INTRODUCTION

Obesity has emerged as a global health challenge due to its increasing prevalence and associated metabolic comorbidities, such as cardiovascular disease, diabetes, and hypertension. Addressing obesity, therefore, extends beyond mere weight reduction; it encompasses enhancing overall metabolic health as evidenced by improvements in parameters such as blood pressure, glycated hemoglobin, and cholesterol.

Current therapeutic modalities for obesity include nutritional and exercise education, behavioral interventions, and pharmacological agents. In patients where conventional methods prove inadequate, bariatric surgery may be a consideration. Although surgical interventions can be efficacious, they are not devoid of drawbacks—they can be irreversible, expensive, and accompanied by potential complications. Recently, endoscopic treatments for obesity and related metabolic disorders have gained increased attention due to innovations in endoscopic technologies. Endoscopic interventions offer a noninvasive strategy for managing obesity, with the promise of sustainable outcomes and a diminished risk profile.

Numerous endoscopic modalities are now available, each boasting a reduced incidence of complications and expedited recovery times relative to their surgical counterparts. However,
the long-term comparative efficacy of these endoscopic methods to bariatric surgery remains under-investigated. In this review, we examine various endoscopic therapies for treating obesity and metabolic disorders and explore their underlying principles, merits, therapeutic outcomes, and associated complications. We further reflect on the future trajectories of endoscopic interventions for obesity by drawing insights from contemporary research.

**SPACE-OCCUPYING ENDOSCOPIC PROCEDURES (RESTRICTIVE ENDOSCOPIC PROCEDURES)**

**Intragastric balloon placement**

Various space-occupying devices have been introduced for managing obesity. Intragastric balloon (IGB) placement is the most prominent among approaches using these types of devices. Positioned within the gastric cavity, the IGB induces satiety by taking up space, subsequently reducing food intake. Additionally, balloon placement has been suggested to impact gastric motility, further contributing to weight loss. Several balloons have received approval from the U.S. Food and Drug Administration (FDA), including the Orbera BioEnterics Intragastric Balloon (Apollo Endosurgery, Austin, TX, USA), Obalon Gastric Balloon (Obalon Therapeutics, San Diego, CA, USA), ReShape Duo Integrated Dual Balloon System (ReShape Medical, San Clemente, CA, USA), and Spatz3 (Spatz, Fort Lauderdale, FL, USA). Notably, in late 2018, Apollo Endosurgery purchased ReShape Duo from ReShape Medical and discontinued ReShape Duo in favor of the Orbera IGB. Additionally, Apollo Endosurgery was acquired by Boston Scientific in 2022.

Numerous meta-analyses have underscored the efficacy of IGBs in promoting weight loss, with outcomes surpassing those of control groups. A 2020 meta-analysis highlighted that IGBs significantly outperformed lifestyle interventions in achieving percent excess weight loss (%EWL) and percent total weight loss (%TWL), registering differences of 17.98% and 4.40%, respectively. A subsequent 2023 meta-analysis further linked IGBs with improvements in insulin resistance, blood pressure, and dyslipidemia.

The IGBs from the different manufacturers differ in their configurations, dimensions, and the number of balloons introduced. Here, the Orbera placement procedure, a popular global choice recently adopted in Korea, is described (Fig. 1). Initially, the balloon is positioned in the stomach, followed by
inflation via the endoscopic introduction of a saline–methylene blue solution (400–700 mL). The silicone balloon maintains a spherical contour after inflation. Methylene blue serves as a diagnostic marker, altering urine color upon balloon rupture.20 Timely endoscopic intervention is essential following a rupture to avert potential intestinal obstructions. Conventionally, balloons are extracted six months post-placement, as prolonged residence diminishes efficacy and increases complications.9

Typical balloon-related complications are transient and encompass symptoms such as abdominal discomfort, nausea, and dyspepsia, which usually recede within a week.21,22 Since gastric acid reflux may worsen or gastric ulcers may occur after balloon insertion, the use of a proton pump inhibitor is important. Severe complications, albeit infrequent, can include esophageal perforation, gastric ulcer bleeding, and aspiration pneumonia.22 One meta-analysis recorded nausea and vomiting as prevalent post-placement complications (in 63.3% and 55.3% of patients, respectively), whereas serious complications were infrequent (5.2%).21

Although IGB placement is relatively safe, their use is time-restricted and some patients revert to their pre-procedure weight, post-removal. However, its nonpermanent nature allows for periodic reintroduction. It is also a viable interim solution that can be attempted before bariatric surgery to mitigate postoperative risks in severely obese individuals. Although recent meta-analyses have affirmed its efficacy,23 additional comprehensive research is required to ascertain the long-term benefits and risk reduction vis-à-vis bariatric surgery.

Currently, IGB placement is the only endoscopic intervention available for obesity treatment in Korea. Recognized as a safe and effective modality for managing obesity in patients with a body mass index (BMI) of 30–40 kg/m², it was sanctioned as a new medical technology and subsidized in 2021. However, empirical Korean data on its effectiveness and safety remain scant, necessitating local research.

Transpyloric Shuttle

The Transpyloric Shuttle (TPS) (BARONova, San Carlos, CA, USA), an FDA-approved (2019) device, consists of a large silicone spherical bulb tethered to a small cylindrical counterpart.9 Its unique design, meant for a 12-month placement, exploits gastric peristalsis to move the smaller bulb past the pylorus, intermittently obstructing the gastric outlet and decelerating gastric emptying.24 Presently, empirical evidence gauging the safety and efficacy of this intervention is minimal, prompting the need for further studies.

ENDOSCOPIC GASTROPLASTY

Similar to surgical gastroplasty, various endoscopic gastroplasty techniques (also known as gastric remodeling techniques) have been developed to minimize the gastric space. Traditional endoscopic vertical gastroplasty focuses on sutureing the mucosal and submucosal tissues. However, newer techniques, such as primary obesity surgery endoluminal (POSE), involve full-thickness suturing of the entire stomach wall.25,26 The post-procedure appearance of the stomach after endoscopic gastroplasty is illustrated in Fig. 2.

Endoluminal vertical banded gastroplasty

The EndoCinch suturing system (C.R. Bard, Murray Hill, NJ, USA) was the pioneering device for endoluminal vertical banded gastroplasty and was approved by the FDA in 2000.27 Initially intended for reflux esophagitis treatment, this device works by aspirating the gastric mucosa and submucosal tissue into an endoscope-tipped capsule and securing it using T-tag sutures.28 The RESTORe system, also by C.R. Bard, is an enhanced version of the EndoCinch and offers deeper stomach wall suturing without needing reloads for multiple sutures.29

Transoral Gastroplasty System

Developed in 2008, the Transoral Gastroplasty (TOGA) Sys-
tem (Satiety, Palo Alto, CA, USA) facilitates the creation of a gastric sleeve.30,31 This system comprises two primary instruments: the TOGA Sleeve stapler and the TOGA Restrictor. The sleeve stapler secures the tissue, after which the TOGA Restrictor constrains the sleeve outlet, finalizing the gastroplasty on the proximal hypoplastic side.32

Endoscopic sleeve gastroplasty

Endoscopic sleeve gastroplasty (ESG) bears similarity to laparoscopic gastrectomy, wherein the anterior wall, greater curvature, and posterior walls are uniformly sutured with full-thickness sutures along the stomach’s longitudinal axis.26,33 To achieve gastric volume reduction, an FDA-approved, cap-based flexible endoscopic suturing system (OverStitch by Apollo Endosurgery, Austin, TX, USA) is employed. A full-thickness suture runs from the anterior to the posterior stomach segment, traversing the stomach wall.33,34 A 2020 meta-analysis revealed a 6-month post-procedure %TWL of 15.1, BMI reduction of 5.65 kg/m², and %EWL of 57.7. This post-procedural weight loss persisted at 12 and 18–24 months with %TWLs of 16.5 and 17.2, respectively; serious adverse events were notably low (2.2%).35 A recent multicenter prospective study showed that ESG not only promoted significant weight loss but also improved one or more metabolic comorbidities in 80% of patients at 52 weeks after the procedure.36

POSE

POSE utilizes the Incisionless Operating Platform (IOP; USGI Medical, San Clemente, CA, USA) to form full-thickness stitches by anchoring tissue junctions against opposing gastric tissue.37 Using unique suture anchors, placements occur at 8–9 sites along the gastric fundus and at 3–4 sites on the lower body. The folds resulting from the procedure, both mechanically and physiologically, restrict the contact of consumed food with the gastric mucosa. In a large-scale clinical study (ESSENTIAL trial) involving a total of 332 patients (221 in the POSE group and 111 in the sham group), 12-month post-procedure %TWLs were 4.95±7.04 in the POSE group and 1.38±5.58 in the sham group.38 A 2022 meta-analysis indicated %EWL of 42.62 at 3–6 months and 48.86 at 12–15 months, with %TWLs of 13.45 and 12.68, respectively; the incidence of serious adverse events was 2.84%.39 Additionally, a newer distal POSE technique (POSE-2) targets the gastric body for suturing, sparing the gastric fundus, has shown promising outcomes.25,40-42

MALABSORPTIVE ENDOSCOPIC PROCEDURE

Endoscopic uptake-reduction procedures, specifically mal-absorptive techniques, serve as innovative approaches for treating metabolic obesity. These methods function by impeding nutrient absorption, predominantly in the proximal sections of the small intestine (including the duodenum and jejunum), resulting in weight loss and improved glycemic control.40,41 The noteworthy procedures in this domain include the following.

Duodenal-Jejunal Bypass Liner

The Duodenal-Jejunal Bypass Liner (DJBL), commercially known as the Endobarrier System (Morphic Medical, Boston, MA, USA), combines a 60 cm liner with a nitinol fixator. This assembly is endoscopically introduced under fluoroscopic guidance.45 Once in place, the fixator secures itself within the duodenal bulb and the liner extends to the proximal jejunum (Fig. 3A). Subsequently, ingested food transitions directly from the stomach to the jejunum, bypassing the duodenum. The resultant separation ensures that the food does not blend with the pancreatic juices and digestive enzymes flowing between the external surface of the liner and the gastrointestinal tract wall. The hypothesized mechanisms and outcomes mirror those of the Roux-en-Y bypass.44 A 2016 meta-analysis underscored that, when contrasted with dietary control, DJBL resulted in significant weight and %EWL reductions, although the variations in glycated hemoglobin and fasting blood glucose levels were not statistically significant.43 However, in a prospective study conducted in the United States, a number of liver abscess cases were reported; consequently, the DJBL was not approved by the FDA.

Gastroduodenonejunal Bypass Sleeve

The Gastroduodenonejunal Bypass Sleeve (ValenTx, Carpinteria, CA, USA) is a 120 cm fluoropolymer sleeve that can be introduced using a combination of endoscopic and laparoscopic techniques.46 The sleeve’s fixator attaches to the gastroesophageal junction, while the sleeve extends to the jejunum. As a result, undigested food bypasses the stomach, duodenum, and

Fig. 3. Endoscopic procedures for malabsorption. Duodenal-jejunal bypass liner (A) and Gastroduodenonejunal bypass sleeve (B).
proximal jejunum, producing a combined effect of volume and absorption limitations (Fig. 3B).45

Duodenal mucosal resurfacing
Duodenal mucosal resurfacing (DMR) using the Revita DMR System (Fractyl Health, Cambridge, MA, USA) aims to rectify anomalous mucosal conditions by facilitating regeneration of normal duodenal mucosa. The procedure involves the placement of a 2.0 cm balloon filled with water at 90°C onto the duodenal mucosa via endoscopic forceps. Subsequent circumferential ablation promotes mucosal healing, characterized by the renovation and repopulation of healthy duodenal mucosa.47 A 2021 meta-analysis emphasized the efficacy of DMR, and also highlighted significant reductions in glycated hemoglobin and liver enzyme levels in patients with non-insulin-dependent type 2 diabetes at postoperative periods of 3 and 6 months.48 However, extended follow-up studies remain necessary.

Incisionless Magnetic Anastomosis System
The Incisionless Magnetic Anastomosis System (GI Windows, Bridgewater, MA, USA) employs a pair of self-assembling magnets to orchestrate a dual-path bowel bypass.49,50 Using both oral and anal approaches, an endoscope is situated within the proximal jejunum and distal ileum. Under fluoroscopic visualization, the magnets are dispatched through the endoscope channels into the jejunum and ileum. Upon alignment, these magnets compress the intestinal walls, culminating in necrotic changes. Following anastomosis, the device is naturally excreted in conjunction with fecal matter.45 In a previous pilot study, the %EWL and %TWL values 12 months after the procedure were 40.2 and 14.6, respectively.50

ASPIRATION THERAPY
Aspiration therapy (AT) is an innovative approach for combating obesity that focuses on extracting food directly from the stomach using a dedicated gastrostomy tube. The AspireAssist device (Aspire Bariatric, King of Prussia, PA, USA), which received FDA approval in 2016, comprises an A-tube and a standard pull-type percutaneous endoscopic gastrostomy tube in conjunction with a gravity flow director system (Fig. 4).51 The efficacy of this therapy arises not just from calorie aspiration but also from prompting behavioral changes in patients. Food expulsion encourages patients to be more conscious of their eating habits, including consuming meals mindfully, chewing meticulously, and maintaining hydration during meals. This often leads to decreased food intake. AT is the only endoscopic bariatric procedure that can be used to treat class III obesity. In a randomized controlled study, the %EWL and %TWL values at 52 weeks in the AspireAssist group were 31.5±26.7 and 12.1±9.6, respectively, which were significantly higher than those in the lifestyle counseling group.52 A recent 2021 meta-analysis reported a 12-month %EWL of 43, outperforming the control group by 25.6%. Additionally, the serious adverse event rate was 3.8%, confirming the credibility of bariatric intervention.53

CONCLUSION
Endoscopic treatments for patients suffering from obesity offer a promising middle ground that includes greater efficacy than dietary and lifestyle adjustments while being less invasive than traditional bariatric surgeries. Apart from the widely recognized IGB procedures, modalities such as endoscopic gastroplasty, malabsorptive endoscopic procedures, and AT are gaining increased acceptance. Continually emerging safety, efficiency, and cost-effectiveness data for these interventions have diversified the therapeutic arsenal against obesity. As technology and techniques evolve, bariatric endoscopic procedures are poised for broader adoption in the battle against obesity and its associated metabolic comorbidities.

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