Review

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Advancements in endoscopic closure techniques for gastrointestinal luminal defects comparative perspectives on OTSC, endo suturing, TTS clips, and X-Tack

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Abstract

Gastrointestinal (GI) defects pose a significant clinical challenge, impacting patient outcomes and healthcare costs. Endoscopic closure techniques have emerged as effective and minimally invasive approaches to manage these defects. This review explores the various endoscopic techniques, including over-the-scope clips (OTSC), endo suturing systems, through-the-scope (TTS) clips, and the X-Tack system. Each technique offers distinct advantages and limitations, making it suitable for specific clinical scenarios. While these devices have demonstrated promising results in clinical practice, further research is needed to optimize their use and address knowledge gaps. Large-scale randomized controlled trials are essential to establish evidence-based guidelines for device selection and procedural techniques. By embracing technological advancements and addressing research limitations, the field of endoscopic closure devices has the potential to revolutionize GI care, leading to improved patient outcomes and expanded therapeutic possibilities.

Keywords: endoscopic closure techniques, endo suturing, over-the-scope clips, TTS clips

Introduction

Gastrointestinal (GI) diseases pose a substantial clinical and economic burden in the U.S., with annual costs reaching $135.9 billion surpassing expenditures for heart disease, trauma, and mental health[1]. They account for over 40.7 million outpatient visits, 3.0 million hospital admissions, and 267 000 new cancer cases annually[2]. Among these, complications such as Clostridioides difficile infection, morbid obesity requiring bariatric intervention, and malignancies like colorectal cancer often lead to GI luminal defects that demand effective management[3-6]. Endoscopic procedures, particularly those addressing conditions like GERD, Barrett's esophagus, and pancreaticobiliary disease, play a growing role in diagnosing and managing such defects[5-8]. However, surgical care continues to face challenges including infection rates, variable outcome metrics, and quality concerns[9-12].

Given the rising procedural volume and complexity, the effective closure of GI luminal defects such as perforations, leaks, and fistulae is critical in minimizing morbidity and improving patient outcomes[13,14]. This review compares Over-the-Scope Clips (OTSC), endoscopic suturing, through-the-scope (TTS) clips, and the X-Tack system, evaluating their clinical effectiveness, applications, and optimal use based on ease of deployment, reliability, and outcomes.

HIGHLIGHTS

- This manuscript explores advanced endoscopic closure techniques, including OTSC, endo suturing, TTS clips, and the X-Tack system, for managing gastrointestinal luminal defects.
- It provides a comparative analysis of these techniques, assessing their effectiveness, clinical applications, and limitations in different GI defect scenarios.
- The review highlights the need for large-scale studies to establish evidence-based guidelines for optimal device selection and procedural strategies.
- Future directions emphasize integrating robotics and artificial intelligence to enhance precision and expand the role of endoscopic closure devices in GI care.

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Novelty and contribution

Although this manuscript effectively consolidates known endoscopic closure techniques, its novelty lies in providing an updated comparison of available devices – including newer modalities such as X-Tack – and proposing a structured framework for device selection based on defect characteristics and anatomical location. This targeted synthesis offers clinicians a practical and timely reference amid a rapidly evolving field.

Overview of gastrointestinal luminal defects

Importance of achieving effective closure in both emergent and elective settings. GI tract defects, such as perforations, anastomotic leaks, and fistulae, arise from various disease states and can occur after a range of endoscopic, surgical, and radiologic procedures. These defects differ significantly in their presentation, as well as in their associated morbidity and mortality[15]. For instance, an acute esophageal perforation caused by an endoscope and a persistent gastro-cutaneous fistula after gastrostomy tube removal are distinct clinical conditions. However, until recently, these issues were often treated similarly with endoscopic techniques. As the number of cases where endoscopic closure is considered increases, it becomes evident that a variety of endoscopic therapies is needed to address this broad range of defects[15].

Gastrointestinal transmural defects are characterized by full-thickness disruption of the GI wall and are generally classified into three categories: perforations, leaks, and fistulas[16]. A perforation refers to an acute rupture, which may be iatrogenic – such as following endoscopic resections, dilation of strictures, or barotrauma – or due to pathologies like Boerhaave's syndrome, active ulceration, diverticulitis, or appendicitis[17]. A fistula represents an abnormal epithelialized tract connecting two surfaces. These may develop due to chronic inflammation, malignancy, or an inadequately treated long-standing leak. Fistulas can be internal, involving communication between intra-abdominal organs, or external, forming between a viscus and the skin surface[18].

Delayed or inadequate treatment of gastrointestinal (GI) leaks can lead to severe complications such as infection, peritonitis, and systemic issues. When leaks are not addressed promptly, especially in the upper GI tract, they are associated with high postoperative mortality rates, with esophagogastric leaks showing mortality between 3% and 25% after esophagectomy[19]. Failure to manage these leaks adequately can result in ongoing infections, leading to further complications like peritonitis, especially in lower GI leaks where anastomotic leaks may escalate to sepsis if not contained[20,21]. Moreover, treatment delays often require more invasive measures, such as surgical interventions, which can worsen patient outcomes. For example, in colorectal anastomotic leaks, the risk of peritonitis increases if the leak is not contained early, necessitating surgical correction in severe cases[22]. The use of endoscopic therapies such as endoscopic vacuum therapy (EVT) and internal drainage, particularly when performed early or in conjunction with enteral diversion, significantly improves outcomes, with success rates exceeding 90% in some studies[23]. These findings emphasize the critical importance of early intervention to prevent systemic complications and improve patient recovery.

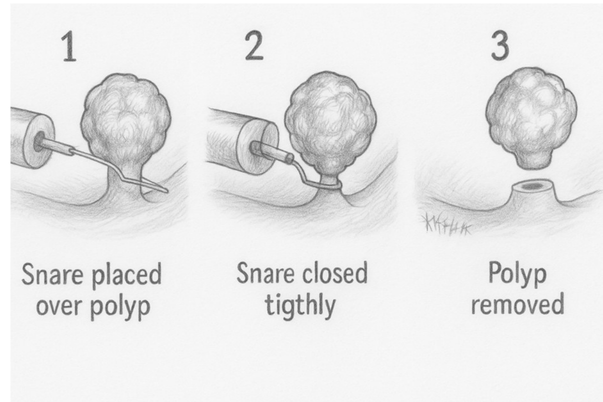

Figure 1. Endoscopic mucosal resection (EMR).

Endoscopic techniques for luminal defect closure

Endoscopic mucosal resection (EMR) is used to remove superficial gastrointestinal lesions, with a maximum resection diameter of 20 mm. Lesions larger than this may require piecemeal resection, which carries a higher recurrence risk[24,25]. Figure 1 illustrates the EMR technique. EMR has evolved into multiple subtypes – injection-assisted, cap-assisted, and ligation-assisted – to enhance safety and effectiveness. The inject-assisted technique involves injecting a solution into the submucosal space to create a "safety cushion" that minimizes gastrointestinal wall damage[26,27]. Other techniques, such as cap-assisted EMR, use a transparent plastic cup to secure the lesion, while ligation-assisted EMR deploys a rubber band to create a pseudopolyp[28,29].

Endoscopic submucosal dissection (ESD) was developed for the en bloc removal of larger lesions, particularly those exceeding 20 mm. As shown in Fig. 2, by injecting saline or sodium hyaluronate into the submucosal layer, ESD allows precise resection control, offering a higher rate of complete resection compared to EMR[30].

Both EMR and ESD are critical for managing early-stage malignant gastrointestinal lesions. While EMR has a lower complication rate, including a bleeding risk of 0.9% and a perforation rate of 0.4–1.3%, ESD offers superior en bloc resection and lower recurrence rates. However, ESD requires highly trained operators to minimize complications[31–33].

Colonic decompression is an established strategy for managing acute colonic conditions, such as acute colonic pseudo-obstruction (ACPO) and colonic volvulus. First demonstrated by Kukora *et al*, colonoscopic decompression was later refined by Bernton *et al* and Morino *et al* through techniques such as transanal colonic tubes and endoscopic stent decompression. The main goal of colonic decompression is to reduce colon diameter, alleviate wall tension, and restore peristalsis, with methods including radiologic and colonoscopic decompression, particularly when the cecal diameter exceeds 12 cm[34]. Studies have shown colonic decompression to be safe, with high clinical success rates and low complication rates, proving its effectiveness in treating colonic distension[35].

Natural orifice transluminal endoscopic surgery (NOTES), also known as "scarless surgery," has gained attention as

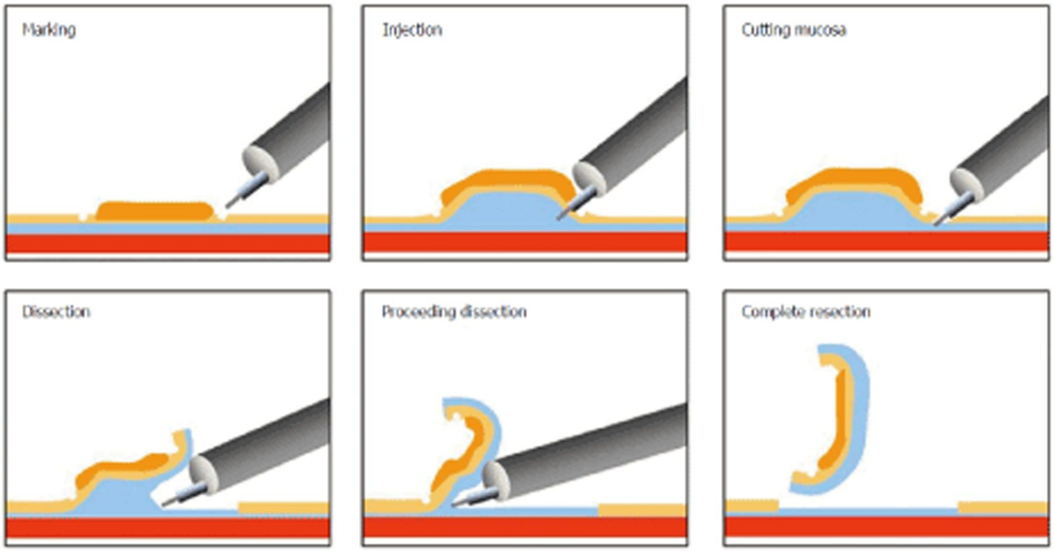

Figure 2. Image of endoscopic submucosal dissection.

a minimally invasive technique. Initially used for diagnosing and treating abdominal abnormalities, NOTES aims to minimize cosmetic changes, avoid abdominal incisions, and reduce invasiveness compared to traditional laparoscopic surgery. Although NOTES offers advantages such as no incisions, less pain, and quicker recovery, challenges such as limited endoscope size and the difficulty of suturing need to be addressed before widespread adoption[36,37].

Endoscopic sleeve gastroplasty (ESG) is a minimally invasive procedure developed to treat obesity and related comorbidities. ESG involves reducing the stomach's functional volume by 80% through suturing, significantly aiding weight loss and improving metabolic outcomes. Studies have shown that ESG is effective and safe, with patients losing significant amounts of weight and experiencing improvements in conditions such as type 2 diabetes, hypertension, and dyslipidemia[38,39].

Comparative analysis of closure techniques

Over-the-scope clips (OTSC)

In 2007, Kirschniak *et al* published the first retrospective case series demonstrating the successful use of the Over-The-Scope-Clip (OTSC®, OVESCO Endoscopy AG, Tübingen) system in treating eight therapy-resistant gastrointestinal bleedings and three wall defects[40]. Subsequent animal studies showed that OTSC outperformed conventional endoclips in closing iatrogenic perforations[41]. Since then, its use has been explored in gastric and colonic animal models, leading to an expanded range of anatomical sites along the luminal gastrointestinal tract where OTSC can be applied. Over time, the indications for OTSC have also broadened[42]. Recent reports highlight its use for securing SEMS in the esophagus[43], closing POEM-access sites[44], and reducing the diameter of gastrojejunal anastomosis after gastric bypass[45]. However, its primary indications remain the closure or treatment of gastrointestinal perforations[46], leakages[47], fistulae, including anorectal lesions[48,49] and uncontrolled gastrointestinal bleeding[50]. Although multiple case series have demonstrated the effectiveness of OTSC in clinical practice, only one large multicenter retrospective case series, involving 17 centers, has been published to date[51]. Additionally, the cost of an OTSC is around $800 per unit, with an extra $900 needed for the twin-grasper method. [109]

The positive outcomes of OTSC in refractory upper gastrointestinal bleeding (UGIB) have led to its consideration as a first-line treatment. A recent clinical trial[52] and multiple observational studies[53,54] suggest that using OTSC as an initial therapy for high-risk peptic ulcers may be cost-effective. The latest clinical practice guidelines from the European Society of Gastrointestinal Endoscopy[55] provide a weak recommendation for its use as a first-line treatment in ulcers larger than 2 cm, those with large vessels (> 2 mm), fibrotic or excavated ulcers, or ulcers located in high-risk areas supplied by the gastroduodenal or left gastric arteries. However, evidence remains limited, and treatment decisions should be individualized based on device availability, the patient's clinical condition, and the endoscopist's experience[56]. OTSC clip placement is considered a safe procedure, with adverse effects being rare. A review of over 1,500 patients reported an adverse event rate below 2%, with only 0.59% classified as severe[57]. OTSC's mechanism and clinical applications are demonstrated in Fig. 3, including its anchoring mechanism and post-placement mucosal healing.

Endo suturing systems

Suturing devices aim to approximate the borders of large defects, similar to surgical suturing, and are equipped with a re-loadable suturing needle that works through an endoscope. The OverStitch device (Apollo Endosurgery, shown in Fig. 4) was introduced in 2009 for full-thickness suturing, while the Endomina System can also create gastrointestinal sutures, though it lacks studies on defect closure[58]. Suturing is technically more challenging than clip placement and requires additional training[59]. It typically begins at the distal edge of the defect, pulling healthy mucosa into apposition for closure[60]. However, limitations arise when dealing with difficult

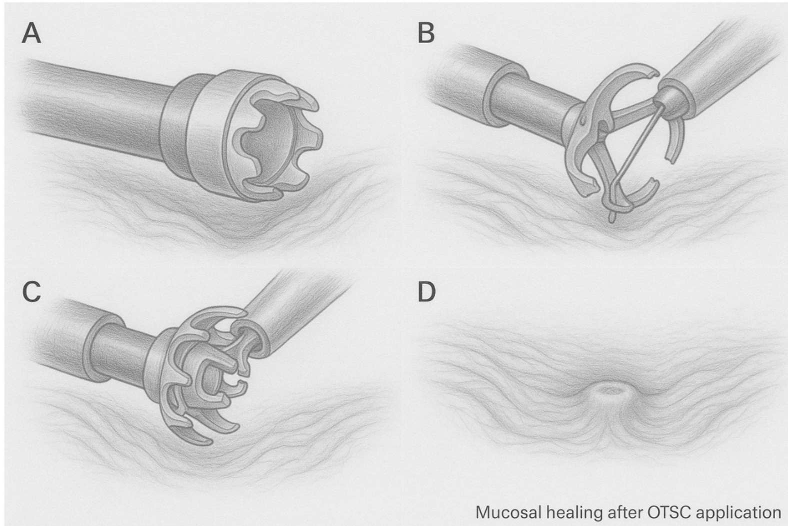

Figure 3. Over the scope clip (OTSC®). (A) OTSC® attached to the tip of the endoscope. (B) Grasping device of the OTSC®. (C) OTSC® with its effective anchor mechanism. (D) Mucosal healing after OTSC® application.

anatomy, such as the duodenum or colon, and concerns like mucosal deformity can interfere with surveillance after resection[61]. Suturing is frequently used for post-interventional defect closure. A case-controlled study comparing suturing and through-the-scope clipping (TTSC) during POEM found similar efficacy and safety, though TTSC was faster and more cost-effective[62]. In colonic perforations, a small retrospective study reported worsening symptoms in TTSC cases, requiring rescue surgery, whereas suturing alone resulted in successful outcomes. Endoscopic suturing has shown varying success rates. A registry study of 137 patients reported 100% feasibility with mucosal defect closure success at 100%, perforations at 94.7%, and fistulae at 64.7%[63]. Mukewar *et al* studied fistula closure post-RYGB, with persistent closure achieved in only 22.4% at 12 months, and recurrence linked to fistulae >20 mm[64]. Chronic fistulae (>3 months) treated with argon plasma coagulation (APC) and suturing showed immediate closure but persistence in only 25% at 3 months[65]. Studies comparing suturing with stents for leaks remain inconclusive due to small sample sizes[66].

The X-Tack system (Apollo Endosurgery) is a novel through-the-scope suturing device designed for mucosal defect closure, using surgical steel helical tacks for anchoring. Feasibility studies show successful placement in 89–92% of cases, though supplementary TTSC was often required[68–70]. While post-resection defect closure outcomes remained durable long-term[71], fistula closure success rates were lower (57.1%)[70]. A randomized controlled trial (RCT) comparing X-Tack and OverStitch found similar efficacy and safety, but X-Tack had significantly lower costs.[72] Further studies are needed to confirm its role, as the lack of full-thickness anchoring may pose limitations.

Figure 4. The Apollo OverStitch TM device[67].

Through-the-scope (TTS) clips

Through-the-scope (TTS) clips are commonly utilized for hemostasis, mucosal defect repair, prosthesis fixation, and fistula closure[73–75]. Recently, there has been growing interest in enhancing endoscopic clip technology for mucosal apposition following advanced tissue resection techniques, including EMR, endoscopic submucosal dissection, and peroral endoscopic myotomy[76–79]. The current body of literature evaluating clip functionality is limited, consisting primarily of benchtop or biomechanical experimental studies[80]. Existing in-vivo comparative studies have focused on either normal mucosa or a single lesion type[81–83]. The conventional through-the-scope clips (TTSCs) are the most commonly used devices for wound closure, delivered directly through the endoscopic working channel with a minimum inner diameter of 2.8 mm. Their advantages include ease of use, rapid deployment, and effective closure of smaller gastrointestinal (GI) defects. However, TTSCs alone are insufficient for larger wounds, which often require complex techniques like endoloop-assisted purse-string sutures[40,84,85]. High-end suturing devices, while capable of closing large defects and performing specialized tasks like endoscopic sleeve gastroplasty[86], also require preloading and operator training for proficient use.

The novel through-the-scope tissue clip (TTS-TC) combines the advantages of traditional TTSCs, including simplicity, flexibility, and compatibility with working channels ≥3.2 mm, while offering enhanced functionality[87]. Notably, TTS-TCs can be repeatedly opened and closed, rotated in real-time for precise positioning, and feature a fixed support column that enables independent clamping on either side of the wound. This design allows effective closure of larger defects by securely approximating both wound edges[87]. Previous studies demonstrated the ability of conventional TTSCs to close GI wounds smaller than 2 cm[88]. In contrast, TTS-TCs successfully closed larger wounds in this study, with average long and short diameters of 4.1 cm and 3.4 cm, respectively. Importantly, none of the TTS-TCs dislodged post-closure, and all wounds achieved complete healing by the 1-month follow-up. The firm clamping strength of TTS-TCs is critical for successful closure, as failure can result in clip dislodgement. Closure times were also efficient, averaging 9.2 minutes, comparable to OTSCs and other suturing devices, though without the additional time needed for device installation and reinsertion[89]. In a study TTS-TCs was found to exhibit significant potential for managing wounds larger than 2 cm, including those in inflamed, thickened, or fibrotic mucosa and anatomically challenging locations where conventional TTSCs are less effective. Following closure, the TTS-TC's support column did not interfere with healing, and all clips detached spontaneously from fully healed wounds[87]. For perforating wounds, TTS-TCs allowed closure either by clamping only the mucosal layers or the full-thickness intestinal wall, as demonstrated in a case of a 4.3 cm × 3.0 cm defect. At follow-up, both approaches resulted in complete healing without complications[87]. Through-the-scope (TTS) clips, used for endoscopic procedures, can cost anywhere from $438 to $600 per clip, with some studies suggesting a tack and suture device costing around $695. [113] Future research should compare outcomes of mucosal-layer versus full-thickness clamping to identify the optimal closure method for perforating wounds.

X-Tack system

Endoscopic resection of gastrointestinal neoplasia is becoming more common, with adverse events (AEs) such as bleeding and perforation being notable complications. Research has shown that defect closure can reduce post-procedural bleeding and perforation rates[90–92]. Various closure devices are available, but they each have limitations[93]. Over-the-scope clips (OTSC) and endoscopic suturing require scope withdrawal for loading, which can be impractical or challenging in certain situations. To address this, the X-Tack system (Apollo Endosurgery, Austin, Texas, United States) has been developed as a through-the-scope (TTS) device, offering a more adaptable solution for robust closure of large and difficult-to-access defects[94].

Preclinical studies have demonstrated the X-Tack system's advantages, including significantly improved immediate technical success, comparable healing rates at 2 and 4 weeks, and a trend toward faster healing in lesions >30 mm compared to TTS clips. Notably, the X-Tack successfully closed two resection sites where TTS clips had failed, including a colonic defect with perforation that healed without complications. Its ability to achieve closure without requiring endoscope withdrawal makes it particularly beneficial for managing challenging colonic perforations or right-sided lesions that are harder to reach with bulkier devices like OTSC[95]. In trials using a smaller-caliber porcine colon, the X-Tack system proved simple and effective, suggesting feasibility for human applications. Although the closure time was longer, this was likely due to a learning curve and the complexity of larger defects. Interestingly, workload analysis indicated that X-Tack caused less user frustration and improved performance compared to TTS clips[95]. The Boston Scientific XTACK-235-H system, a specialized endoscopic suturing device, is designed for single-patient use and facilitates secure tissue closure through its helix tacking mechanism. This advanced tool is a key component in endoscopic procedures, providing a reliable solution for tissue approximation. The XTACK system is sold in a box containing three units, with a listed price of $6026.07. [114]

Future studies should compare X-Tack to other closure tools, such as OTSC and endoscopic suturing, to evaluate its cost-effectiveness. Its higher retention rates at 4 weeks, compared to TTS clips[82], suggest potential applications beyond defect closure, such as endoscopic marking, stent anchoring, and feeding tube fixation, though further investigation is needed. The X-Tack system, made of surgical-grade steel, is MRI-conditional and comparable in safety to TTS clips. However, long-term safety data, particularly for its use in marking, remains incomplete and warrants future research. The X-Tack system's innovative approach offers adaptability, precise anchoring, and reduced trauma, particularly for irregular or hard-to-reach lesions. While limitations include its recent development, operator learning curve, and cost considerations, early evidence and case reports highlight its effectiveness in achieving robust defect closures. A summary comparison of these techniques, including indications, advantages, and limitations, is provided in Table 1.

Self-expandable metal and plastic stents provide internal containment and facilitate healing by diverting luminal contents. They are particularly useful in managing leaks and perforations, especially in the esophagus and proximal GI tract. However, migration and insufficient sealing of larger defects remain limitations[20]. Endoscopic Vacuum-Assisted Closure, adapted from surgical negative pressure therapy, promotes defect healing via continuous suction. It is particularly effective in treating anastomotic leaks and perforations, with high clinical success rates. Limitations include multiple procedures and the need for specialized equipment[16]. Internal Traction-Assisted Suspended Closure uses traction sutures to approximate defect edges under tension, enabling better visualization and closure. While promising in select cases, data remains limited and technique standardization is pending[17].

Factors influencing technique selection

Several factors influence the selection of endoscopic techniques in gastroenterology, with key considerations including patient characteristics, the complexity of the procedure, and the experience level of the provider. For patients with lower physical status grades and less demanding procedures, moderate sedation is often preferred due to its favorable risk profile and efficiency. On the other hand, general anesthesia is typically selected for more complex and lengthy procedures that require a higher level of patient immobility and control[96]. Patient satisfaction remains a critical aspect of endoscopic procedures and is influenced by multiple factors, including the technical expertise of the endoscopist, pain management strategies, and effective communication with the patient. Studies have demonstrated that patient satisfaction is significantly impacted by both pre-procedure and post-procedure interactions with healthcare providers[97,98].

The use of monitored anesthesia care (MAC) has been on the rise in recent years, driven by a combination of patient-related

Table 1

Comparative analysis of endoscopic closure techniques

Technique	Description	Indications	Advantages	Limitations	Effectiveness & price	References
Over-the-Scope Clips (OTSC)	OTSC is a system capable of closing therapy-resistant gastrointestinal bleedings, wall defects, and fistulae. It involves strong clamping abilities for closure.	- Gastrointestinal perforations—Leakages—Fistulae (including anorectal lesions)—Uncontrolled GI bleeding	- Strong clamping ability—Effective for large, fibrotic, or high-risk ulcers—Low adverse event rate (below 2%)	- Preloading requires scope withdrawal—Limited by scope maneuverability—May cause ulcers/stenosis post-placement	High effectiveness for large defects and bleeding control. Cost: moderate to high	[40–57]
Endo Suturing Systems	Devices like OverStitch enable full-thickness suturing through an endoscope for defect closure, requiring additional operator training.	- Post-interventional defect closure—Gastrointestinal fistulae—Colonic perforations	- Feasible for large defects—High precision in tissue approximation—Durable outcomes with training	- Technically challenging—Less effective for difficult anatomy (e.g., duodenum/colon)—Higher cost	Very high effectiveness with expert operators. Cost: high	[58–66]
Through-the-Scope (TTS) Clips	Conventional endoscopic clips delivered via the endoscope's working channel; effective for small GI defects, hemostasis, and prosthesis fixation.	- Hemostasis—Mucosal defect repair—Fistula closure—Fixation of prostheses	- Ease of use—Rapid deployment—Cost-effective for smaller defects	- Insufficient for large defects—Limited strength in fibrotic/inflamed mucosa	Moderate effectiveness for small mucosal issues. Cost: low	[40,73–88]
Novel TTS Tissue Clips (TTS-TC)	Advanced TTS clips with improved features like real-time rotation, fixed support columns, and capability for repeated opening/closure.	- Larger GI defects—Challenging anatomical sites—Full-thickness perforations	- Effective for larger wounds (up to 4 cm)—No reinsertion required—Strong clamping strength and rapid healing	- New technology requiring further validation—Limited long-term data	High potential effectiveness, pending further studies. Cost: moderate	[87–89]
X-Tack System	A novel TTS suturing device using helical tacks for anchoring, designed for mucosal defect closure without endoscope withdrawal.	- Post-resection defect closure—Colonic perforations—Hard-to-access lesions	- Adaptable for difficult locations—Lower cost compared to OTSC or OverStitch—MRI-conditional safety	- Requires training—Limited full-thickness anchoring—Efficacy varies for fistula closure	Moderate to high effectiveness depending on site. Cost: moderate	[68–72,82,94,95]

factors such as advanced age, racial differences, and the presence of comorbid medical conditions, as well as provider- and facility-related considerations[99]. Despite its benefits, a notable trend in patient satisfaction is a decline over time following the procedure, which may be attributed to recall bias or altered perceptions of discomfort after the event[97]. This phenomenon underscores the importance of managing patient expectations and improving communication before and after the procedure. Interestingly, there appears to be a disconnect between the perspectives of endoscopists and their patients regarding the importance of communication. While endoscopists may underestimate the value of thorough pre- and post-procedure discussions, patients place significant importance on these interactions as part of their overall satisfaction[98]. This gap in perception highlights the need for healthcare providers to prioritize patient-centered communication strategies to optimize the patient experience and outcomes. These findings emphasize the multifaceted nature of factors influencing the selection of endoscopic techniques and the determinants of patient satisfaction. A balance between procedure-specific requirements, sedation strategies, and patient-centered care is essential to achieving successful clinical outcomes and ensuring a positive patient experience. Key factors guiding the choice of endoscopic closure techniques are outlined in Table 2.

Table 2

Factors influencing technique selection

Factors	Description
Patient characteristics	Age, comorbidities, and physical status grades determine sedation type (moderate sedation vs. general anesthesia).
Procedure complexity	Longer, more complex procedures often require general anesthesia or advanced closure techniques like OTSC or suturing systems.
Endoscopist experience	Proficiency and familiarity with specific devices influence technique selection.
Patient satisfaction	Driven by pain management, technical expertise, and pre/post-procedure communication. Recall bias may affect long-term satisfaction.
Device availability	Device cost, availability, and training needs play a significant role in the selection of closure techniques.

Clinical outcomes and comparative evidence

OTSC has demonstrated efficacy in treating various gastrointestinal (GI) conditions, including bleeding and perforations. Kirschniak *et al* reported an 85% success rate in treating therapy-resistant GI bleedings and wall defects[40]. Comparative studies indicate OTSC is superior to conventional endoclips for closing iatrogenic perforations, with closure success rates ranging from 75% to 95% depending on defect size and location[41,42]. Its expanded applications include securing SEMS, closing POEM-access sites, and reducing gastrojejunal anastomosis diameter[43–45]. OTSC's primary indications remain the closure or treatment of GI perforations, leakages, fistulae, and uncontrolled GI bleeding, with hemostasis success rates of 88–100% in refractory cases[46–50]. A multicenter retrospective case series involving 17 centers further supports its efficacy, with a technical success rate of 89.5% and clinical success in 80% of patients[51]. Endoscopists require 10–15 supervised cases to gain proficiency in OTSC deployment. Mastery depends on experience with complex GI defects. OTSC has a higher upfront cost than traditional clips but is cost-effective due to lower reintervention rates. Adverse events occur in 5–10% of cases, mostly minor mucosal injuries[52–57].

EndoSuturing systems, such as OverStitch and Endomina, enable full-thickness suturing but are technically demanding. The OverStitch device, introduced in 2009, has a 90% technical success rate for post-interventional defect closure. However, its success in fistula closure varies, ranging from 50% to 80%, depending on the fistula type[58–61]. The Endomina system, designed for transoral gastric suturing, has demonstrated a 75–85% success rate in clinical studies[62–66]. Proficiency in OverStitch requires training in 20–30 live or simulated cases. Hands-on experience is essential for developing the necessary dexterity. Suturing systems are significantly more expensive than OTSC or TTS clips. Adverse events, including mucosal deformity, occur in 10–15% of cases, with device misfiring reported in 3–5% of cases[68–72].

TTS clips remain widely used for hemostasis and mucosal defect repair, achieving closure rates of 60–85%. Advances in TTS-TCs have increased success rates to 85–95% for larger wounds[76–79]. The X-Tack system, a novel TTS suturing device, has demonstrated a 92% immediate technical success rate for mucosal defect closure, surpassing conventional TTS clips in durability[87]. Standard TTS clips require minimal training, while X-Tack demands 5–10 supervised cases for proficiency. TTS clips are the most cost-effective option, with a low adverse event rate (~3%). X-Tack has a higher cost but offers improved retention in challenging anatomical locations[82,95].

Clinical trials suggest OTSC and EndoSuturing outperform conventional TTS clips for full-thickness closure. X-Tack provides enhanced mucosal-layer repair with fewer clip dislodgments. Cost-effectiveness remains a concern for EndoSuturing, while OTSC is emerging as a preferred option for refractory GI bleeding. Further studies are needed to evaluate long-term outcomes.

Endoscopic techniques have shown promising outcomes in gastroenterology. Endoscopic mucosal resection (EMR) and endoscopic submucosal dissection (ESD) provide curative outcomes for early cancers with fewer complications than surgery[100]. EUS-guided gastroenterostomy (EUS-GE) has demonstrated high technical and clinical success rates for gastric outlet obstruction, with lower complication rates compared to surgical gastrojejunostomy[101]. Various endoscopic antireflux treatments have shown good short-term efficacy compared to sham procedures, pharmacological, or surgical treatments for chronic gastroesophageal reflux disease[102]. These advancements in therapeutic endoscopy aim to improve patient outcomes, reduce complications, and provide alternatives to more invasive procedures[100]. However, outcomes research in gastroenterology and endoscopy is crucial for assessing the effectiveness of these techniques and their impact on patient care[103].

Limitations

A clear limitations section is essential for contextualizing this review. First, current literature on GI defect closure is largely composed of case series and retrospective studies, with a paucity of randomized controlled trials, limiting the strength of conclusions. Additionally, this review does not include a formal meta-analysis or risk-of-bias assessment, which restricts quantitative synthesis and evidence grading. Many of the newer techniques described (e.g., internal traction-assisted closure, EVAC) are still evolving and lack long-term data. Thus, while this review provides a comprehensive summary of available modalities, ongoing studies and future high-quality trials are necessary to refine clinical algorithms and validate efficacy across diverse clinical contexts.

Future directions and innovations

The field of endoscopic closure devices is poised for substantial growth. Ongoing research and development aim to refine device technology and materials, prioritizing improved performance and reduced complications. A promising direction involves integrating robotics and artificial intelligence into endoscopic procedures. These technologies have the potential to enhance precision, expedite procedures, and expand the scope of endoscopic interventions.

Despite significant strides, crucial knowledge gaps persist, particularly regarding the long-term outcomes and comparative effectiveness of different closure devices. Large-scale randomized controlled trials are essential to establish evidence-based guidelines for optimal device selection and procedural techniques. By addressing these research gaps and embracing technological advancements, the field can continue to evolve, leading to improved patient outcomes and an expanded therapeutic role for endoscopic closure devices.

Conclusion

In conclusion, the field of endoscopic closure devices has witnessed significant advancements, offering innovative solutions for managing a range of gastrointestinal (GI) defects. Over-the-scope clips (OTSC), endo suturing systems, through-the-scope (TTS) clips, and the X-Tack system each present unique strengths and limitations, making them suitable for specific clinical scenarios. While these devices have shown promise in clinical practice, further research is needed to optimize their use and address knowledge gaps. Large-scale randomized controlled trials are essential to establish evidence-based guidelines for device selection and procedural techniques. By embracing technological innovations such as robotics and artificial intelligence, the future of endoscopic closure devices holds the potential to revolutionize GI care, leading to improved patient outcomes and expanded therapeutic possibilities.

Ethical approval

Ethics approval was not required for this review.

Consent

Informed consent was not required for this review.

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Author contributions

A.M.: conceptualization, investigation, methodology, project administration; M.P., T.S., Z.W.H., and D.T.: data curation, formal analysis, software, visualization; N.A.S.: conceptualization, project administration, resources, writing – original draft; N.N.K.: formal analysis, investigation, methodology, validation; H.A.: data curation, investigation, validation, writing – review & editing.

Conflicts of interest disclosure

The authors declare no conflict of interest.

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