 2a.

Roux-en-Y gastric bypass has developed into the 'gold-standard' of bariatric surgical procedures. In the majority of patients, it will provide adequate weight loss (generally reported as around 60% excess weight loss at 5-year follow-up [14,

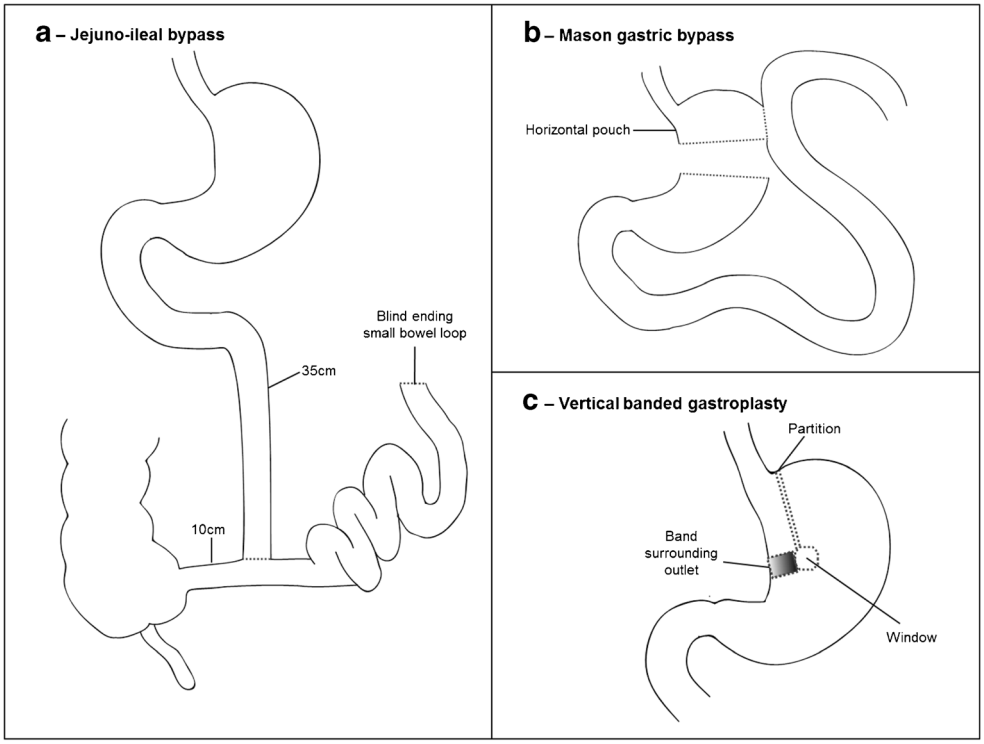

Fig. 1 **a** Diagrammatic representation of jejuno-ileal bypass with 35-cm alimentary limb anastomosed to ileum 10 cm from ileocaecal valve, with blind-ending loop of remaining small bowel. **b** Loop horizontal divided gastric bypass of Mason. **c** Vertical banded gastroplasty with representation of gastric partition with inferior window, and encircling of the pouch outlet with a mesh strip or silastic ring

28]), with a low profile of complications. Potential adverse events include anastomotic leak (a rare complication with a reported incidence of around 0.6% [29]) and the development of internal hernia at the mesenteric defect around the jejuno-jejunostomy or Petersen's space (caused by herniation of small bowel loops between the roux limb, transverse

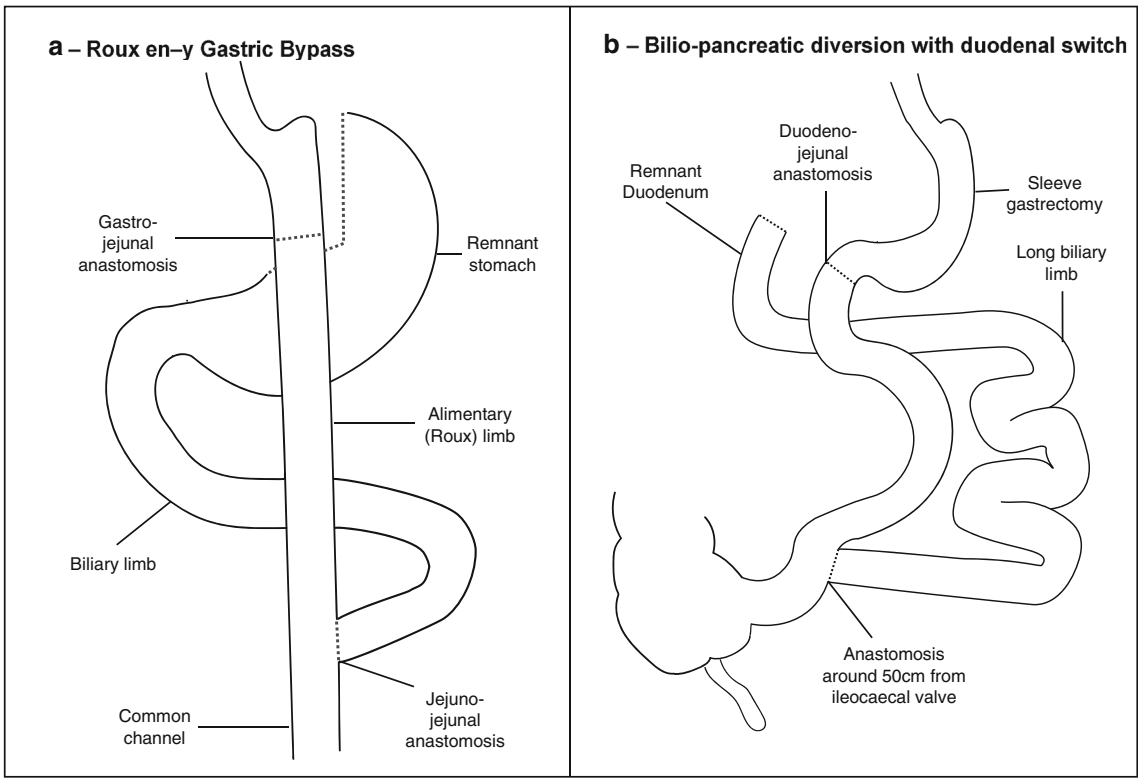

Fig. 2 Diagrammatic representation of Roux-en-Y gastric bypass (**a**) and biliopancreatic diversion with duodenal switch (**b**)

mesocolon and retroperitoneum). The risk of internal hernia can be significantly reduced by closure of these defects which has traditionally consisted of using a non-absorbable running suture, although this has been associated with increased risk of early intestinal obstruction [30]. Alternative methods of internal hernia defect closure include the use of fibrin glue or metallic clips [31, 32].

Multiple modifications of gastric bypass have been made over time, with some driven by concerns regarding potential weight regain with long-term follow-up. J.C. Torres developed a vertical lesser curvature pouch coupled with a distal configuration for RYGB which involved a common limb of around 150 cm (alimentary limb 90 cm and long biliary limb) [33]. This procedure produced good weight loss but there were issues relating to protein malnutrition. Fobi developed a modification referred to as the transected silastic vertical gastric bypass, which involved a vertical gastric pouch of around 10–25 ml in size surrounded loosely by a piece of silastic tubing [34, 35]. This procedure was developed from experience with revisional cases to RYGB from vertical banded gastroplasty and silastic ring vertical gastroplasty and was considered to reduce distension of the gastric pouch and gastro-jejunostomy stoma over time [35].

The concept of adding a restrictive band around the gastric pouch as part of a banded RYGB remains a controversial topic within present-day bariatric surgical practice. Current evidence from the available randomized trials appears to indicate that long-term weight loss may be better maintained in patients who receive such a restrictive band at the time of RYGB compared with standard RYGB [11, 36]. This is believed to be due to the prevention of progressive dilatation of the gastric pouch or gastro-jejunostomy over time. A recent meta-analysis indicated that banded gastric bypass was associated with additional excess weight loss of around 5%, at the expense of increased food intolerance and post-operative vomiting [37]. These promising results have led to some surgeons considering the addition of a non-adjustable band as the standard of care with RYGB [13], although significant concerns exist regarding potential of band slippage or erosion [38]. The reported incidence of the need for band removal is between 1.5 and 2.3% [38, 39]). The application of a non-adjustable band during RYGB does not presently comprise part of standardized practice for the majority of surgeons internationally largely due to these potential concerns and further large-scale studies are necessary to clearly define outcomes relating to this procedure.

Biliopancreatic Diversion and Duodenal Switch

Following the previous experience with jejuno-ileal bypass, Scopinaro proposed the procedure of biliopancreatic diversion (BPD) in 1979 [24]. This procedure involved a partial gastrectomy with closure of the duodenal stump. The jejunum was then transected and the distal portion of jejunum anastomosed to the gastric pouch to form the alimentary limb. The proximal section of the jejunal loop (biliary limb) was anastomosed to the distal ileum [24]. Proposed benefits of BPD over the previously described jejuno-ileal bypass included that it was possible to have fat and starch malabsorption whilst the enterohepatic bile salt circulation was left undisturbed, and there was no long excluded intestinal loop [24]. Outcomes with this procedure were excellent in terms of weight loss with a mean permanent reduction of around 75% of initial excess weight [40]. However, patients did suffer with significant issues related to protein malnutrition, anaemia, electrolyte disturbance and neurological complications (due deficiencies in various B vitamins including B_1, B_2, B_6 and B_{12}) [12, 40]. Frequent voluminous and malodorous stools and post-gastrectomy syndrome (including anastomotic ulceration and dumping symptoms) were also common complications following BPD [41].

In 1988, Hess developed the duodenal switch (DS) as a hybrid procedure between Scopinaro's BPD and the Roux-en-Y duodenojejunostomy procedure developed by DeMeester to treat pathological duodenogastric reflux [4, 42, 43]. During this procedure, the entire greater curvature of the stomach was removed in the form of a vertical parietal gastrectomy. The duodenum was then transected as far distal to the pylorus as possible (generally 4–5 cm). Precise limb lengths were calculated, with the length of the alimentary limb calculated as 40% of the total small bowel length (typical alimentary limb length between 250 and 300 cm). This alimentary limb was then anastomosed to the duodenum in an end-to-end orientation. The distal end of the alimentary limb was then anastomosed as an end-to-side anastomosis with the distal ileum around 50 cm from the ileocaecal valve [42]. A representative diagram is provided in Fig. 2b. Duodenal switch procedures were extremely effective in terms of weight loss; however, they have significant associated complications and were therefore reserved for superobese patients (typically defined as body mass index (BMI) above 50 kg/m^2 [15]). Although there was a decreased incidence of post-gastrectomy syndrome compared with BPD, other complications remain similar to BPD including the risk of significant protein malnutrition, micronutrient deficiencies, anaemia and malodorous stools [41].

More recently, the principles of biliopancreatic diversion have been further developed by A. Torres to propose the single anastomosis duodeno-ileal bypass with sleeve gastrectomy (SADI-S) procedure [16]. This procedure involves a sleeve gastrectomy with dissection continued along the first portion of the duodenum to the gastroduodenal artery at which point the duodenum is divided. An iso-peristaltic duodeno-ileal anastomosis

is then formed between this section of the duodenum and the ileum 200 cm from the ileocaecal valve.

Gastric Restrictive Procedures

The concept of a purely restrictive procedure for the purposes of weight loss was initially developed by Mason in the 1970s as a horizontal gastroplasty technique [44]. This procedure involved stapling the stomach transversely from the greater curvature to leave a small orifice for the passage of food into the lower portion of the stomach. However, long-term weight loss with this form of gastroplasty was poor and Mason went on to develop the procedure of vertical banded gastroplasty in 1980 [17]. This procedure involved the formation of a vertical pouch of around 50-ml volume based on the lesser curvature of the stomach. The stomach is stapled to form the pouch but not divided, and the outlet is encircled by a mesh strip or silastic ring (Fig. 1c) [17]. This procedure was associated with good initial weight loss, but long-term weight regain (particularly in patients with a predilection to sweet foods [18]), outlet obstruction, recanalization of the proximal stomach and gastro-oesophageal reflux were all potential complications [41]. Up to 39% of patients required revisional surgery due to weight regain or vomiting/food intolerance [10]. Although this procedure was utilized widely up until the mid-1990s, it has now been largely abandoned from present-day bariatric practice.

Gastric restriction via the use of an external gastric band was initially developed by Wilkinson and Molina as a non-adjustable external gastric band [4, 45]. Following this, an adjustable version to allow for alteration of restriction via the installation of fluid via a subcutaneous port was developed by Kuzmak [46] and Forsell [47]. Over time, the technique for placement of adjustable gastric bands has been adapted from a technique involving peri-gastric dissection to a plane of dissection through the *pars flaccida* which has now become the standardized method of gastric band placement. The *pars flaccida* technique is associated with reduced incidence of band slippage compared with those placed via a peri-gastric approach [20]. Although this procedure enjoyed popularity in the early 2000s, the rates of adjustable gastric band insertion have reduced over time and now only represent around 5% of all operations performed internationally [1].

Advent of Laparoscopy

Following the introduction of laparoscopy, it was possible to adapt the procedures described above to be completed via this form of approach. Gastric banding was easily adaptable to laparoscopic surgery and the first accounts of this being completed laparoscopically were reported in 1993 [22, 48]. Other forms of bariatric surgery were more challenging to convert to a laparoscopic technique but the first report of a laparoscopic RYGB was by Wittgrove in 1993 [23]. Utilization of laparoscopy for gastric bypass was soon demonstrated to be associated with significantly improved patient outcomes compared with open surgery [21, 49] and has now long been established as the standard-of-care for bariatric surgical procedures with 99.3% of all bariatric procedures worldwide being completed via a laparoscopic approach [1]. Laparoscopic surgery is associated with improved patient outcomes with reduction in length of stay, re-admission rate and mortality [50]. Benefits of laparoscopy to the surgeon include that the access provided to the upper part of the abdomen is far superior to what can be achieved via open surgery.

Development of Sleeve Gastrectomy

Professor David Johnston in Leeds (UK) initially proposed the utilization of a long lesser curvature vertical gastric tube in order to allow for a more physiological form of gastroplasty which did not require the insertion of any foreign material as was required as part of vertical banded gastroplasty [51]. This was described as the 'Magenstrasse and Mill' operation which involved a gastric tube (Magenstrasse (Street of the stomach)) formed over a 36-Fr bougie. A channel between the gastric antrum and the excluded gastric reservoir was preserved. This procedure allowed for the preservation of normal antral grinding of solid food in the antral 'Mill' [51].

Laparoscopic sleeve gastrectomy was initially reported as a component of laparoscopic biliopancreatic diversion with duodenal switch where a long vertical lesser curve sleeve with parietal gastrectomy is performed as part of the procedure [52]. For patients with a BMI above 50, Gagner began utilizing a sleeve gastrectomy as an initial procedure to facilitate weight loss prior to a second stage conversion to gastric bypass or biliopancreatic diversion with duodenal switch [53]. These patients demonstrated good weight loss following sleeve gastrectomy alone with around 35% excess weight loss in these initial patients [53]. In a separate cohort of patients, Anthone had completed a longitudinal gastrectomy alone in 21 patients who were considered too high risk for a duodenal switch procedure [54]. These patients also demonstrated similar weight loss with 45% excess weight loss. McMahon then adapted the concept of the 'Magenstrasse and Mill' procedure operation in order to perform a sleeve gastrectomy as a definitive procedure and was able to demonstrate the long-term effectiveness of this procedure with 55% of patients having greater than 50% excess weight loss at 8–9-year follow-up [19]. A representative diagram of a sleeve gastrectomy is provided in Fig. 3a.

Since this early experience with sleeve gastrectomy, the utilization of this procedure has continued to increase, and it

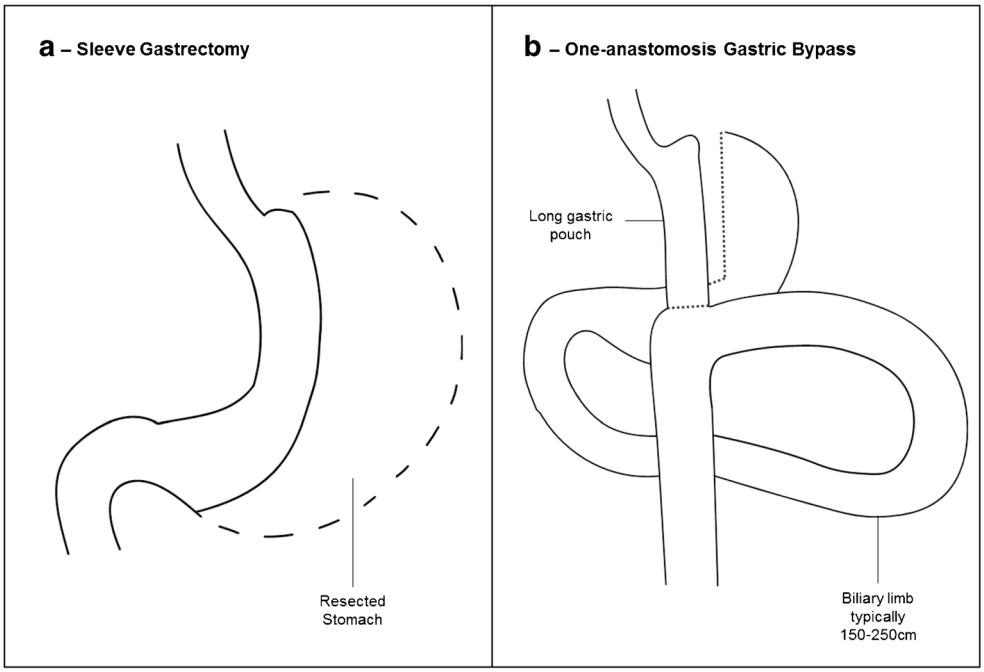

Fig. 3 Diagrammatic representation of sleeve gastrectomy (**a**) and one-anastomosis gastric bypass (**b**)

has now become the most common form of bariatric surgery performed worldwide [1]. Multiple studies have demonstrated no significant difference in outcomes between sleeve gastrectomy and RYGB in terms of weight loss and resolution of comorbidities [14, 28]. Further evaluation of these procedures alongside laparoscopic adjustable gastric banding is being completed as part of the By-Band-Sleeve study which has recently completed recruitment [55, 56].

Sleeve gastrectomy can be associated with worsening of gastro-oesophageal reflux symptoms which can be severe enough to require revision to gastric bypass for resolution [57]. This procedure can also be associated with disruption of the staple line at the angle of His which can represent a very challenging issue to resolve with the mainstays of treatment being adequate drainage, nutritional support and antibiotic therapy. In these cases, there is a potential need for re-operation or endoscopic measures for definitive control [58].

One-Anastomosis Gastric Bypass

A gastric bypass procedure involving only one anastomosis (also previously known as mini-gastric bypass or single anastomosis gastric bypass) was designed by Rutledge in 1997 [59]. This procedure involves a long lesser curvature gastric pouch down to or beyond the incisura, with an end-to-side anastomosis to a loop of jejunum 150–250 cm from the ligament of Treitz (Fig. 3b). In a large initial series of 2410 patients, one-anastomosis gastric bypass (OAGB) was associated with good outcomes in terms of weight loss, with low mortality and complication rates (0.08% and 5.9% respectively). This procedure has recently been evaluated in a large-scale multicentre randomized trial with OAGB compared with RYGB (YOMEGA trial) [60]. This trial identified significantly shorter operative times with OAGB (mean operative time 85 min (S.D. 35)) compared with RYGB (111 min (S.D. 42); $p < 0.001$). Equivalence was demonstrated between the two procedures in terms of excess weight loss and improved glucose homeostasis in the OAGB group with a more significant reduction in HbA_{1c} in this cohort. However, in this study, the patients receiving OAGB (with a standardized biliopancreatic limb length of 200 cm) were found to have more issues relating to nutritional deficiencies compared with RYGB patients [60]. For this reason, many surgeons now advocate utilizing a shorter biliopancreatic limb length of 150 cm in order to avoid significant nutritional complications [61].

The utilization of OAGB has increased in recent years and now represents nearly 8% of all bariatric surgical procedures performed worldwide [1]. Possible concerns remain regarding the potential for the development of malignancy at the site of the gastro-jejunal anastomosis due to the presence of bile within the gastric tube. However, there have been no reported cases of this occurrence to date. Further long-term evaluation of outcomes of OAGB compared with RYGB and other bariatric procedures is necessary to definitively establish the future role of this procedure.

Robotic Surgery

The utilization of robotic technology for the purposes of bariatric surgery has been proposed to have the additional

benefits of superior visualization of the surgical field with three-dimensional vision, improved surgical dexterity with greater freedom of movement, and improved ergonomics [62]. The use of robotic techniques for the purposes of gastric bypass has been reported since the mid-2000s [63, 64], but has not thus far been adopted widely into routine surgical practice. This has largely been due to the associated increase in expense associated with robotic surgery alongside significantly longer operative times, with no identifiable improvement in outcomes compared with laparoscopic surgery [65]. Other studies have reported that outcomes are inferior with robotic surgery with higher rates of early morbidity, although this may be related to surgeon's development through their proficiency-gain curve associated with this new technology [66, 67]. Based upon these findings, the role of robotic surgery within the field of bariatric surgery does not appear to have been clearly defined as of yet. However, it remains conceivable that this form of technology may play a significant future role in the development of novel bariatric procedures that may not be technically feasible using conventional laparoscopic techniques.

Endoscopic Techniques

In recent years, endoscopic techniques have been proposed as potential methods of achieving meaningful weight loss in patients without the need for formal surgical intervention [2]. These procedures can be divided into those that involve the stomach and those that produce affects within the proximal small bowel.

One of the initial endoscopic techniques developed was the intragastric balloon, which acts as a space-occupying lesion within the stomach. Although initially developed in 1985, due to a significant profile of complications, these early gastric balloons were removed from the market in 1992 [68]. However, developments in this area have led to a number of these devices achieving FDA approval since 2015 [2, 69]. These include single intragastric balloons [70] and dual-balloon systems which are placed endoscopically [71]. These devices are only designed as a temporary measure and undergo planned removal after an interval period of around 6 months. Balloons have also been developed that can be swallowed by the patient without the need for endoscopic placement [72, 73]. After being swallowed by the patient, the position of these balloons is confirmed via fluoroscopic guidance prior to filling. They do not require endoscopy for removal as a release valve is designed to automatically deflate the balloon after 16 weeks and the balloon is excreted through the gastrointestinal system [73]. These forms of space-occupying device have been demonstrated to have good short-term outcomes with one large meta-analysis demonstrating excess weight loss of 25.4% at 12-month follow-up [74]. Potential complications of these devices include abdominal pain, nausea, need for early explantation, migration and perforation [74, 75]. Weight loss outcomes can also be transient with weight regain being a potentially significant issue following device removal. In one large study, 53% of patients had achieved greater than 20% excess weight loss at 1-year post-removal, whereas after a 5-year follow-up, only 23% of patients had maintained this level of weight loss [76]. The successful use of intragastric balloons for extremely high BMI patients prior to definitive surgery has also been reported with a median BMI reduction from 57.4 to 52.15 (BMI reduction 4.25 kg/m^2 (range 1.3 to 13.9)) [77].

Alternative gastric procedures involve remodelling of the stomach to reduce the gastric reservoir. These can involve an endoscopic sleeve gastroplasty utilizing full-thickness sutures using the Overstitch device (Apollo Endosurgery, Austin, TX) [2]. This creates a tubular sleeve by sequential sutures of the anterior and posterior walls of the stomach [78]. Endoscopic sleeve gastroplasty has been associated with good weight loss outcomes with total body weight loss of 16–18% at 12–24-month follow-up, as well as improvements in metabolic outcomes [79, 80]. Alternative endoscopic therapies include the Primary Obesity Surgery Endoluminal (POSE) procedure which creates eight to ten full-thickness plications along the gastric fundus and distal body of the stomach [2]. In a randomized trial, POSE was associated with total body weight loss of 13.0% (excess weight loss 45.0%) at 12-month follow-up, compared with 5.3% total body weight loss (excess weight loss 18.1%) in the control group ($p < 0.01$) [81]. The final gastric endoscopic therapy involves partial aspiration of each meal following ingestion via a percutaneously placed gastrostomy tube [82].

Small bowel endoscopic techniques aim to prevent absorption within the proximal portion of the small intestine. The duodenal-jejunal bypass liner is placed endoscopically and is designed as a temporary device which is removed after around 6 to 12 months. They are designed to prevent contact of food with digestive enzymes from the pancreas until they enter the jejunum, in a similar manner to the biliopancreatic limb of the RYGB [2]. These have been shown to be associated with greater weight loss and improvement in HbA1c levels compared with best medical therapy [83]. However, the weight reduction following duodenal-jejunal bypass liner appears to be diminished after a 4-year follow-up [84]. They are also associated with a significant morbidity profile with potential complications including abdominal pain, nausea and vomiting, gastrointestinal bleeding, device occlusion, need for early explantation and oesophageal perforation during device removal [83]. An additional randomized trial was terminated early in 2014 due to the development of seven hepatic abscesses in the treatment group [85]. An alternative technique to induce malabsorption in the proximal small bowel is duodenal mucosal resurfacing [2]. This involves thermal

ablation of the duodenal mucosa to promote regeneration which is believed to lead to reduced insulin resistance and has in initial studies been associated with improved glycaemic control [86, 87].

A novel endoscopic technique which has been proposed involves the utilization of magnetic devices to produce a dual-path enteral bypass from the jejunum to the terminal ileum. Self-assembling magnets are placed simultaneously at enteroscopy and colonoscopy and then cause permanent necrosis of the intestinal wall to produce a permanent bypass [88]. However, this remains an experimental technique, and all reported cases required laparoscopic evaluation (along with abdominal radiograph) to confirm the position of magnet placement which brings into question the benefits of such a procedure over traditional laparoscopic surgery.

Conclusions and Future Perspectives

The surgical treatment of patients with obesity and metabolic syndrome has evolved considerably over the past 50 years. Large advances have been made in relation to restrictive procedures (including sleeve gastrectomy and gastric band), gastric bypass and malabsorptive procedures such as biliopancreatic diversion. Other procedures such as vertical banded gastroplasty are now not routinely performed as part of current bariatric surgical practice, although knowledge of these procedures is still required for present-day surgeons who may be confronted with patients who have previously undergone these forms of surgery. Arguably, one of the largest developments in bariatric surgical practice has been the advent of laparoscopic surgery with the associated improvement in patient outcomes and technical advances in surgical approaches and ergonomics. The role of endoscopic techniques is yet to be definitively established but it is likely that these methods will develop alongside traditional surgical methodology synergistically and complement each other in the management of patients with obesity and metabolic syndrome.

In the current era of rapid technological advancement within healthcare, the field of bariatric and metabolic surgery has the potential to continue to develop in order to further improve patient outcomes. Although there remains scope for novel surgical techniques, other areas of healthcare development may represent the largest potential gains for improving patient outcomes. Across the field of healthcare delivery, there has been a focus upon delivering personalized therapies that are specifically tailored to each individual [89]. This has the potential to take various forms including analysing an individual's genetic composition to select the most effective form of therapy [90], or modulating a patient's gut microbiome as a therapeutic intervention for the management of obesity and metabolic syndrome [91, 92].

Recent years have seen significant advances in novel pharmacological therapies for the treatment of obesity-related conditions such as type 2 diabetes (T2DM) where glucagon-like peptide-1 (GLP-1) analogues including liraglutide or semaglutide have demonstrated promising results [93–95]. These advances in pharmacological treatments may allow for bariatric and metabolic surgical procedures to be used in conjunction with novel medical therapies in a combined approach as complementary techniques for treatment of T2DM (similar to that which is considered the 'gold-standard' in the treatment of many cancer types with surgery being utilized alongside chemotherapy, radiotherapy or pharmacological therapy) [96].

The role of artificial intelligence within surgical practice also remains to be established, and this has already been utilized to automatically recognize the operative steps involved in laparoscopic sleeve gastrectomy [97]. This could provide a potentially useful training and research tool, as well as having the ability to define assess intra-operative technique for the risk of developing post-operative complications, and thus provide a real-time warning to operating surgeons of these potential hazards [97].

By coupling current surgical therapies for the management of complex obesity and metabolic syndrome with the rapid technological advancement which is currently being developed in many fields of healthcare, it is possible that the future will hold even more significant advances in this field than those which have already occurred over the past 50 years of bariatric surgical practice.

Compliance with Ethical Standards

Conflict of Interest Tom Wiggins, Mohamed Majid and Sanjay Agrawal declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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