Diabetes, Metabolic Syndrome and Obesity

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REVIEW

Recent Advances in Metabolic and Bariatric Surgery: A Narrative Review of Therapeutic Strategies for Weight Loss and Metabolic Health

Bing Zhao[1–3,*], Feilong Wang[1–3,*], Yerui Bi[1,4,*], Lei Li[1,4,*], Yabin Xia[1–3], Yan Jin[1–3,*]

[1]Department of Gastrointestinal Surgery, The First Affiliated Hospital of Wannan Medical University (Yijishan Hospital of Wannan Medical University), Wuhu, Anhui, 241001, People's Republic of China; [2]Department of Hernia and Bariatric Surgery, The First Affiliated Hospital of Wannan Medical University (Yijishan Hospital of Wannan Medical University), Wuhu, Anhui, 241001, People's Republic of China; [3]Anhui Province Key Laboratory of Non-coding RNA Basic and Clinical Transformation (Wannan Medical University), Wuhu, Anhui, 241001, People's Republic of China; [4]Wannan Medical University, Wuhu, Anhui, 241001, People's Republic of China

*These authors contributed equally to this work

Correspondence: Yabin Xia; Yan Jin, Department of Gastrointestinal Surgery & Department of Hernia and Bariatric Surgery, The First Affiliated Yijishan Hospital of Wannan Medical University, Wuhu, Anhui, 241001, People's Republic of China, Tel +86-18805536006; +86-13545905510, Email 77278431@qq.com; jinyanyijishan@wnmc.edu.cn

Abstract: Metabolic and bariatric surgery (MBS) plays an important role in the management of obesity and related metabolic disorders, particularly in patients who meet established surgical criteria. The field has transitioned from open procedures to laparoscopic surgery, and the current landscape includes multiple operations with distinct efficacy-risk profiles. Alongside established procedures such as sleeve gastrectomy (SG), newer approaches—such as endoscopic metabolic interventions and robot-assisted platforms—are being evaluated for their feasibility, safety, learning curve, and potential outcome benefits. However, important questions remain regarding long-term durability, complication patterns, revisional surgery, patient selection, cost-effectiveness. To map these developments, we screened PubMed literature up to March 10, 2026 using terms such as "metabolic and bariatric surgery" and "sleeve gastrectomy", with emphasis on the International Federation for Surgery and Other Therapies for Obesity (IFSO) and higher-level evidence when available. We then synthesize findings across surgical technique evolution, indications and complications, unresolved challenges, and future directions, including how artificial intelligence (AI) and machine learning (ML) may support perioperative risk prediction and individualized treatment planning. This work aims to support clinicians in tailoring MBS plans and to guide future research priorities.

Keywords: metabolic and bariatric surgery, obesity, diabetes, follow-up data, complications

Introduction

Obesity is a major global driver of preventable morbidity and health-system burden. The WHO estimates that in 2022, 1 in 8 people worldwide had obesity, with 43% of adults overweight and 16% obese (Body Mass Index (BMI) ≥30 kg/m^2), around 35 million children under 5 were overweight in 2024.[1] Classified as a chronic, relapsing disease stemming from complex biological and environmental interactions, excess adiposity raises risks of type 2 diabetes mellitus (T2DM), cardiovascular disease, obstructive sleep apnea (OSA), and certain cancers.[1–3] For eligible patients where intensive lifestyle interventions and pharmacotherapy fail to achieve adequate or lasting weight loss, metabolic and bariatric surgery (MBS) is the most evidence-based option for long-term weight reduction. It works mainly through procedure-specific changes in gastrointestinal anatomy and neurohormonal signaling, and also improves or remits obesity-related comorbidities like T2DM, hypertension (HTN), and OSA.[4] MBS reduces diabetic patients' medication needs and shortens complication-related hospital stays, easing economic burdens.[5] Notably, obese patients undergoing MBS see a 49.2% lower mortality risk and a 6.1-year longer life expectancy, highlighting its unique advantages in obesity treatment.[6]

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However, the rapid evolution of surgical techniques, coupled with unresolved questions regarding long-term durability, complication patterns, revisional surgery, patient selection, and cost-effectiveness, creates a need for a comprehensive, up-to-date synthesis of recent evidence. This narrative review aims to systematically map the latest advances in MBS, compare the efficacy and safety profiles of established and emerging procedures, identify key clinical challenges, and highlight future research directions to guide personalized treatment planning.

Materials and Methods

This narrative review was reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. A targeted literature search was conducted in the PubMed database, covering all relevant records from database inception to March 10, 2026. We combined MeSH headings and free-text keywords for the field and major procedures, including "metabolic and bariatric surgery, weight loss metabolic surgery, sleeve gastrectomy, Roux-en-Y gastric bypass, one-anastomosis gastric bypass, biliopancreatic diversion with duodenal switch, single anastomosis duodena-ileal bypass with sleeve gastrectomy, sleeve gastrectomy with transit bipartition, single-anastomotic sleeve ileal bypass, endoscopic duodenal-jejunal bypass liner, robotic-assisted metabolic and bariatric surgery and revisional bariatric and metabolic surgery". A representative structure was: (bariatric/metabolic surgery terms) AND (procedure terms). When synthesizing evidence, we prioritized guidelines from the International Federation for Surgery and Other Therapies for Obesity (IFSO) and high-level clinical evidence (randomized controlled trials, meta-analyses, and large-scale multicenter cohort studies).

Inclusion criteria: 1. Clinical studies, systematic reviews, meta-analyses and high-quality narrative reviews focusing on MBS surgical techniques, weight loss efficacy, metabolic outcomes, complications and emerging technologies; 2. Study populations consisting of patients with obesity and related metabolic disorders who received MBS; 3. Articles published in English; 4. Studies with extractable data on efficacy, safety or long-term prognosis.

Exclusion criteria: 1. Case reports and small-sample studies with fewer than 10 cases; 2. Basic experimental studies and animal studies; 3. Conference abstracts without complete full-text data; 4. Duplicate publications and studies with overlapping patient cohorts.

Two researchers independently completed literature screening in two sequential stages (title/abstract screening and full-text screening), and disagreements were resolved by discussion or consultation with a third senior researcher.

The initial database search yielded 1328 relevant records. After removing 316 duplicate records, 1012 records remained for title and abstract screening. Among them, 797 records were excluded because they did not meet the requirements of study type, research topic, or language, leaving 215 records for full-text assessment. After full-text review, 37 records were further excluded, with specific reasons as follows: 16 studies had insufficient core outcome data, 12 were small-sample case series (<30 cases), and 9 were non-clinical basic research studies. Finally, 178 articles were included in this narrative review, including 89 cohort studies, 23 randomized controlled trials, 34 systematic reviews and meta-analyses, 18 large-scale registry-based studies, and 14 technical innovation studies and expert consensus articles. The detailed stepwise screening process is presented in the PRISMA flowchart (Figure 1).

Review of the Development History of Metabolic and Bariatric Surgery (MBS)

Early Surgical Approaches

Early observations that patients with surgically shortened intestines could lose weight motivated the first malabsorptive operations for obesity.[7] Historical accounts often credit Henrikson with an early obesity-directed small-bowel resection in 1952 (reported as a 105cm resection).[8] Jejunoileal bypass later operationalized the same malabsorption principle by excluding large segments of small intestine from nutrient contact, producing marked early weight loss.[9] However, long-term follow-up highlighted unacceptable adverse outcomes—including profound malabsorption and metabolic complications—which ultimately led to the procedure's decline and a shift toward safer techniques and stricter indications.[10]

Evolution and Advancements in Surgical Techniques

As evidence has accumulated on obesity and its metabolic comorbidities, MBS has evolved from earlier, higher-risk operations to more standardized procedures with improved safety. In the 1970s, Griffen advanced gastric bypass by

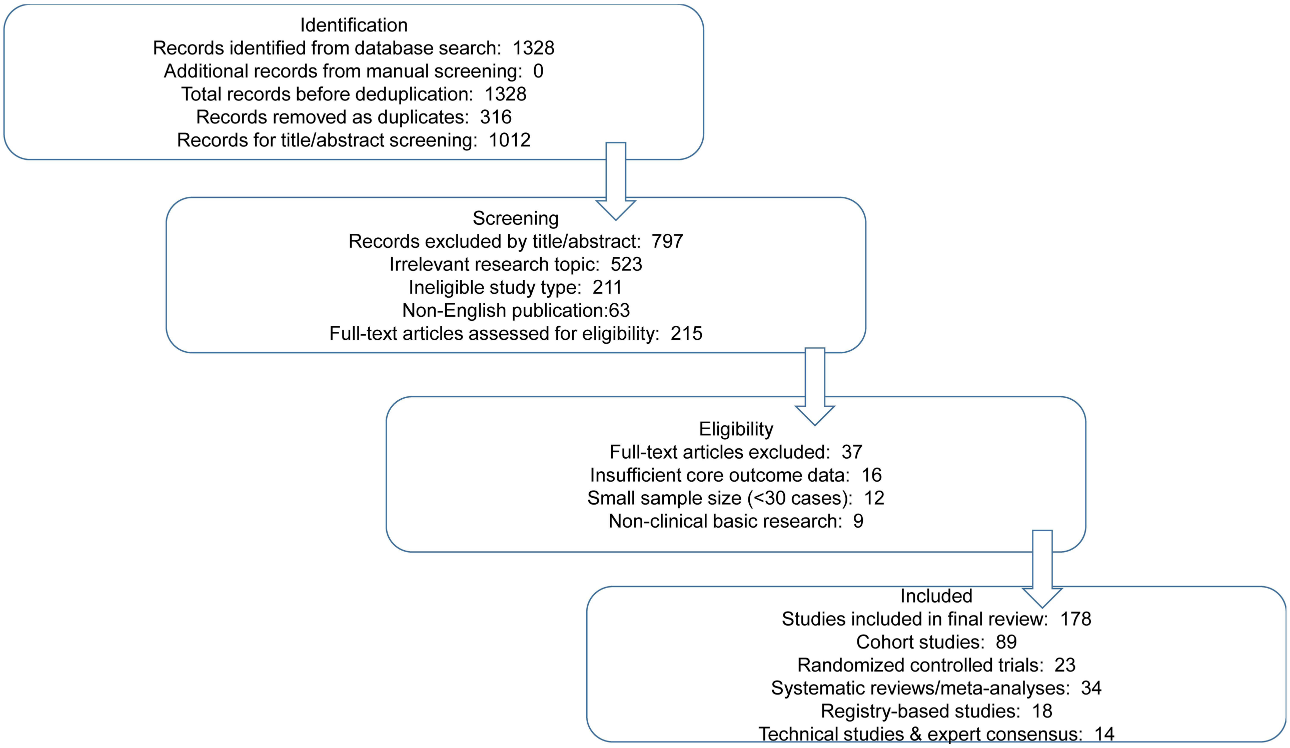

Figure 1 PRISMA flowchart of the study selection process.
Notes: The flowchart demonstrates the number of records identified, screened, assessed for eligibility, and finally included in the review, with detailed reasons for exclusion at each screening stage.

introducing a Roux-en-Y anastomosis between the gastric remnant and the jejunum.[11] Since the early 2000s, the expanding use of laparoscopic platforms has shifted many bariatric operations toward minimally invasive approaches that often reduce access-related trauma and shorten recovery compared with open surgery. Contemporary practice includes laparoscopic sleeve gastrectomy (LSG), Roux-en-Y gastric bypass (RYGB), one-anastomosis gastric bypass (OAGB), biliopancreatic diversion with duodenal switch (BPD/DS), single-anastomosis duodena-ileal bypass with sleeve gastrectomy (SADI-S), and sleeve gastrectomy with twin-channel anastomosis (SG-TB). More recently, single-anastomotic sleeve ileal bypass (SASI) has been introduced as a newer MBS option, adding to the expanding set of procedures used to treat obesity and related metabolic disease (Figure 2).

Overview of Surgical Approaches

Sleeve Gastrectomy (SG)

Development History and Evolution

Sleeve gastrectomy (SG) is now among the most commonly performed bariatric operations worldwide. Clinically, SG was introduced in the early 1990s primarily as the first stage of a staged strategy for BPD/DS. A key technical milestone came in 1999, when the first LSG was performed, an approach that reduced operative invasiveness and supported broader adoption. By 2008, accumulating follow-up evidence indicated that SG alone could produce clinically meaningful weight loss, leading to its recognition and promotion as an independent bariatric procedure.[12] Continued advances in laparoscopic techniques have further shaped the evolution and dissemination of SG. SG, due to its minimally invasive advantages, has rapidly gained popularity.[13] SG removes the greater curvature and the fundus of the stomach, leaving a narrow tubular structure that limits food intake while preserving the pylori. Its advantages include that the surgery is limited to the stomach and maintains the endoscopic access of the duodenum, among others.

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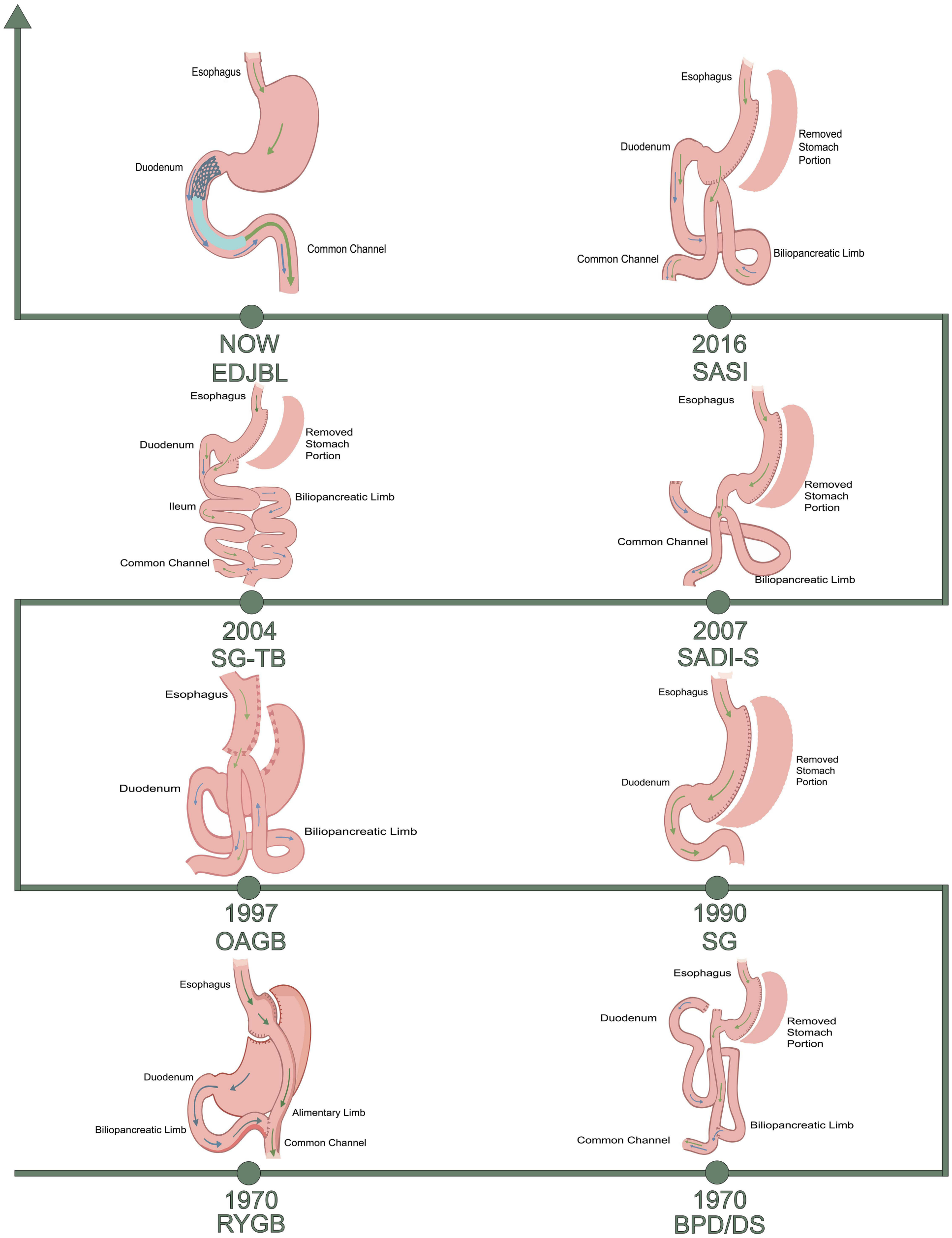

Figure 2 Landmark surgical procedures in bariatric and metabolic surgery from the early days to the present. The timeline documents 56 years of progress, beginning with the gastric bypass procedure proposed by Griffen in 1970, which established a Roux-en-Y anastomosis between the gastric stump and the jejunum. Key developments include: In the 1970s, Scopinaro first described BPD/DS as biliopancreatic diversion (BPD); in the 1990s, SG was introduced as the first stage of a staged surgical strategy for BPD/DS; at the end of the 20th century, Robert Rutledge first proposed OAGB in 1997, initially known as mini-gastric bypass; In the early 21st century, SG-TB and SADI-S were successively proposed. In 2016, Professor Tarek Mahdy introduced the SASI procedure, based on gastric bypass surgery and the Santoro procedure. In recent years, the latest advancements in endoscopic weight loss and metabolic therapy have expanded minimally invasive treatment options for obesity management, with EDJBL being the most representative. Currently, our department is actively performing single-port sleeve gastrectomy procedures using the techniques described above.
Note: This figure is an original drawing created by the authors, no copyright permission is required.
Abbreviations: RYGB, Roux-en-Y Gastric Bypass; BPD/DS, biliopancreatic diversion with duodenal switch; SG, sleeve gastrectomy; OAGB, one-anastomosis gastric bypass; SG-TB, sleeve gastrectomy with transit bipartition; SADI-S, single anastomosis duodena-ileal bypass with sleeve gastrectomy; SASI, single anastomosis sleeve ileal bypass; EDJBL, endoscopic duodenal-jejunal bypass liner.

Indications

As a first-line MBS, the indications for SG align with international guidelines: (1) MBS is recommended for individuals with BMI ≥35 kg/m^2, regardless of the presence, absence, or severity of co-morbidities; (2) MBS should be considered for individuals with metabolic diseases and BMI 30.0–34.9 kg/m^2, (3) the BMI threshold should be adjusted for the

Asian population: BMI ≥25 kg/m^2 suggest clinical obesity, and BMI ≥27.5 kg/m^2 population should consider MBS; (4) Appropriately selected children and adolescents should be considered for MBS.[14] Mainstream revisional bariatric surgeries after SG include RYGB, OAGB, BPD/DS, SADI-S, SG-TB and SASI.[15]

Weight Changes

Postoperative weight change exhibits a typical nonlinear trajectory, with an initial rapid weight loss phase typically lasting 12–18 months. In one study, at 3 months post-surgery, patients lost 18.9 ± 6.9 kg of excess body weight.[16] Median percentage excess weight loss (%EWL) at 1 year after surgery was 52.0%.[17] A multicenter retrospective study in Japan found that the total weight loss percentage after one year was 30.1%.[18] A 10-year follow-up study of adolescent laparoscopic sleeve gastrectomy showed: BMI was 44.94 ± 4.33 kg/m^2 and 30.11 ± 7.10, before, and 10-year following surgery, respectively, a reduction of 33.24%. Su et al found that percentage total weight loss (%TWL) at postoperative months 1, 3, 12, and 60 were 10.6%, 18.1%, 29.3%, and 26.6%, respectively. The %TWL at months 1 and 3 were significantly correlated with %TWL after 5 years ($P < 0.01$). The weight regain rate was 29.8% at 5 years.[19]

Metabolism-Related Monitoring

Improvement in HTN is one of the key metabolic benefits of SG. Postoperative blood pressure control is closely correlated with the degree of weight loss, with mean reductions of 10–15 mmHg in systolic blood pressure and 5–10 mmHg in diastolic blood pressure. Blood pressure reductions are often apparent in the early postoperative phase and, in available follow-up, can remain evident over the longer term.[20] Lipid measures show a parallel pattern of improvement: total cholesterol (TC), low-density lipoprotein cholesterol (LDL-C), and triglycerides (TG) tend to decline, while high-density lipoprotein cholesterol (HDL-C) rises. In one study, 12 months after surgery, mean relative changes were 15.2% (TC), 18.7% (LDL-C), 32.4% (TG), and 12.8% (HDL-C). The magnitude of blood pressure and lipid changes generally tracks with the degree of postoperative weight loss and accompanying shifts in dietary intake.[20] A study from China revealed that the remission rates for HTN, T2DM, fatty liver, hyperlipidemia (HLD), and OSA were 89.5%, 95.5%, 82.6%, 81.7%, and 61.7%, respectively, one year after surgery ($P < 0.05$).[21]

Complications

Early postoperative complications primarily included bleeding, anastomotic leakage, gastric stenosis, and infection, with an overall complication rate of 1.4%.[22–24] Postoperative bleeding is one of the most common early complications of SG, occurring at a rate of approximately 1.0% to 3.0%,[25] related to the handling of short gastric vessels, hemostasis quality at the greater curvature resection margin, and patients' coagulation status. Anastomotic leakage, the most severe early complication, occurs in 0.5–2.5% of cases,[22] mostly at the gastroesophageal junction or proximal gastric body, caused by excessive staple-line tension, tissue ischemia, or improper stapler use. Postoperative nausea and vomiting are frequent in SG patients, affecting 30.0–50.0%,[26] and preoperative scopolamine significantly reduces its 24-hour incidence.[26] The association between Helicobacter pylori infection and early SG complications remains controversial; eradication therapy does not significantly lower early complication rates.[27] New-onset Gastroesophageal Reflux Disease (GERD) is the most common long-term complication, affecting 20–40% of patients,[28] resulting from elevated intragastric pressure, altered His angle, and impaired lower esophageal sphincter function. Mazin found that the incidence rate of gallstones was 16.3%.[29]

Nutrition-Related Monitoring

Preoperative screening for common micronutrient deficiencies is a critical component of perioperative care, as undiagnosed deficiencies can exacerbate postoperative nutritional complications and impair recovery.[30] Nutritional deficiencies represent another significant long-term complication of SG, primarily involving iron, vitamin B12, vitamin D, and protein deficiencies. Nutritional monitoring post-SG should continue for at least 12 months. The incidence of iron deficiency ranges from approximately 14%, while vitamin B12 deficiency occurs in about 5.3% of cases. Vitamin D deficiency occurs in 25% of cases.[31] Vitamin B12 deficiency in SG patients may manifest as severe clinical presentations including peripheral neuropathy and pancytopenia.[32,33] Weight rebound or insufficient weight loss occurs in approximately 20.0% to 30.0% of SG patients, associated with dietary habits, psychological factors, and adaptive gastric capacity expansion.[23] A 10-year follow-up study reported a 32–37% incidence of hair loss in adolescent SG patients, linked to multiple nutritional deficiencies.[34]

Roux-en-Y Gastric Bypass (RYGB)

Development and Evolution

RYGB underwent a technical evolution from open surgery to laparoscopic techniques. Early gastric bypass procedures primarily utilized open approaches. With the maturation of laparoscopic technology, laparoscopic Roux-en-Y gastric bypass gradually became the standard procedure.[35] RYGB is designed to limit food intake by creating a small gastric pouch and to reduce nutrient absorption by bypassing the long limb of the intestine. This approach achieves a favorable balance between weight loss efficacy and safety by restricting food intake while decreasing nutrient absorption. Compared to earlier jejunoileal bypass procedures, RYGB significantly reduced the incidence of malnutrition and metabolic disorders while improving patients' glycemic control and insulin sensitivity, laying the foundation for its application in diabetes treatment.

Indications

Indications for RYGB primarily depend on BMI and obesity-related complications. International guidelines recommend weight loss surgery for patients with BMI ≥40 kg/m^2 or BMI ≥35 kg/m^2 accompanied by severe obesity-related complications.[36] However, it may also be applied when other bariatric procedures fail or complications arise, such as weight regain after sleeve gastrectomy, chronic anastomotic leaks, or refractory GERD, where conversion to RYGB may be considered as a corrective procedure.[37,38] For patients with obesity and refractory GERD, RYGB is the preferred anti-reflux surgical option.[39] In specific metabolic conditions, such as some refractory type 2 diabetes patients, RYGB may be considered at a BMI of 30–35 kg/m^2, but requires individualized assessment.[40]

Weight Changes

RYGB surgery achieves an average %EWL of 68.5% at 1 year postoperatively, maintained at 65.2% at 2-year follow-up.[35] The maximum %EWL after RYGB peaked at 18 months postoperatively, stabilized at 24 months, and exceeded 50% at 6 months postoperatively.[41] David et al found that the %TWL was greater with RYGB than with SG. At 1 year, RYGB patients had 28.4%TWL, SG 23.0%TWL. At 5 years, RYGB had 21.7%TWL, SG 16.0%TWL.[42] Between 3 and 5 years postoperatively, some patients experienced weight regain, with average weight recovery reaching 10–15 kg, showing significant individual variation.[43] Ten-year follow-up data indicate that RYGB maintains substantial weight loss (EWL ≥90%), though weight regain occurs in some patients.[44] A cohort study demonstrated that gastric pouch size, assessed based on stapler number, significantly impacts short-term weight loss outcomes. Patients with smaller gastric pouches exhibited more pronounced BMI reductions at 6 and 12 months postoperatively. Short-term weight loss outcomes are closely correlated with surgical technical parameters, including anatomical features such as gastric pouch volume, length of the biliopancreatic arm, and length of the Roux limb.[45]

Metabolic Monitoring

85%, 84.8%, and 81.1% of the patients improved or remitted T2DM, HTN, and HLD.[46] A meta-analysis comparing RYGB with SG for diabetes remission demonstrated RYGB's superiority in T2DM remission.[47] Long-term follow-up data for RYGB showed a 55.3% maintenance rate of excess weight loss at 10 years post-surgery, with complete diabetes remission rates of 45.2% at 5 years and 28.7% at 10 years.

Complications

Research data show a 30-day major complication rate of 27.51% after RYGB.[48] Long-term complications include internal hernia in 2–6% of cases, marginal ulcers in 8–12% of cases.[49,50] Anastomotic leakage is one of the most severe early complications, typically presenting with fever, tachycardia, abdominal or respiratory symptoms, and leukocytosis.[51] Marginal ulceration at the gastrojejunal anastomosis remains common, with reported incidence ranging widely (0.6–16%) due to variations in follow-up, diagnostic criteria, and patient risk profiles. Its development is multifactorial, involving persistent acid exposure, local ischemia, nonsteroidal anti-inflammatory drug use, and *Helicobacter pylori* infection.[52,53] Dumping syndrome is a frequent functional sequela, with a prevalence of 10–50%.[54] Severe dumping often correlates with greater weight loss but reduced quality of life.[55] Treatment is individualized, starting with dietary modification and pharmacotherapy, with endoscopic interventions such as transoral outlet reduction used for selected patients to improve symptoms and manage weight regain.[54,56,57]

Nutrition-Related Monitoring

Nutritional deficiencies can emerge and persist months to years after RYGB, creating a sustained need for monitoring and long-term management, particularly for iron, vitamin B12, and calcium.[58] Mechanistically, the procedure reroutes ingested food away from the duodenum and proximal jejunum, reducing exposure to key absorptive segments for iron and calcium and thereby increasing deficiency risk over follow-up.[59] Reduced gastric capacity and decreased gastric acid secretion further impair vitamin B12 release and absorption. Systematic reviews and meta-analyses indicate that the incidence of vitamin B complex deficiencies is significantly higher after RYGB than after SG.[58] Ten-year follow-up data revealed iron deficiency rates of 41.0%, vitamin B12 deficiency rates of 8.5%, and vitamin D deficiency rates of 35.8%.[60,61]

One-Anastomosis Gastric Bypass (OAGB)

Development and Evolution

The OAGB was first proposed by Robert Rutledge in 1997, initially termed the Mini-Gastric Bypass.[62,63] OAGB creates a smaller gastric pouch to promote faster satiety. Subsequently, it bypasses the jejunum, forming a 150 to 200 cm segment of the biliary-pancreatic duct and an end-to-side gastrojejunostomy. Compared to the traditional RYGB, OAGB simplifies the surgical steps, requiring only one anastomosis, theoretically reducing operating time and potential complication risks.

Indications

OAGB is indicated for patients with BMIs ≥ 40 kg/m^2 or ≥ 35 kg/m^2 accompanied by obesity-related medical conditions such as T2DM, HTN, HLD or OSA.[64]

Weight Changes

A meta-analysis incorporating multiple studies showed that the average %EWL at 1-year post-OAGB was 85.2%, compared to 78.5% for RYGB. Regarding safety.[65] A retrospective cohort study demonstrated that 1-year %TWL after OAGB could exceed 30%, with %EWL surpassing 70%. Long-term follow-up data indicated that %TWL remained within the 25–30% range at 5 years post-surgery, suggesting OAGB delivers sustained weight loss effects. Compared with SG, OAGB demonstrated significantly higher %TWL at both 1 and 3 years postoperatively.[66]

Metabolic Monitoring

One study found that OAGB is comparable to RYGB in weight loss outcomes and T2DM remission rates, and even outperforms it in some investigations.[65] Systematic reviews indicate that complete remission rates (defined as discontinuation of all antidiabetic medications with HbA1c <6%) for T2DM exceed 80% after OAGB.[65,67] Partial remission rates (defined as discontinuation of all antidiabetic medications with HbA1c <6.5%) surpass 90%.[67] The remission rates in T2DM, HTN, HLD and OSA were as follows: 94%, 94%, 96%, 90%.[68]

Complications

OAGB 5-Year Complications Overall rate: 4.5–10.3%, Ulcers: 1–6%.[69,70] OAGB, a major procedure in MBS, has complications primarily focused on bile reflux and anastomotic issues.[62,71] Bile reflux is one of the most characteristic postoperative complications of OAGB, stemming from the lack of anti-reflux mechanisms at the gastrojejunal anastomosis.[67] A prospective multicenter study using modified hepatobiliary scintigraphy reported a symptomatic bile reflux rate of approximately 12.5%.[63] In OAGB, anastomotic complications are uncommon overall; pooled estimates from systematic reviews place anastomotic leak roughly in the 1.2–2.8% range, with most events occurring within the first 30 postoperative days.[72] Technical factors are contributory, and some comparative evidence suggests lower leak rates with linear stapling than with circular anastomoses.[73] Anastomotic ulcers represent a major type of mid-term complication following OAGB. Studies report an anastomotic ulcer incidence of approximately 1.8–3.5%, with about 0.3% progressing to perforation[74,75] Risk factors include nonsteroidal anti-inflammatory drug use, smoking, Helicobacter pylori infection, and excessive anastomotic tension. Ulcer perforation usually requires emergency surgery, including repair or conversion to RYGB.[76]

Nutrition-Related Monitoring

Postoperative malabsorption following OAGB has been demonstrated to result in deficiencies of nutrients such as calcium, folic acid, vitamin D or B12, iron, and zinc. In rare cases of severe malnutrition, secondary surgical intervention may be required.[77] A study involving nearly 50,000 patients with OAGB showed that the incidence of severe malnutrition requiring hospitalization was approximately 0.9%. The risk was significantly elevated in patients with Biliary-pancreatic limb > 150 cm.[78]

Biliopancreatic Diversion with Duodenal Switch (BPD/DS)

Development and Evolution

BPD/DS originated in the 1970s and was first described by Scopinaro as biliopancreatic diversion (BPD).[79,80] The original BPD procedure involved distal gastrectomy, gastrojejunostomy, and long-arm Roux-en-Y reconstruction, but carried risks of complications such as dumping syndrome and marginal ulcers.[80] Consequently, Marceau and Hess modified the original technique in the 1990s, preserving pyloric function and introducing duodenal switch, thereby establishing the modern BPD/DS procedure. The technical rationale of BPD/DS relies on multiple synergistic mechanisms.[80,81] BPD/DS begins with SG, preserving approximately 100–150 mL of gastric volume to create a restrictive effect. Subsequently, the jejunum is transected 250 cm distal to the Treitz ligament, with its distal end anastomosed to the first segment of the duodenum to form a food passage; The proximal biliary-pancreatic tract is anastomosed to the ileum 50–100 cm proximal to the ileocecal valve, creating a biliary-pancreatic fluid pathway. This anatomical design ensures food and biliary-pancreatic fluids mix only within the shared pathway, significantly reducing the surface area for fat and starch absorption.[79,82] The shared pathway typically spans 100 cm, a length that determines the degree of malabsorption and the risk of nutritional complications.[80,82]

Indications

For patients with super obesity (BMI > 50 kg/m^2), BPD/DS can be an effective bariatric operation.[83] BMI ≥40 kg/m^2 with severe metabolic diseases (such as T2DM, OSA, HTN, etc) is also an indication for BPD/DS. Despite its complexity, the conversion of RYGB to BPD/DS can be performed in a single stage; however, the use of an unconventional technique has been demonstrated to be ineffective in reducing the high complication rate. BPD/DS has been demonstrated to be a viable procedure following RYGB in selected patients, exhibiting comparable efficacy to distalisation of RYGB and potentially reduced risk.[84]

Weight Changes

A follow-up study revealed that one year after BPD/DS surgery, patients achieved a %TWL of 43.22% ± 7.71% and a %EWL of 100.11% ± 33.29%.[81] %EWL at 3 years was 40.1% for SG, 54.1% for RYGB, and 67.4% for BPD/DS, with BPD/DS performing significantly better (P < 0.001).[85] A 10-year comparative analysis of patients with BMI ≥ 50 kg/m^2 showed that the average %EWL rate in the BPD/DS group was 85.2%, significantly higher than 68.3% in the SG group and 77.1% in the RYGB group.[80] Ten-year postoperative follow-up data indicate that patients maintained an average %EWL of over 70%, a result significantly superior to other weight-loss surgical procedures.[79]

Metabolic Monitoring

A BPD/DS study involving 45 patients found that 88.9% (N = 8), 86.6% (N = 13), and 55.5% (N = 5) of patients experienced resolution or improvement of their T2DM, HTN, and HLD, respectively.[86] Regarding T2DM remission, complete diabetes remission at 5 years was 29% for SG, 61% for RYGB, and 79% for BPD/DS.[85] At 10 years post-BPD/DS, the complete remission rate reached 78.4%, compared to 45.2% for SG and 62.7% for RYGB. The long-term remission rate of T2DM after BPD/DS is significantly higher than that of other weight-loss surgeries. Another long-term follow-up study of BPD/DS patients demonstrated a complete remission rate for T2DM exceeding 75% at 10 years post-surgery. The study cohort had a mean baseline HbA1c of 8.2%, which decreased to 5.8% at 10 years, with most patients requiring no hypoglycemic medication.[79]

Complications

The incidence of major complications within 30 days after BPD/DS varies across studies but generally ranges from 3.8% to 15.2%.[83,87] The incidence of duodenal stump leakage ranges from approximately 1.2% to 2.8%, typically occurring 5–10 days postoperatively.[79,87] Among surgical complications, anastomotic leakage represents one of the most severe early complications, occurring at a rate of approximately 1.5–3.2%.[79,88] Intra-abdominal hemorrhage occurs in about 1.8–4.1% of cases, while incisional infection ranges from 2.3–5.6%.[79] Duodenal-ileal anastomotic stricture occurs in approximately 3–7% of cases, typically presenting 3–6 months postoperatively. Surgical revision is considered only after multiple failed endoscopic treatments, occurring in less than 2% of cases.[79] Bile reflux gastritis is a common functional complication after BPD/DS, occurring in approximately 15–25% of patients. Its development is associated with altered bile flow pathways and impaired gastric emptying function.[79] Dumping syndrome occurs in approximately 8–15% of BPD/DS patients, lower than in RYGB. Early dumping symptoms correlate with rapid entry of hyperosmolar food into the small intestine, while late symptoms are associated with reactive hypoglycemia. Dietary adjustments constitute the primary management strategy, including eating smaller, more frequent meals, avoiding high-sugar foods, and separating liquid and solid food intake.[79]

Nutrition-Related Monitoring

One year after BPD-DS surgery, the prevalence of albumin deficiency was 16.7%, iron deficiency was 16.7%, and zinc deficiency was 50%. Anemia affected 8.3% of patients. Vitamin A deficiency was 58.3%, and vitamin E deficiency was 50%. Asymptomatic gallstones significantly increased from 0% preoperatively to 41.7% postoperatively.[81] The incidence of vitamin and trace element deficiencies after BPD/DS is significantly higher than after other bariatric procedures, necessitating lifelong supplementation.[89]

Single Anastomosis Duodena-Ileal Bypass with Sleeve Gastrectomy (SADI-S)

Development and Evolution

SADI-S is a novel MBS developed in recent years.[67,90] First proposed by Sánchez-Pernaute et al in 2007, this procedure aims to simplify the traditional BPD/DS. Traditional BPD/DS surgery involves two anastomoses, presenting technical complexity and higher complication risks. SADI-S simplifies the procedure by eliminating one anastomosis.[90] SADI-S begins with SG, removing approximately 80% of the stomach to create a tubular gastric structure; followed by a duodenal-ileal end-to-side anastomosis 250–300 cm distal to the ligament of Treitz, creating a single anastomotic site. This design preserves pyloric function, reduces dumping syndrome incidence, and enhances the incretin effect by diverting bile and pancreatic juice to the distal ileum.[67] The evolution of SADI-S has undergone multiple technical refinements. Early versions employed shorter ileal loops, but subsequent studies demonstrated that longer common channels (typically 250–300 cm) better balance weight loss efficacy with the risk of nutritional complications.[90]

Indications

Indications include severe obesity (BMI ≥50 kg/m^2), multiple metabolic disorders, or situations where other weight loss interventions have failed.[91] For patients requiring more intensive metabolic intervention—particularly when diabetes remission is the primary goal—SADI-S may be superior to RYGB or SG procedures.[91–93] For refractor T2DM, SADI-S is also considered a treatment option even when BMI falls within the 30–35 kg/m^2 range.[67] For patients experiencing weight regain or weight loss failure after SG, SADI-S may serve as a revision surgical option.[94,95] In these patients, SADI-S as a revision procedure offers additional weight loss and metabolic improvement, with 5-year follow-up data demonstrating significant secondary weight reduction effects.[96]

Weight Changes

In a study demonstrating an average %EWL of 78.7% and %TWL of 36.8% at 12 months.[97–99] A systematic review included 1088 patients with SADI-S, with a mean preoperative BMI of 49.66 kg/m^2. Five-year follow-up data showed a TWL of approximately 33.67% and an EWL of approximately 72.88%.[100] SADI-S is effective across various BMIs, though outcomes may vary depending on preoperative weight. Enochs et al found that patients with a baseline BMI below 45 kg/m^2 achieved 95% weight loss at both 12 and 24 months. Although patients with higher baseline BMIs experienced smaller reductions in weight, these were still statistically significant.[101] Notwithstanding these unanticipated findings, the results persist in supporting the utilization of SADI-S in patients with elevated BMIs.

Metabolic Monitoring

Comorbidity remission rates for T2DM, HTN, HLD and OSA were of 75.8%, 61.2%, 60.4%, 71.9%, respectively.[92] Both animal studies and clinical data demonstrate that SADI-S surgery significantly improves post-operative glycemic control. Compared to other mainstream weight-loss procedures (such as SG and OAGB), it achieves similar or superior remission rates for T2DM.

Complications

The 30-day complication rate ranges from 2.6% to 11%. Hernias: 0–0.57% Stenosis: 0.3% Gallstones: 7.7%.[102–105] Dumping syndrome occurs in 10% to 15% of SADI-S procedures, lower than the 20% to 30% rate seen with traditional RYGB. Diagnosis relies on clinical symptoms and an oral glucose tolerance test.[106] Bile reflux occurs in 8% to 12% of SADI-S procedures, primarily due to the absence of bile diversion in the Roux-en-Y configuration. The Braun anastomosis, as a prophylactic measure for bile reflux after SADI-S, has shown a significant reduction in reflux incidence in preliminary studies. This technique facilitates distal bile diversion by creating a side-to-side anastomosis between the afferent and efferent loops.[107]

Nutrition-Related Monitoring

Metabolic surgery-related malnutrition risk varies by procedure, mainly affected by small bowel bypass extent and resultant absorptive capacity reduction.[108,109] Classic duodenal switch (DS) has a marked malabsorptive component, leading to higher deficiencies of fat-soluble vitamins (A, D, E, K) and trace elements, especially with inconsistent supplementation and long-term monitoring.[110] SADI-S, though technically simpler, bypasses the duodenum and proximal jejunum, causing iron and B12 deficits in follow-up; its 12-month iron deficiency rate is 35–45% and B12 deficiency 25–30% in some studies, highlighting the need for standardized surveillance and supplementation.[106] Thanks to a longer preserved common channel, SADI-S has a lower malnutrition risk than traditional DS: a prospective comparative study found SADI-S had lower postoperative rates of protein malabsorption (8.2% vs 12.7%), vitamin B12 deficiency (15.3% vs 22.4%) and iron deficiency (18.6% vs 24.1%) than traditional BPD/DS.[109] SADI-S also has a lower malnutrition risk than SG, which involves no malabsorptive mechanism. Protein-energy malnutrition affects 5–8% of SADI-S patients, presenting as excessive weight loss, muscle wasting and hypoalbuminemia, and can be prevented by daily protein intake $\geq$ 60g (prioritizing high-quality sources) and appropriate protein supplements.[106]

Sleeve Gastrectomy with Transit Bipartition (SG-TB)

Development and Evolution

In 2004, SG-TB was first proposed to address nutrient loss and malabsorption issues associated with techniques such as RYGB or BPD/DS, enhance neuroendocrine-gastrointestinal responses to food intake, facilitate weight loss, and improve diabetic conditions.[111] The technical principles of SG-TB include two main components: First, a standard SG is performed, removing approximately 80% of the stomach volume to create a tubular stomach. Subsequently, an anastomosis is established between the gastric antrum and the terminal ileum, forming a dual-channel system. The evolution of SG-TB reflects the shift in bariatric metabolic surgery from simple weight reduction to comprehensive metabolic regulation.[112]

Indications

Indications include patients aged 18 to 65 with any BMI,[113] as well as those with a BMI greater than or equal to 50 kg/m^2 (regardless of whether they have obesity-related diseases). When gastric banding is not recommended, SG-TB can serve as an effective alternative for GERD, weight regain, and poorly controlled diabetes.[64] Due to the feasibility of endoscopic procedures, SG-TB is also suitable for patients at risk of gastric cancer or precancerous lesions, whereas RYGB cannot achieve this.[112]

Weight Changes

A study looking back at data from 355 patients revealed that one year after SG-TB surgery, the average %EWL hit 78.2%.[114] On the other hand, the %EWL one year after SG alone usually varies between 60–70%. SG-TB shows better short-term weight-loss results than SG, and this difference might be due to the extra metabolic regulatory mechanisms offered by the dual-channel structure. A multicenter retrospective cohort study announced that the mean %EWL 12 months after SG-TB surgery was 85.3%, with good consistency among different centers as the coefficient of variation was 12.7%.[112] It is worth mentioning that Topart et al showed that at the 2-year mark, although BPD/DS had better weight-loss results than SG-TB, there were more complications after BPD/DS. In another study, they indicated SG-TB's obvious superiority over RYGB in weight loss (TWL 44.8% vs 38.4%, $p < 0.0001$).[112,115] Long-term follow-up information suggests that SG-TB has a relatively steady trend in maintaining weight beyond 5 years. One study with an average follow-up of 7.2 years displayed a %EWL of 65.4% at 5 years post-surgery, which stayed at 61.8% at 7 years. Compared with traditional RYGB, SG-TB showed non-inferiority in long-term weight maintenance.[116] However, the SG-TB Long-Term Diabetes Study found that SG-TB was superior to SG and RYGB.[117,118]

Metabolic Monitoring

In a study involving 355 patients, Muzaffer et al found that 281 patients (79.2%) achieved and maintained complete remission. Another 31 patients (8.7%) experienced improvement in T2D.[114] The remission rate of T2DM may relate to SG-TB's dual mechanism of action: reducing caloric intake through gastric volume restriction while altering nutrient absorption and hormone secretion patterns via intestinal bypass.[112] Santoro et al demonstrated a resolution rate of 91% and 70% for OSA and HLD, respectively. After surgery, 72% of patients with a preoperative diagnosis of HTN no longer needed medications.[119]

Complications

The overall complication rate over two years was 10.2%.[114] Studies indicate that early complications (within 30 days) occur in 6% of cases, primarily manifesting as anastomotic leakage, bleeding, and obstruction. Late complications include gallstones (21.9%), incisional hernia (3.1%), adhesive intestinal obstruction (2.4%), stricture (2.3%), and ulceration (0.07%).[120]

Nutrition-Related Monitoring

Long-term nutritional monitoring revealed that at 5 years post SG-TB, the incidence of iron deficiency was 12.4%, vitamin B12 deficiency was 8.7%, and vitamin D deficiency was 15.3%. These deficiency rates are lower than those observed after traditional BPD but higher than those after SG alone.[116] The long-term nutritional risks of SG-TB primarily stem from alterations in nutrient absorption pathways due to the ileum-stomach anastomosis. Compared to conventional SG, SG-TB preserves continuity between the gastric antrum and duodenum, theoretically reducing the risk of micronutrient deficiencies such as iron, calcium, and vitamin B12. Long-term follow-up studies of SG-TB report that approximately 15–25% of patients meet criteria for at least one micronutrient deficiency at 5 years, although estimates vary by deficiency definition, supplementation adherence, and follow-up completion rates. Across studies, iron deficiency and vitamin D deficiency are most frequently reported. However, published protocols for post-SG-TB surveillance remain inconsistent, and there is no widely accepted standard regarding monitoring intervals, recommended laboratory panels, or biochemical thresholds that should trigger supplementation or escalation of care.[112]

Single Anastomosis Sleeve Ileal Bypass (SASI)

Development and Evolution

In 2016, Professor Tarek Mahdy proposed SASI based on gastric bypass surgery and Santoro's operation.[121] SASI and Single Anastomosis Sleeve Jejunal (SAS-J) are novel bariatric metabolic procedures with distinct anatomical approaches.

SASI involves a single anastomosis between the gastric fundus and terminal ileum following SG, typically positioned 250–300 cm from the ileocecal valve. SAS-J, conversely, creates a single anastomosis between the sleeve stomach and jejunum.[122,123] In SAS-J, the sleeve stomach is anastomosed to the jejunum, typically positioned 200–250 cm below the Treitz ligament.[124,125] Both procedures preserve a relatively long biliary-pancreatic tract, though the SASI tract typically measures 300–350 cm, while the SAS-J tract is approximately 200–250 cm.[123] The shorter common channel in SASI theoretically enhances malabsorption effects. Conversely, the longer common channel in SAS-J may reduce risks of malabsorption-related complications.[124]

Indications

SASI is a weight-loss and metabolic surgery combining restrictive and malabsorptive mechanisms, with increasing application in treating obesity and related metabolic diseases in recent years. However, its indications lack clear guideline recommendations. Based on systematic reviews and multicenter studies, the primary indications for SASI include: BMI ≥ 35 kg/m^2, or a BMI ≥ 30 kg/m^2 with uncontrolled metabolic disorders (eg, type 2 diabetes, hypertension, dyslipidemia, obstructive sleep apnea)[66,126,127] Obesity-related comorbidities: Such as type 2 diabetes, metabolic syndrome, refractory hypertension, dyslipidemia, obstructive sleep apnea, etc., where lifestyle interventions and medical treatments have yielded poor results.[66,126,127] Patients seeking both weight loss and metabolic improvement with minimal impact on nutrient absorption: SASI preserves partial gastrointestinal continuity, theoretically reducing malnutrition risk compared to traditional bypass procedures.[126,128]

Weight Changes

Systematic Review and Meta-Analysis: 38 studies, 2555 patients, follow-up ranging from 6 to 60 months. 6-month TWL was 63.07%, 12-month TWL was 82.44%, and 24-month TWL was 93.21%.[126] Single-center prospective study: 43 patients, 12-month EWL 85.6%, BMI decreased from 45.6 to 25.8, TWL 42.7%.[129,130] Multicenter comparative study: TWL and EWL at 6 and 12 months post-SASI were higher than those of SG and OAGB.[66] Other studies: EWL reached 88.83% at 12 months.[131,132]

Metabolic Monitoring

A systematic review included 38 studies (2555 patients) with follow-up ranging from 6 to 60 months. The remission rates for SASI in T2DM, HTN, HLD, and OSA were 92.67%, 79.06%, 82.64%, and 81.04%, respectively.[126] Another multicenter retrospective study demonstrated that SASI achieved higher remission rates for T2DM than SG and OAGB, at 97.7%, 71.4%, and 86.7%, respectively; while remission rates for other comorbidities (HTN, HLD, OSA) were comparable to SG and OAGB.[66] A single-center follow-up of 30 patients reported an 87.5% T2DM remission rate, 71.4% HTN remission rate, and 100% OSA remission rate.[129] Another 12-month follow-up study achieved a 95.8% T2DM remission rate (Table 1).[130]

Complications

A study showed that the incidence of Clavien-Dindo Grade I complications after SASI was approximately 4.8%, Grade II was 6.0%, and Grade IIIb was 2.4%.[130] Complications include gastrojejunal anastomotic stenosis, stoma ulceration, gallstones (2.5–43.3%), significant changes in bowel habits (diarrhea or constipation), and excessive weight loss requiring conversion to gastric sleeve surgery.[133–135] In another retrospective analysis, postoperative diarrhea occurred in approximately 43.3% of patients, hypoproteinemia in 23.3%, and some patients developed nutrition-related complications such as iron deficiency anemia and vitamin D/B12 deficiency.[129] The incidence of bile reflux was 37.5% in the group without Braun anastomosis, with reflux esophagitis occurring in 18.8% of cases. These rates were significantly reduced after Braun anastomosis.[107]

Nutrition-Related Monitoring

Iron Deficiency and Iron-Deficiency Anemia: Multiple studies indicate a high incidence of iron deficiency following SASI surgery, with rates reaching up to 70% in some investigations. Iron-deficiency anemia is also commonly observed.[129,136] Vitamin D Deficiency: Postoperative vitamin D deficiency rates exceed 63.3%, with some studies reporting rates as high as 80%.[129,137] Vitamin B12 Deficiency: Although less prevalent than iron and vitamin D deficiencies, The prevalence of

Table 1 Efficacy and Metabolic Outcomes of MBS Procedures (1-Year Follow-Up Unless Stated)

Procedure	% EWL	% TWL	T2DM Remission Rate	HTN Remission Rate	HLD Remission Rate	OSA Remission Rate
SG	52.0%	29.3%	95.5%	89.5%	81.7%	61.7%
RYGB	68.5%	28.4%	85.0%	84.8%	81.1%	Not reported
OAGB	85.2%	30.0%	94.0%	94.0%	96.0%	90.0%
BPD/DS	100.1%	43.2%	88.9%	86.6%	55.5%	Not reported
SADI-S	78.7%	36.8%	75.8%	61.2%	60.4%	71.9%
SG-TB	78.2%	44.8%	79.2%	72.0%	70.0%	91.0%
SASI	88.8%	42.7%	92.6%	79.1%	82.6%	81.0%

Abbreviations: MBS, metabolic and bariatric surgery; SG, sleeve gastrectomy; RYGB, Roux-en-Y gastric bypass; OAGB, one-anastomosis gastric bypass; BPD/DS, biliopancreatic diversion with duodenal switch; SADI-S, single anastomosis duodena-ileal bypass with sleeve gastrectomy; SG-TB, sleeve gastrectomy with transit bipartition; SASI, single anastomosis sleeve ileal bypass; EWL, excess weight loss; TWL, total weight loss; T2DM, type 2 diabetes mellitus; HTN, hypertension; HLD, hyperlipidemia; OSA, obstructive sleep apnea.

vitamin B12 deficiency is 6.6%. Hypoalbuminemia: Some patients develop hypoalbuminemia postoperatively, suggesting inadequate protein intake or absorption.[129] Other Micronutrient Deficiencies: Deficiencies in zinc, folate, and other micronutrients have also been reported, though their incidence rates are relatively low (Table 2).

Table 2 Complications and Nutritional Deficiencies of MBS Procedures

Procedure	30-Day Overall Complication Rate	Key Complications (Incidence)	Key Nutritional Deficiencies (Incidence, Follow-Up Time)
SG	1.4%	Anastomotic leakage: 0.5–2.5% Gallstones: 16.3% (30d) New-onset GERD: 20–40% (long-term)	Iron: 14.0% (1y) Vitamin B12: 5.3% (1y) Vitamin D: 25.0% (1y)
RYGB	27.51%	Marginal ulcers: 8.0–12.0% (30d) Internal hernia: 2.0–6.0% (30d) Dumping syndrome: 10–50% (long-term)	Iron: 41.0% (10y) Vitamin B12: 8.5% (10y) Vitamin D: 35.8% (10y)
OAGB	4.5–10.3%	Bile reflux: ~12.5% (long-term) Anastomotic ulcers: 1.0–6.0% Anastomotic leak: 1.2–2.8% (30d)	Calcium, folate, vitamin D/B12, iron, zinc deficiencies (variable incidence)
BPD/DS	3.8–15.2%	Duodenal stump leakage: 1.2–2.8% (30d) Bile reflux gastritis: 15–25% (long-term) Duodenal-ileal stricture: 3–7% (3–6mo)	Vitamin A: 58.3% (1y) Vitamin E: 50.0% (1y) Iron: 16.7% (1y) Zinc: 50.0% (1y)
SADI-S	2.6–11%	Hernias: 0–0.57% (30d) Stenosis: 0.3% (30d) Gallstones: 7.7% (30d) Dumping syndrome: 10–15% (long-term)	Iron: 18.6–45% (1y) Vitamin B12: 15.3–30% (1y) Protein malabsorption: 8.2% (1y)
SG-TB	6.0%	Gallstones: 21.9% (long-term) Incisional hernia: 3.1% (long-term) Anastomotic leakage: <6% (30d)	Iron: 12.4% (5y) Vitamin B12: 8.7% (5y) Vitamin D: 15.3% (5y)
SASI	13.2%	Postoperative diarrhea: ~43.3% Hypoproteinemia: ~23.3% Bile reflux: 37.5% (without Braun anastomosis)	Iron: up to 70.0% (1y) Vitamin D: 63.3–80.0% (1y) Vitamin B12: 6.6% (1y)

Abbreviations: GERD, gastroesophageal reflux disease; d, days; mo, months; y, years.

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New Advances in Metabolic Weight Loss Surgery

Surgical Technique Innovations

Recent advances in endoscopic bariatric and metabolic therapies have expanded minimally invasive options for obesity management. Unlike laparoscopic bariatric surgery, these interventions are delivered endoluminal—most commonly via a transoral approach—thereby avoiding abdominal incisions and potentially reducing postoperative pain and recovery time. However, reported efficacy and durability vary across techniques and patient populations, underscoring the need to clarify indications and outcome expectations across procedures. Its operational principles primarily rely on two mechanisms: restricting food intake and reducing nutrient absorption.[138] For instance, endoscopic duodenal-jejunal bypass liner (EDJBL) insertion is a representative endoscopic treatment. It draws inspiration from the RYGB principle used in bariatric surgery. Through a gastroscope, a covered sleeve is placed in the duodenum and upper jejunum, Food in the stomach passes through the pylorus and crosses the EDJBL to enter the jejunum directly, bypassing the duodenum and upper jejunum. Meanwhile, pancreatic juice and bile enter the jejunum through the space between the EDJBL and the intestinal wall.[139] EDJBL prevents direct contact between chyme and the mucosa of the duodenum and upper jejunum, thereby reducing energy absorption and regulating the secretion of glucose-dependent insulinotropic polypeptide and glucagon-like peptide-1, thereby achieving weight loss and regulating glucose and lipid metabolism.[140,141] EDJBL is a single-use device comprising a delivery system and a retrieval system. The sleeve consists of a coated scaffold and a medical-grade polymer membrane tube, The upper end of the coated scaffold is released in the duodenal bulb, while the membrane tube can extend into the upper jejunum.[142]

EDJBLI indications include: (1) Patients aged 18 to 65 years who are overweight (BMI 24 to 28 kg/m^2) or obese (BMI ≥28 kg/m^2), ie, BMI >24 kg/m^2; (2) For overweight and obese patients under 18 or over 65 years old, multidisciplinary treatment (MDT) involving pediatrics, nutrition, and other specialties is recommended Comprehensive assessment of patient age, comorbidities, and the procedure's benefits versus risks should precede implementation with full informed consent from the patient and family; (3) For patients with severe obesity-related complications, implementation should proceed cautiously following MDT discussion.[143]

A meta-analysis of 17 studies showed that after device retention for (9.2 ± 3.1) months, the %TWL and %EWL at device removal were 18.9% (95% confidence interval (CI): 7.2–30.6%) and 36.9% (95% CI: 29.2–44.6%), respectively Twelve months after EDJBL removal, patients maintained a 10.7 kg reduction from baseline (95% CI: 5.0–16.4 kg) (P<0.0001).[144] Another randomized controlled trial involving 170 obese patients with T2DM demonstrated that, on top of combined lifestyle and medical interventions, the EDJBL group exhibited significantly higher %TWL at 12-month device removal compared to the control group: (10.6±6.2)% versus (5.4±5.8)%, respectively. Additionally, the EDJBL group exhibited significant reductions in systolic blood pressure, serum cholesterol, and alanine aminotransferase levels. However, at 12 months post-device removal, the %TWL in both groups was (5.1±5.4) % and (4.6±5.7) %, respectively, with no statistically significant difference; Regarding T2DM management, HbA1c levels decreased by 1.3% from baseline at device removal (8.4±4.0 months). However, no statistically significant difference existed between groups at 12 months post-EDJBL removal.[145]

In a prospective clinical trial of EDJBL, the EDJBL study was terminated in March 2015 due to a 3.5% incidence of liver abscesses.[146] Subsequently, following device modifications and safety data review, a new clinical trial commenced in the United States in February 2019. Currently, EDJBL has not received approval from the US Food and Drug Administration. In China, the National Medical Products Administration has approved EDJBL for clinical weight loss treatment. Short-term clinical studies in China have demonstrated favorable weight loss outcomes with EDJBL: at 3-month device removal, %TWL and %EWL ranged from 8.7% to 8.9% and 34.4% to 47.9%, respectively, while serum transaminase levels and insulin resistance improved. Regarding safety, the incidence of serious adverse events was significantly lower. %EWL were 8.7–8.9% and 34.4–47.9%, respectively, with concurrent improvements in serum transaminase levels and insulin resistance. Regarding safety, the incidence of serious adverse events was significantly reduced.[147,148] However, global research on EDJBL remains limited globally, necessitating further large-scale, multicenter clinical studies to validate its long-term efficacy and safety.

Robotic-Assisted Metabolic and Bariatric Surgery (RAMBS)

Since Cadiere et al documented the inaugural instance of robotics utilized in bariatric surgery in 1999, there has been a marked progression in the field, signifying a significant advance in the domain of surgical technology.[149] The laparoscopic approach to bariatric surgery is now regarded as the gold standard However, as robotic surgery has become more prevalent and has been increasingly utilized by urology, gynecology, colorectal and general surgery, robotic-assisted metabolic and bariatric surgery (RAMBS) has emerged as an alternative. A plethora of preceding studies have indicated that RAMBS is growing in popularity, with utilization almost doubling from 2015 to 2018.[150,151] Robotic surgery offers three-dimensional vision, increased dexterity, and precision achieved by downscaling the surgeon's movements. Downsizing, enables fine tissue dissection, and effectively filters out physiological tremors.[152] It overcomes the restraint of torque on ports from thick abdominal wall, and minimizes port site trauma by remote center technology.[153]

RAMBS has emerged as a state-of-the-art approach in treating severe obesity, combining the precision of robotic technology with the established benefits of weight loss surgery.[154] RAMBS has demonstrated lower mortality within 90 days, albeit with a longer operative time particularly during the initial stages of the learning curve, while maintaining similar safety and efficacy for obesity compared to laparoscopy in other outcomes.[155] Patients with extreme obesity are better suited for RAMBS. A study found that the postoperative complication rate for patients with a BMI exceeding 60 was less than 10% following RAMBS surgery.[156]

RAMBS involves higher costs and longer preparation times. However, as experience accumulates, preparation times will decrease, and costs will also decline as material prices fall.[157] From 2015 to 2020, RAMBS became significantly more prevalent, while complication rates, length of hospital stay, and duration of surgery all decreased significantly, demonstrating that RAMBS is an increasingly safe and option. The data collected in 2020 demonstrate that patients undergoing RAMBS are typically characterized by a higher level of risk, as evidenced by a higher average BMI and a greater prevalence of prior bariatric surgery in comparison to laparoscopy. This finding indicates that surgeons are utilizing the robotic approach not only as a substitute for laparoscopic bariatric surgery, but also as an alternative option for procedures and patients that would be challenging to perform laparoscopically (Table 3).[158]

Limitations

Challenges Facing Robotic-Assisted Metabolic and Bariatric Surgery (RAMBS)

RAMBS offers theoretical advantages in technical precision and operational flexibility, but it does not eliminate the need for a first assistant. A comparative study indicates that robot-assisted RYGB and SG still require the same number of assistants as laparoscopic procedures in terms of surgical team configuration.[159] Regarding operative time, robot-assisted procedures typically take longer, primarily due to equipment setup and docking time.[159,160]

Several nationwide analyses have demonstrated that robotic surgery is associated with increased rates of anastomotic or staple line leaks, wound infections, and delayed discharge when compared to LSG and RYGB.[161,162] It has been demonstrated in other reports that there is an increased operative duration for both robotic RYGB and robotic SG, with associated risks of prolonged anesthesia exposure and venous thromboembolism.[162–165]

The learning curve for robotic surgery is steeper than that for laparoscopic surgery, requiring specialized training to achieve proficiency. The surgeon's learning curve is a critical factor affecting the safety and efficacy of bariatric

Table 3 Comparison of Key Advantages and Disadvantages of Emerging MBS Techniques

Procedure	Advantages	Disadvantages
EDJBL	Minimally invasive, quick recovery, noticeable short-term results, and highly reversible	Limited efficacy, high incidence of device-related complications, and poor long-term outcomes
RAMBS	Sustained and significant weight loss, comprehensive metabolic improvement, suitable for critically ill patients	Invasive, costly, surgical risks, and a longer recovery period

Abbreviations: EDJBL, endoscopic duodenal-jejunal bypass liner; RAMBS, robotic-assisted metabolic and bariatric surgery.

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procedures.[166,167] The learning curve for robot-assisted bariatric surgery is generally longer than for laparoscopic surgery. A systematic review indicates that the safety and efficiency of robotic bariatric surgery improve with accumulated surgical experience.[166] The learning curve phase is typically assessed using metrics such as operative time, conversion to open surgery rates, and complication incidence.[166,167] Proficiency in bariatric surgery may shorten the learning curve for other complex minimally invasive procedures. Surgeons with prior high-volume bariatric laparoscopic experience tend to reach proficiency in minimally invasive D2 gastrectomy in fewer cases, as reflected by faster stabilization of operative time and perioperative outcomes (eg, complications and lymph-node retrieval)[167] This likely reflects "transferable" minimally invasive skills—such as advanced dissection, intracorporeal suturing, and stapling—that overlap across laparoscopic and robotic platforms.[160,167] Cross-over effects in technical skills exist between laparoscopic and robot-assisted surgery, suggesting proficiency in one technique may facilitate mastery of another.[160]

Adopting new surgical or interventional technologies typically involves an extended learning period that extends beyond technique alone to include safe use of unfamiliar equipment and an understanding of its clinical limitations. In the early implementation phase—often the first supervised cases—performance is more variable and errors or unsuccessful attempts may be more common until workflows stabilize. A standardized, stepwise training pathway can shorten the time to reliable proficiency, particularly when it integrates simulation, virtual reality where appropriate, and case-based discussion focused on decision points and failure modes. Digital platforms such as YouTube have also been explored as educational resources, though their reliability varies significantly, highlighting the need for curated, peer-reviewed training content.[168] As programs mature over subsequent months, multi-center training initiatives can further support consistent uptake by pooling expertise, case exposure, and shared benchmarks.

Challenges Facing Revisional Bariatric and Metabolic Surgery (RMBS)

Revisional bariatric and metabolic surgery (RMBS) is being performed more frequently, reflecting both longer follow-up after primary procedures and an expanding pool of post-bariatric patients.[169,170] In US bariatric surgery training programs, the share of revisional cases increased from 6.1% to 16.3% between 2012 and 2021.[169] In an Italian multicenter prospective observational cohort, revisions comprised 13.5% of weight-loss operations, suggesting a comparable order of magnitude in a different health system.[171]

Indications are heterogeneous, but most series identify weight regain or inadequate weight loss as the leading reason for revision (often reported in the 40–60% range), followed by management of procedure-specific complications or persistent metabolic disease. For example, worsening reflux after sleeve gastrectomy and nutritional complications after gastric bypass are recurrent triggers for revisional evaluation.[170]

Compared with primary bariatric procedures, revisions are technically more complex, often requiring longer operative time and carrying higher short-term risk, one comparative analysis reported higher 90-day complications (8.2% vs 15.6%) and readmissions (4.1% vs 9.3%) after revision. Hypoalbuminemia has also been associated with increased postoperative morbidity, underscoring the role of preoperative nutritional assessment in this population.[171–173]

Finally, survey data indicate substantial inter-surgeon variation in indications, procedure selection, and perioperative pathways, which may contribute to differences in timing of revision and outcomes across centers.[174]

Future Directions in Metabolic and Bariatric Surgery

Application of Precision Medicine in Metabolic and Bariatric Surgery

Precision medicine is increasingly being applied to bariatric and metabolic surgery to individualize both procedure selection and postoperative management using patient-specific biomarkers, genomic information, and other multi-omics profiles.[74,175] In the period from approximately 2015 to 2025, multi-omics studies—including genomics, metabolomics, and microbiome profiling—have helped characterize obesity as a heterogeneous metabolic disorder rather than a single entity, supporting more nuanced phenotype definitions and motivating efforts to predict differential surgical benefit (Table 4).[74] This direction reflects the well-recognized complexity of obesity—shaped by interacting genetic, environmental, and behavioral factors—which makes uniform surgical pathways unlikely to serve all patients equally well.

Table 4 Applications of Multi-Omics Research in Precision MBS

Technical Field	Specific Applications	Precision Medicine Integration Point
Genomics	Prediction of Surgical Reactions	Genetic Variation and Its Association with Weight Loss and Diabetes Remission
Metabolomics	Postoperative Metabolic Monitoring	Association between Metabolite Profiles and Complication Risk
Microbiome	Regulation of the Gut Microbiota	Association Between Microbiome Composition and Postoperative Metabolic Improvement
Imaging informatics	Preoperative Anatomical Assessment	Gastric Volume, Fat Distribution, and Surgical Approach Selection

Translating these insights into practice typically requires coordinated input from genetics, nutrition, and psychology to align surgical planning with biological risk and behavioral context.

Gut microbiome modulation represents a key mechanistic link between bariatric surgery and metabolic improvement, particularly for type 2 diabetes remission. Translational studies have demonstrated that both RYGB and SG induce rapid and sustained shifts in gut microbial composition, increasing the abundance of beneficial taxa such as Akkermansia muciniphila and Faecalibacterium prausnitzii while reducing pro-inflammatory species. These microbial changes enhance intestinal barrier function, increase production of short-chain fatty acids, and modulate bile acid metabolism, all of which contribute to improved insulin sensitivity and glucose homeostasis. Notably, fecal microbiota transplantation from post-bariatric surgery patients to germ-free mice has been shown to recapitulate the metabolic benefits of surgery, confirming the causal role of the microbiome in these effects.

Research Hotspots in Artificial Intelligence and Machine Learning

The application of Artificial Intelligence (AI) and Machine Learning (ML) in bariatric and metabolic surgery has emerged as a significant research focus. International expert consensus indicates that AI technology is primarily applied in surgical planning, risk prediction, postoperative complication monitoring, and long-term outcome assessment.[176] Machine learning algorithms integrate multimodal data—including electronic health records, imaging data, laboratory test results, and patient-reported outcomes—to construct personalized predictive models.[177]

Virtual Reality and Augmented Reality based simulators have been evaluated as adjuncts to surgical skills training, with several studies reporting improved task performance on simulator-specific metrics (eg, error counts and time to completion) compared with conventional practice However, the extent to which these gains transfer to the operating room varies by procedure complexity and assessment method. AI enabled navigation has also been explored for intraoperative guidance, typically combining real-time imaging with anatomical landmark recognition, reported benefits include more consistent localization and decision support, though robustness can degrade when image quality or anatomy differs from training data.[177]

For postoperative risk prediction, deep learning models have been trained on perioperative variables to estimate complication risk (eg, anastomotic leak, hemorrhage, venous thromboembolism), but many studies remain retrospective and require external validation and calibration assessment before clinical deployment Beyond risk prediction, recent work has emphasized the clinical value of translating predictive models into actionable prophylaxis strategies. Registry data analyses have demonstrated that risk-stratified postoperative care protocols—tailored to individual patient complication risk profiles—can significantly reduce the incidence of major adverse events such as anastomotic leakage and venous thromboembolism.[178] Natural language processing methods applied to operative notes and pathology reports can extract structured fields for registries and research, yet performance depends strongly on documentation style and institution-specific terminology.[177]

Table 5 Key Findings of the Narrative Review

Domain	Key Findings
Established Procedures	SG remains the most widely performed MBS procedure, with favorable safety and 1-year %EWL of 52.0%; RYGB demonstrates superior long-term T2DM remission compared to SG.
Emerging Procedures	Single-anastomosis procedures (OAGB, SADI-S, SASI) offer comparable or superior short-term weight loss and metabolic benefits but lack long-term (≥10y) safety data.
Perioperative Care	ERAS protocols reduce early complications and hospital stays; preoperative micronutrient screening is essential to prevent postoperative deficiencies.
Technological Advances	RAMBS improves precision in complex cases but has a steeper learning curve; AI/ML shows promise for personalized risk prediction and treatment planning.
Unresolved Challenges	Weight regain affects 20–30% of patients at 5 years; revisional surgery carries higher complication rates; long-term data for newer procedures are limited.

Conclusion

MBS is widely positioned as an effective intervention for obesity and associated metabolic disease, with reproducible benefits for body weight and for obesity-related comorbidities, including T2DM, HTN and HLD. While SG remains a benchmark procedure, current surgical discourse increasingly includes newer operations such as OAGB, SG-TB and SASI. Among these, OAGB is frequently highlighted for a more straightforward operative configuration relative to RYGB, while pursuing similar therapeutic endpoints (Table 5).

From an outcome's perspective, perioperative developments—particularly the maturation of minimally invasive techniques—have improved the early postoperative profile (approximately within 30 days), with fewer complications, reduced length of stay, and better tolerability from the patient perspective. In the longer term (commonly framed as ≥5 years of follow-up), the literature often supports durability of benefit, but also repeatedly notes two practical limitations: gradual weight regains in a subset of patients and the challenge of maintaining the initial metabolic response. In this context, anti-obesity medications are increasingly considered as adjuncts once weight loss stabilizes or regain begins (often after the first postoperative year), although evidence is still insufficient to define best-practice timing or dosing. When primary surgery does not achieve intended outcomes—or when late complications arise—secondary procedures (conversion, revision, or reversal) function as remedial options; clearer international standards on terminology, indications, and reporting would help make these strategies more comparable across centers.

Perioperative care innovations have also contributed to improved patient outcomes, with Enhanced Recovery After Surgery (ERAS) protocols reducing early postoperative complication rates by 20–30% and shortening average hospital stays by 1–2 days in most MBS procedures. Future work is therefore trending toward more personalized decision-making, using patient characteristics and metabolic or genetic profiling to better predict outcomes, while endoscopic therapies and metabolic modulation devices broaden the therapeutic landscape for patients who cannot undergo traditional surgery. Across both surgical and non-surgical innovations, long-duration follow-up remains the limiting requirement for judging real-world safety and efficacy. In particular, 10-year follow-up data are urgently needed for newer single-anastomosis procedures such as SADI-S and SASI to fully characterize their long-term weight loss durability, metabolic benefit persistence, and complication profiles. This will reinforce the broader shift from weight loss alone toward comprehensive, long-term metabolic management.

Abbreviations

MBS, metabolic and bariatric surgery; SG, sleeve gastrectomy; RYGB, Roux-en-Y gastric bypass; IFSO, International Federation for Surgery and Other Therapies for Obesity; AI, artificial intelligence; ML, machine learning; BMI, body mass index; T2DM, type 2 diabetes mellitus; OSA, obstructive sleep apnea; HTN, hypertension; OAGB, one-anastomosis gastric bypass; BPD/DS, biliopancreatic diversion with duodenal switch; SADI-S, single anastomosis duodena-ileal bypass with sleeve gastrectomy; SG-TB, sleeve gastrectomy with transit bipartition; SASI, single anastomosis sleeve ileal bypass; EWL, excess weight loss; TWL, total weight loss; TC, total cholesterol; LDL-C, Low-Density Lipoprotein Cholesterol; HLD, hyperlipidemia; GERD, gastroesophageal reflux disease; BPD, biliopancreatic diversion; DS, duodenal switch; SAS-J, single anastomosis sleeve jejunal; EDJBL, endoscopic duodenal-jejunal bypass liner; CI, confidence interval; RAMBS, robotic-assisted metabolic and bariatric surgery; RMBS, revisional bariatric and metabolic surgery; ERAS, enhanced recovery after surgery.

Data Sharing Statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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Author Contributions

Bing Zhao (BZ): Conceptualization, Data curation, Methodology, Writing – Original Draft, Writing – Review & Editing. Feilong Wang (FLW): Data curation, Methodology, Writing – Original Draft, Writing – Review & Editing. Yerui Bi (YRB): Data curation, Methodology, Writing – Original Draft. Lei Li (LL): Data curation, Methodology, Writing – Review & Editing. Yabin Xia (YBX): Conceptualization, Methodology, Funding Acquisition, Supervision, Writing – Review & Editing. Yan Jin (YJ): Conceptualization, Funding Acquisition, Supervision, Writing – Review & Editing. All authors gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors declare that they have no competing interests.

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