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REVIEW

Advanced innovations in reducing anastomotic leak: a review of emerging biomaterial applications in colorectal surgery

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Abstract

The rising global incidence of colorectal cancer surgeries has been paralleled by advancements in minimally invasive techniques such as laparoscopic and robot-assisted surgeries. Despite these improvements, anastomotic leaks remain a significant postoperative complication, leading to increased mortality. Traditionally, diverting ileostomy has been the preferred method to reduce this risk, yet it carries its own set of complications and impacts on patient quality of life. Recent advancements in biomaterial science have introduced alternative methods to protect anastomosis without the need for external stomas. This review explores current technological approaches, including devices like Colovac, LeakGuard, CG-100, the C-seal, and the Self-degrading Intestinal Diversion stent, which aim to replicate the protective effects of ileostomy while minimizing associated complications. The Colovac device, an intraluminal bypass sheath, and the LeakGuard biodegradable stent are both designated as "breakthrough devices" by the FDA. The CG-100, C-seal devices, and Self-degrading Intestinal Diversion stent also demonstrate potential in reducing anastomotic leakage rates through innovative mechanisms. However, widespread clinical adoption of these devices requires further validation through large-scale randomized controlled trials to assess their long-term outcomes and cost-effectiveness. This review highlights the potential of these innovations to enhance the safety and efficacy of colorectal cancer surgeries, ultimately improving patient outcomes and quality of life.

Keywords Anastomotic leak · Colorectal surgery · Ileostomy alternatives

Introduction

The global incidence of colorectal cancer surgeries has been rapidly increasing, fueled by advancements in minimally invasive surgical techniques such as laparoscopic and Da Vinci robot-assisted surgeries [1, 2]. Despite these technological strides, the incidence of anastomotic leaks following colorectal surgery has not significantly decreased [3]. Anastomotic leak is a serious complication that can lead to increased morbidity, prolonged hospitalization, and even mortality [4].

To reduce the risk of anastomotic leak, the creation of a protective diverting ileostomy remains the most commonly employed and reliable method after low anterior resection for colorectal cancer [5, 6]. This technique diverts the fecal stream away from the anastomosis, allowing the anastomosis to heal without the stress of fecal contamination. However, ileostomy is associated with a range of complications, including peristomal skin complications, stoma retraction, stoma avascular necrosis, stoma stenosis, stoma bowel prolapses, stoma bleeding, postoperative fluid and electrolyte imbalance, and parastomal hernia [7]. Additionally, the need for a second surgery to reverse the ileostomy introduces further risks, extends recovery time, and diminishes the patient's quality of life [8, 9]. These complications also impose substantial psychological and economic burdens on patients.

In light of these challenges, recent advancements in biomaterial science have led to the development of various new methods and materials designed to replace protective ileostomy. These innovations aim to achieve similar reductions in anastomotic leak rates while minimizing the associated complications and burdens.

This review aims to summarize the current mainstream technological approaches and their clinical applications. The integration of these advanced biomaterials and novel

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surgical techniques into clinical practice has the potential to reduce anastomotic leak rates and improve patient outcomes. However, their widespread adoption requires further validation through large-scale randomized controlled trials. Additionally, understanding the long-term outcomes and cost-effectiveness of these new approaches is essential for their acceptance in standard surgical practice. Through this exploration, we hope to contribute to the ongoing efforts to enhance the safety and efficacy of colorectal cancer surgeries, ultimately improving patient outcomes and quality of life.

Two principles instead of ileostomy

Murphy's development of the intestinal compression ring in 1892, known as the "Murphy Button," marked a pivotal advancement in surgical techniques for intestinal anastomosis [10]. Despite its initial promise, the device was ultimately abandoned due to significant adverse effects, including foreign body reactions and ischemic necrosis at the anastomotic site, attributed to the mechanical pressure it exerted. This complication underscored the necessity for improvements in anastomotic device design to minimize such deleterious outcomes. In subsequent decades, specifically the 1980 s and 1990 s, the introduction of the polyglycolic acid Biofragmentable Anastomotic Ring (BAR) by Valtrac (Davis & Geck, Inc.) sought to address some of these concerns [11]. The BAR, made from bioabsorbable materials, aimed to provide a temporary scaffold for anastomosis, subsequently degrading to avoid long-term foreign body reactions. However, it too encountered significant challenges, notably anastomotic ischemic necrosis due to mechanical pressure, which constrained its broader clinical adoption [12].

The underlying principle of ileostomy, utilized in postoperative colorectal cancer management, emphasizes delaying the anastomotic contact with fecal matter to reduce the incidence of anastomotic fistula and facilitate adequate healing time [13]. In this context, two innovative technical designs have been proposed to replicate the protective effects of ileostomy without necessitating external stomas. The first design concept involves situating a device proximate to the anastomotic site to forestall stool contact. This device remains in place until the anastomosis has sufficiently healed, after which it either degrades biologically or is removed, thereby allowing the restoration of normal bowel function. This approach aims to minimize the duration and impact of mechanical pressure on the anastomotic tissue, potentially reducing the risk of ischemic complications. The second design concept parallels the functionality of an ileostomy by positioning biodegradable material at the distal end of the small intestine. This material occludes the intestinal lumen, diverting fecal matter through a proximal drainage tube. Following the degradation of the biodegradable material and sufficient healing of the anastomosis, the drainage tube is removed, and natural defecation is resumed after the closure of the small intestinal sinus and overlying skin.

These designs have catalyzed the development of various clinical products intended to offer outcomes comparable to traditional ileostomy. Preliminary evaluations suggest that these innovations may be non-inferior to ileostomy, providing effective alternatives for managing postoperative colorectal anastomosis with potentially reduced complications and enhanced patient quality of life. Continued research and clinical trials will be essential in determining their efficacy and safety profiles in diverse patient populations.

Current clinical applications to anastomotic protection in colorectal surgery (Table 1)

The Colovac device (CD)

The management of anastomotic healing post-low anterior resection (LAR) presents a significant clinical challenge due to the risk of leakage. Although traditional diversion strategies, typically involving ileostomy, are reliable, they entail considerable complications and require subsequent surgical intervention for ileostomy closure [14].

The CD, recently designated as a "breakthrough device" by the FDA, offers an innovative solution. It is an intraluminal bypass sheath equipped with a stent and a vacuum mechanism that secures it over the anastomosis site [15]. This intraluminal approach provides temporary fecal diversion without the need for external stomas.

The CD is advantageous in laparoscopically assisted colorectal cancer surgeries. After intestinal reconnection, the Colovac introducer is deployed transanally to position the device adjacent to the anastomosis. Activation of the vacuum mechanism anchors the Colovac for approximately 10 days, covering the critical healing period, after which it is endoscopically removed transanally without requiring further surgical intervention [16].

In the SAFE-1 study (NCT03352570), the CD demonstrated a 100% anastomotic protection rate in 15 patients [15, 16]. A phase III multicenter randomized controlled trial (NCT05010850) is ongoing to evaluate the effectiveness of the CD against standard ileostomy in 342 patients [17]. Primary endpoints include major complications within 12 months and the reduction in stoma creation rates. Secondary endpoints include quality of life and device tolerability.

Table 1 Comparative summary of current anastomotic protection devices

Device name	Function and mechanism	Advantages (pros)	Disadvantages (cons)	Clinical validation status
Colovac device	Intraluminal bypass sheath secured by vacuum mechanism to temporarily divert feces from anastomosis site	- Minimally invasive, no external stoma - Removable transanally without surgery—FDA "breakthrough device"	- Requires endoscopic removal - Limited long-term safety data	Phase III randomized controlled trial ongoing (NCT05010850)
LeakGuard	Biodegradable intraluminal stent providing temporary barrier during anastomosis healing period	- Fully biodegradable, no removal needed—Environmentally friendly - FDA "breakthrough device"	- Lack of publicly available RCT data - Short-term effectiveness only	Currently lacks randomized controlled trial data
CG-100	Temporary silicone intraluminal bypass sheath with balloon and fixation ring to divert fecal flow	- Easy implantation and removal without surgery - Avoids external stoma complications	- Requires manual removal after 10 days - Potential device migration	Ongoing multicenter clinical trials (NCT03423485, NCT05632744, NCT02109991)
C-seal	Biodegradable intraluminal sleeve sutured with a circular stapler, preventing extravasation if dehiscence occurs	- Fully biodegradable -Minimally invasive placement -Low leakage rate reported in early studies	- Sutured placement requires technical skill - Limited long-term efficacy data	Large-scale multicenter RCT completed; awaiting broader adoption (Trial NTR3080)
Self-degrading Intestinal Diversion stent (Collapsible Intestinal Stapler Type HB)	Biodegradable stent implanted in ileum to fully obstruct lumen temporarily, diverting feces through proximal tube	- Fully biodegradable; avoids ileostomy reversal surgery - Reduces patient discomfort	- Requires proximal enterostomy tube - Limited clinical experience	Phase III RCT currently ongoing (NCT06204497)

LeakGuard

The introduction of the LeakGuard biodegradable stent represents a significant advancement in the management of anastomotic leakage, a critical complication in colorectal surgery. The FDA's "breakthrough device" designation underscores the potential of this innovative technology to transform the current treatment paradigms for serious postoperative complications [18]. The LeakGuard stent is designed to serve as an intraluminal barrier during the critical postoperative healing period following enteroenteric anastomosis. The deployment of the stent is achieved intraoperatively, obviating the need for a temporary stoma, which not only simplifies the surgical procedure but also substantially reduces healthcare costs. Estimates suggest a savings exceeding $25,000 per patient, highlighting its economic advantages.

Constructed from a medical-grade absorbable polymer, the LeakGuard stent provides a biocompatible and biodegradable solution that integrates seamlessly with the body's natural processes. Within approximately 10 days post-surgery, the stent degrades and is excreted through normal fecal elimination, eliminating the need for secondary removal procedures. This characteristic is particularly advantageous, as it minimizes patient discomfort and the risk of additional surgical interventions.

A noteworthy aspect of the LeakGuard stent is its commitment to environmental sustainability. It is manufactured using environmentally friendly, biodegradable materials, and the production process adheres to principles of clean technology, aiming for a zero-carbon footprint. This makes LeakGuard not only a clinically beneficial device but also a model for sustainable medical technology development.

In the context of postoperative protection, the LeakGuard stent represents a novel approach to mitigating the risks associated with anastomotic leakage. By providing a temporary yet effective barrier, it supports the integrity of the anastomosis during the crucial early healing phase, thereby reducing the incidence of leakage and associated complications. The integration of this biodegradable stent into surgical practice promises to enhance patient outcomes and streamline postoperative care. However, unfortunately, no publicly accessible randomized controlled clinical trials have been conducted on this device so far. More rigorous evidence is needed to further validate its efficacy and safety.

CG-100

The CG-100 anastomotic protection device, developed by Colospan, represents a significant innovation in the management of gastrointestinal resection surgeries. This device aims to reduce the incidence of anastomotic leakage, a critical complication often observed postoperatively, which can lead to severe complications and necessitate the formation of a temporary or permanent stoma.

Anastomotic leakage is a predominant concern following colorectal surgeries, with reported incidence rates ranging from 1 to 20%, depending on the patient population and the complexity of the surgical procedure [19]. The CG-100 device addresses this issue by providing a temporary intraluminal bypass, thereby diverting fecal matter away from the anastomotic site during the critical healing period [20].

The design of the CG-100 consists of a silicone tubular sheath that is positioned at the colonic anastomosis site using a proprietary delivery system. The distal end of the sheath is stabilized by three inflatable balloons, which secure the device in place within the colon. Additionally, the device features an extraluminal fixation ring that circumferentially surrounds the colon. This dual-fixation mechanism, combining the balloons and the extraluminal ring, ensures that the sheath remains firmly positioned, preventing downward migration while allowing for synchronized movement with the rectum. This dynamic stabilization is crucial in preventing mechanical injury to the colonic wall, which could otherwise compromise the anastomotic integrity.

The clinical efficacy of the CG-100 is predicated on its ability to minimize direct contact between fecal matter and the healing anastomotic site, thereby reducing inflammatory responses and potential infection that could precipitate leakage. Studies have demonstrated that protected anastomosis leads to improved healing outcomes and lowers the necessity for diverting stomas, which carry their own risks and complications, such as stoma prolapse, skin irritation, and psychosocial distress.

Notably, the CG-100's design facilitates both implantation and removal without the need for additional surgical intervention. The device can be extracted 10 days post-implantation when anastomotic healing is typically sufficient to reduce leakage risk. This minimally invasive removal process, which can be completed within minutes, enhances patient recovery and reduces hospital stay durations.

Currently, the CG-100 is available in the European Union and Israel (NCT05632744, NCT02109991), with Investigational Device Exemption (IDE) clinical trials ongoing in the USA [21, 22]. A clinical trial (NCT03423485) was designed to evaluate the CG-100 device, a disposable and temporary intraluminal bypass device intended to reduce fecal contact with the anastomosis after colorectal surgery [23]. Colospan is initiating a pivotal, prospective, multicenter, single-arm, open-label study to assess the safety and performance of the CG-100 device in colorectal surgery patients. The study will enroll up to 137 patients across 12 sites in Europe, Israel, and the USA. The primary objective is to evaluate the performance of the CG-100 device in reducing fecal contact with the anastomosis. Secondary objectives include the assessment of clinical and radiographic anastomotic

leak performance, the success rate of device positioning and maintenance, and the ease of device application and removal. Additionally, the safety of the CG-100 device will be evaluated. These trials will provide further insight into the device's safety and efficacy, potentially paving the way for broader adoption in clinical practice. The CG-100 anastomotic protection device holds promise for revolutionizing postoperative management in colorectal surgery by significantly reducing the incidence of anastomotic leakage and the associated necessity for stoma formation. Continued clinical evaluation and widespread implementation could ultimately improve patient outcomes and quality of life following gastrointestinal resections.

C-seal

Anastomotic leakage represents a significant complication following colorectal surgery, often necessitating invasive intervention and impacting patient morbidity and mortality rates. The development of intraluminal biodegradable drainage tubes, specifically the C-seal, aims to reduce the incidence of such leaks. The C-seal is strategically sutured to the anastomosis using a circular stapler [24], thereby acting as a barrier against the extravasation of colonic contents should dehiscence occur [25].

A retrospective study evaluated the incidence of anastomotic leakage requiring reintervention with the use of the C-seal [26]. Among 37 patients monitored for three months post-surgery, only one (3%) experienced leakage necessitating reintervention, significantly lower than the 11% reported in the literature. Additionally, there was one case of rectovaginal fistula and three cases (8%) of spontaneously drained perianastomotic abscesses. Preliminary research results reveal that it has safety and effectiveness. Therefore, the efficacy of C-seal in preventing anastomotic leakage was rigorously evaluated in a prospective multicenter randomized controlled trial (NTR3080) [27]. This trial specifically targeted the prevention of anastomotic leakage that necessitates reintervention within 30 days post-surgery. The trial design incorporated a robust sample size of 616 patients, randomized equally into the C-seal and control groups. Stratification was meticulously planned based on the surgical center, anastomosis height relative to the peritoneal reflection, and the intended creation of a temporary deflecting stoma. Inclusion criteria were stringent, encompassing patients aged 18 and above requiring colorectal anastomosis via a circular stapler in an elective surgical setting. The protocol mandated oral mechanical bowel preparation, with exclusion criteria effectively ruling out patients with clinical signs of peritonitis. Randomization and trial oversight were managed by the C-seal study team, ensuring standardization in the application of the C-seal and comprehensive monitoring throughout the study.

The primary endpoint centered on the incidence of clinical anastomotic leaks leading to re-intervention within the first 30 days post-surgery. Interim analyses were predefined at 50% and 75% patient enrollment to assess early efficacy and safety signals. Additionally, the trial incorporated a 1-year follow-up period to capture long-term outcomes, with data analyzed on an intention-to-treat basis to maintain the integrity of randomization.

This trial not only addresses a critical need in colorectal surgery but also exemplifies a methodologically sound approach to evaluating innovative surgical adjuncts. The anticipated results from this multicenter trial hold the potential to significantly influence clinical practice by validating the C-seal as an effective measure against anastomotic leakage, thereby enhancing patient outcomes and reducing postoperative complications.

Self-degrading Intestinal Diversion stent

Recent advances in colorectal surgery have enabled more patients with low rectal cancer to undergo anus-preserving procedures [28]. Despite these advancements, effective prevention of anastomotic leakage remains crucial.

The "Collapsible Intestinal Stapler Type HB" (Self-degrading Intestinal Diversion stent) represents an innovative surgical approach that employs a biodegradable stent for temporary intestinal diversion. The stent is implanted in the distal ileum during rectal cancer resection, fully obstructing the intestinal lumen. An enterostomy created proximal to the stent ensures complete diversion of intestinal contents. The stent gradually disintegrates within approximately 3 weeks, allowing removal of the enterostomy tube once intestinal patency is restored, thus obviating the need for secondary reversal surgery.

A retrospective analysis in 2020 evaluated 34 patients receiving the Self-degrading stent (SDT) after LAR [29]. The median degradation duration was 21 days. Complications included anastomotic leakage in one patient (2.9%) and intestinal obstruction in another (2.9%). Following these encouraging outcomes, a randomized controlled clinical trial (NCT06204497) was initiated to rigorously evaluate the efficacy and safety of SDT versus ileostomy in rectal cancer patients at high leakage risk [30]. The primary measure is serious complication rates within 90 days post-surgery, while secondary endpoints include overall complications, postoperative hospital stay duration, costs, and quality of life.

Critical analysis and clinical integration of anastomotic protection devices

While current anastomotic protection devices exhibit considerable promise, their integration into clinical practice requires a careful understanding of patient-specific factors,

anatomic considerations, and adjunctive therapies. Surgeons must critically assess patient selection, anatomical suitability, and therapeutic contexts to optimize device utilization.

Patient selection criteria

Not all patients undergoing colorectal resection will equally benefit from these devices. Candidates most likely to benefit include patients at elevated risk for anastomotic leakage, such as those undergoing ultra-low anterior resection (generally defined as ≤ 5 cm from the anal verge), individuals with compromised nutritional or immunological status, and patients with significant comorbidities such as diabetes or cardiovascular disease. Conversely, low-risk patients undergoing high colorectal or sigmoid anastomosis may gain minimal benefit relative to standard surgical techniques and may not justify the additional device-related intervention.

Anatomic considerations (height of anastomosis)

Device utility strongly correlates with anastomotic height. For instance, intraluminal diversion devices (e.g., Colovac, CG-100, and LeakGuard) demonstrate maximum clinical benefit in very low or ultra-low anterior resections (≤ 5–7 cm from anal verge), where anastomotic leak rates are substantially higher, and traditional ileostomy is frequently indicated. Higher anastomoses (≥ 10–12 cm) generally present lower leak rates and may not benefit proportionally from routine use of these protective devices, given the low absolute risk reduction relative to cost and potential complications.

Impact of neoadjuvant chemoradiotherapy (CRT)

Neoadjuvant CRT is known to impair wound healing, thus increasing anastomotic leak risk. Patients receiving preoperative CRT for rectal cancer may represent an ideal subgroup for the prophylactic deployment of protective devices. However, caution is advised due to the altered tissue characteristics following CRT. Device selection in these patients should emphasize minimal tissue trauma, ease of removal, and careful monitoring for device migration, especially for intraluminal anchored devices (such as CG-100). Devices that degrade spontaneously (e.g., LeakGuard, Self-degrading Intestinal Diversion stent) may be advantageous, as they avoid secondary interventions in irradiated tissues, reducing the risk of complications associated with delayed healing.

Limitations of self-degrading devices in delayed healing

A critical consideration when using biodegradable devices (e.g., LeakGuard and Self-degrading Intestinal Diversion stent) is the predetermined timeframe of protection (approximately 10–21 days), after which the device disintegrates irrespective of anastomotic healing status. If healing is incomplete at this point, there is a significant risk of leakage and related complications. Therefore, careful patient selection and proactive postoperative monitoring, including early endoscopic or radiological assessment, are essential. If there is doubt regarding anastomotic integrity at the expected degradation timeframe, surgeons should have contingency management strategies, including timely endoscopic or surgical intervention, clearly defined preoperatively.

Clinical implementation recommendations

Current evidence advocates for a tailored, patient-specific approach rather than routine implementation of novel anastomotic protection devices. Surgeons should judiciously evaluate individual patient risk factors alongside device-specific characteristics when selecting appropriate interventions. Devices such as Colovac and CG-100 are particularly suitable for patients undergoing ultra-low anterior resections or for those who are contraindicated for conventional ileostomy due to significant comorbidities or strong patient preferences; however, these options necessitate careful consideration given the requirement for timely removal and potential technical complexities. In contrast, devices like LeakGuard and C-seal, which degrade spontaneously without the need for secondary interventions, are well suited for intermediate-risk patients who would benefit from temporary anastomotic protection; nonetheless, their limited duration of protection demands vigilant postoperative monitoring and preparedness for potential intervention if healing is delayed. The Self-degrading Intestinal Diversion stent presents an optimal choice for patients otherwise indicated for a diverting ileostomy but who strongly prefer to avoid the associated morbidity of an external stoma. Nevertheless, due to its predefined degradation timeline, this device is best reserved for patients with anticipated standard healing trajectories and requires close clinical surveillance throughout the critical postoperative period to manage any complications promptly.

In conclusion, surgeons should approach these novel protective devices not as universal replacements for ileostomy but as selective tools tailored to patient-specific risk profiles, anatomical considerations, and adjunctive treatment contexts. Further rigorous randomized controlled trials must clarify optimal patient selection and detailed clinical implementation protocols to ensure maximal safety and efficacy.

Conclusions and perspectives

The prevention of anastomotic leakage following LAR remains a significant clinical challenge [31]. Despite substantial advancements in surgical methodologies and the

introduction of innovative medical devices, the ileostomy continues to be the gold standard in mitigating the risk of leakage. But it carries its own set of complications and impacts on patient quality of life, such as dehydration, electrolyte imbalances, and the psychological burden associated with a stoma. The comprehensive analysis of risk factors emphasizes the complexity of preventing anastomotic leakage through a singular approach [32]. Factors such as gender, nutritional status, medication use, tumor location, size, and the administration of neoadjuvant chemoradiotherapy are critical preoperative considerations [33–35]. Intraoperative factors, including blood loss, surgical technique, and the number of stapler firings, further complicate the landscape of potential interventions [36–38]. The landscape of alternative devices to ileostomy is diverse, yet none has achieved the reliability and efficacy required to supplant the traditional procedure entirely. Current medical devices, while promising, cannot assure absolute prevention of anastomotic leakage. Our review has identified two predominant technical approaches that merit consideration (Fig. 1).

This review explores current technological approaches, including devices like Colovac, LeakGuard, CG-100, the C-seal, and the Self-degrading Intestinal Diversion stent, which aim to replicate the protective effects of ileostomy while minimizing associated complications. The Colovac device functions as an intraluminal bypass sheath meticulously engineered to prevent fecal matter from making contact with the anastomotic site, thereby mitigating the risk of leakage. In parallel, the LeakGuard is a biodegradable stent designed to offer temporary safeguarding during the crucial healing phase. Both of these devices have garnered designation as "breakthrough devices" by the FDA, emphasizing their potential to fulfill previously unmet clinical needs. In contrast to the traditional use of ileostomy, these innovations present a profound advancement by obviating the necessity for an external stoma, thereby preserving the structural integrity of the gastrointestinal tract and enhancing the overall quality of life for patients. The Colovac and LeakGuard notably diminish the physiological and psychological burdens associated with ileostomy, such as the complexities of stoma management, body image concerns, and the need for subsequent surgical procedures to reverse the stoma.

The CG-100 and C-seal devices introduce alternative mechanisms for the attenuation of anastomotic leakage. The

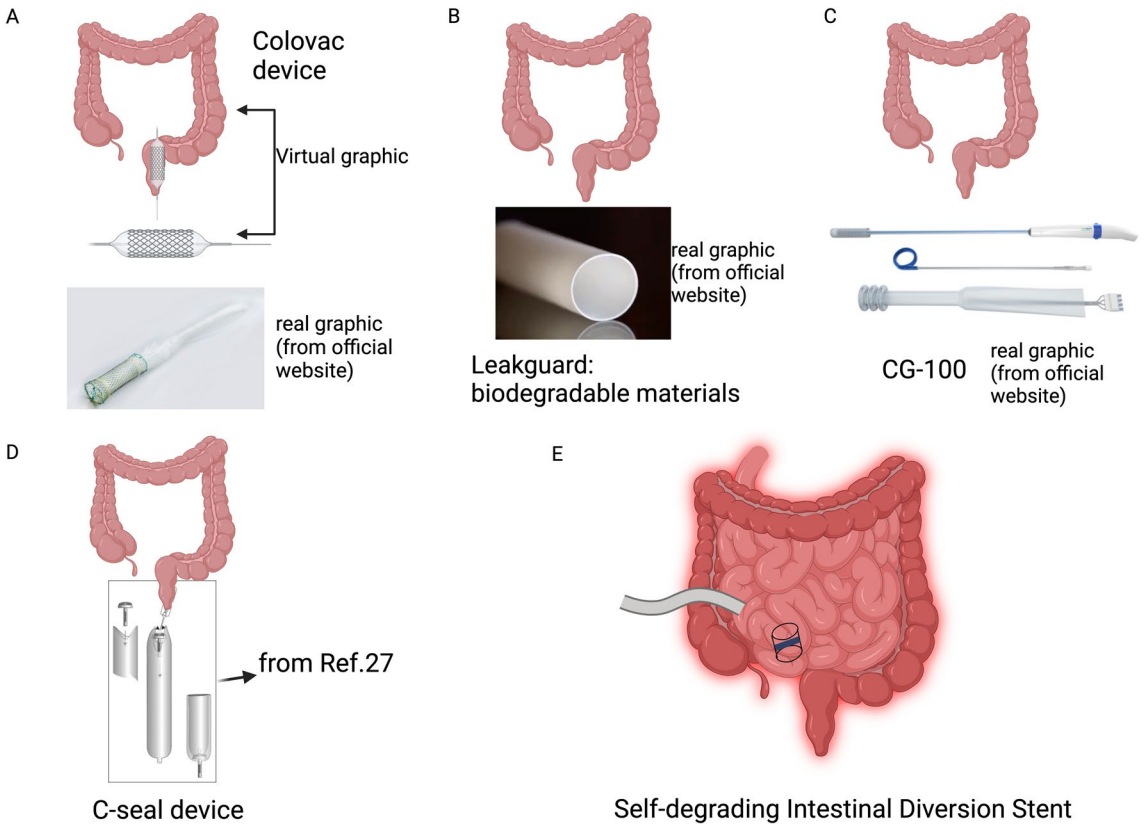


Fig. 1 Current clinical applications to anastomotic protection in colorectal surgery. **A** Colovac device (real graphic from official website, https://www.safeheal.com/); **B** LeakGuard, a biodegradable material (real graphic from official website, https://safeguardsurgical.com/); **C** CG-100 device (real graphic from official website, https://colospan.com/); **D** C-seal device (image refers from Ref.27); **E** schematic diagram of Self-degrading Intestinal Diversion stent

Table 2 Clinical trials involving clinical applications to anastomotic protection in colorectal surgery

Device name	Brief name	Phase	Clinicaltrials.gov Identifier
Colovac	SAFE-1	II	NCT03352570
	SAFE-2	III	NCT05010850
LeakGuard	None		None
CG-100	CLD-001	II	NCT02109991
	CLD-017	II	NCT03423485
	CLD-113	II	NCT05632744
C-Seal*		III	NTR3080(Netherlands)
Self-Degrading Intestinal Diversion stent	SRRSH.SDT	III	NCT06204497

*The C-seal study is registered in the Netherlands

CG-100 employs an innovative sealing mechanism to protect the anastomosis, whereas the C-seal functions as a protective sleeve, physically isolating the anastomosis from intestinal contents. These devices represent less invasive alternatives to conventional methods, aiming to preserve normal bowel function and minimize postoperative complications. These innovations mark a significant departure from existing practices by emphasizing localized, temporary solutions that obviate the need for long-term lifestyle modifications. By maintaining the inherent continuity of the bowel, these devices may significantly reduce the incidence of complications such as bowel obstruction and stoma-associated morbidity.

The Self-degrading Intestinal Diversion stent epitomizes a pioneering approach by incorporating biodegradation into its design, enabling it to offer temporary support without necessitating removal. This innovation has the potential to simplify postoperative care and minimize the need for further interventions, thus distinguishing itself from both traditional ileostomy and other non-biodegradable devices.

These devices are presently undergoing rigorous evaluation in multicenter phase II/III clinical trials (Table 2; detailed descriptions of these clinical studies have been elucidated in the preceding sections). Preliminary findings indicate potential benefits; however, definitive evidence is requisite to substantiate their efficacy in clinical practice. To unequivocally establish the efficacy and safety profiles of these devices, comprehensive comparative studies remain imperative. It is essential to conduct extensive, randomized controlled trials to rigorously evaluate long-term outcomes, including patient quality of life, complication rates, and cost-effectiveness. The expectation is that, with further validation, these devices will substantially benefit patients undergoing LAR by reducing the incidence of anastomotic leakage, thereby mitigating the associated pain and the financial burdens intrinsic to ileostomy.

The ongoing research and development in this field are pivotal, as they hold the potential to precipitate a paradigm shift in the postoperative management strategies for colorectal cancer surgeries. Nevertheless, the multifaceted feature of anastomotic leakage necessitates a comprehensive approach that integrates these advanced devices with meticulous surgical techniques and robust patient management protocols to achieve optimal clinical outcomes.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Ethical approval An ethical exemption was granted for this study.

Competing interests The authors declare no competing interests.

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References

1. De Rosa M, Bugiantella W, Arteritano F, Mariani L, Ermili F, Ceccarelli G (2024) The evolution of minimally invasive robotic surgery in the last 20 years. In: Ceccarelli G, Coratti A (eds) Robotic surgery of colon and rectum. Springer International Publishing, Cham, pp 3–10. https://doi.org/10.1007/978-3-031-33020-9_1
2. Siegel RL, Wagle NS, Cercek A, Smith RA, Jemal A (2023) Colorectal cancer statistics, 2023. CA A Cancer J Clinicians 73(3):233–254. https://doi.org/10.3322/caac.21772
3. Tsalikidis C, Mitsala A, Mentonis VI, Romanidis K, Pappas-Gogos G, Tsaroucha AK, Pitiakoudis M (2023) Predictive factors for anastomotic leakage following colorectal cancer surgery: where are we and where are we going? Curr Oncol 30(3):3111–3137. https://doi.org/10.3390/curroncol30030236

4. He J, He M, Tang JH, Wang XH (2023) Anastomotic leak risk factors following colon cancer resection: a systematic review and meta-analysis. Langenbecks Arch Surg 408(1):252. https://doi.org/10.1007/s00423-023-02989-z
5. Aker M, Askari A, Rabie M, Aly M, Adegbola S, Patel K, Currow C, Nunn R, Hadjittofi C, Rankin A, Halai S, Elsamani K, Bondje S, Mohamed I, Lee J, Wong J, Robertson-Waters E, Uddin A, Hollingshead J (2021) Management of anastomotic leaks after elective colorectal resections: the East of England experience. A retrospective cohort. Int J Surg 96:106167. https://doi.org/10.1016/j.ijsu.2021.106167
6. Phan K, Oh L, Ctercteko G, Pathma-Nathan N, El Khoury T, Azam H, Wright D, Toh JWT (2019) Does a stoma reduce the risk of anastomotic leak and need for re-operation following low anterior resection for rectal cancer: systematic review and meta-analysis of randomized controlled trials. J Gastrointest Oncol 10(2):179–187. https://doi.org/10.21037/jgo.2018.11.07
7. Murken DR, Bleier JIS (2019) Ostomy-related complications. Clin Colon Rectal Surg 32(3):176–182. https://doi.org/10.1055/s-0038-1676995
8. Rubinkiewicz M, Witowski J, Wysocki M, Pisarska M, Kłęk S, Budzyński A, Pędziwiatr M (2019) Investigating risk factors for complications after ileostomy reversal in low anterior rectal resection patients: an observational study. J Clin Med 8(10):1567
9. Lv Q, Shu XP, Peng D, Li SQ, Xiang Z (2024) Predictors of complications after prophylactic ileostomy reversal for rectal cancer: a retrospective study. World J Gastrointest Surg 16(5):1354–1362. https://doi.org/10.4240/wjgs.v16.i5.1354
10. Murphy JB (1895) The use of the Murphy Button. South Med Rec 25(4):215–216
11. Wood JS, Frost DB (1993) Results using the biofragmentable anastomotic ring for colon anastomosis. Am Surg 59(10):642–644
12. Bobkiewicz A, Studniarek A, Krokowicz L, Szmyt K, Borejsza-Wysocki M, Szmeja J, Marciniak R, Drews M, Banasiewicz T (2017) Gastrointestinal tract anastomoses with the biofragmentable anastomosis ring: is it still a valid technique for bowel anastomosis? Analysis of 203 cases and review of the literature. Int J Colorectal Dis 32(1):107–111. https://doi.org/10.1007/s00384-016-2661-z
13. Mu Y, Zhao L, He H, Zhao H, Li J (2021) The efficacy of ileostomy after laparoscopic rectal cancer surgery: a meta-analysis. World J Surg Oncol 19(1):318. https://doi.org/10.1186/s12957-021-02432-x
14. Parini D, Bondurri A, Ferrara F, Rizzo G, Pata F, Veltri M, Forni C, Coccolini F, Biffl WL, Sartelli M, Kluger Y, Ansaloni L, Moore E, Catena F, Danelli P (2023) Surgical management of ostomy complications: a MISSTO-WSES mapping review. World J Emerg Surg 18(1):48. https://doi.org/10.1186/s13017-023-00516-5
15. D'Urso A, Komen N, Lefevre JH (2020) Intraluminal flexible sheath for the protection of low anastomosis after anterior resection: results from a First-In-Human trial on 15 patients. Surg Endosc 34(11):5107–5116. https://doi.org/10.1007/s00464-019-07279-8
16. De Hous N, D'Urso A, Cadière GB, Cadière B, Rouanet P, Komen N, Lefevre JH (2023) Evaluation of the SafeHeal Colovac+ anastomosis protection device after low anterior resection for rectal cancer: the safe anastomosis feasibility evaluation (SAFE) 2019 trial. Surg Endosc 37(9):7385–7392. https://doi.org/10.1007/s00464-023-10272-x
17. Hain E, Lefèvre JH, Ricardo A, Lee S, Zaghiyan K, McLemore E, Sherwinter D, Rhee R, Wilson M, Martz J, Maykel J, Marks J, Marcet J, Rouanet P, Maggiori L, Komen N, De Hous N, Lakkis Z, Tuech JJ, Sylla P, Attiyeh F, Cotte E (2024) SafeHeal Colovac Colorectal Anastomosis Protection Device evaluation (SAFE-2) pivotal study: an international randomized controlled study to evaluate the safety and effectiveness of the Colovac Colorectal Anastomosis Protection Device. Colorectal Dis. https://doi.org/10.1111/codi.17012
18. Surgical S (2024) SafeGuard surgical receives FDA "breakthrough" designation. SafeGuard Surgical https://safeguardsurgical.com/
19. Sciuto A, Merola G, De Palma GD, Sodo M, Pirozzi F, Bracale UM, Bracale U (2018) Predictive factors for anastomotic leakage after laparoscopic colorectal surgery. World J Gastroenterol 24(21):2247–2260. https://doi.org/10.3748/wjg.v24.i21.2247
20. Reshef A, Ben-Arie G, Pinsk I (2019) Protection of colorectal anastomosis with an intraluminal bypass device for patients undergoing an elective anterior resection: a pilot study. Tech Coloproctol 23(6):565–571. https://doi.org/10.1007/s10151-019-02015-9
21. (2014) A prospective, multi-center, single-arm, open-label study designed to evaluate safety, tolerability and performance profile of the Colospan Device CG-100 in patients undergoing colorectal surgery. https://clinicaltrials.gov/study/NCT02109991
22. (2022) Evaluation of CG-100 intraluminal bypass device. https://clinicaltrials.gov/study/NCT05632744
23. (2017) A Prospective, multi-center, single-arm, open-label study designed to evaluate safety and performance profile of the CG-100 intraluminal bypass device in patients undergoing colorectal surgery. https://clinicaltrials.gov/study/NCT03423485
24. Kolkert JL, Havenga K, ten Cate Hoedemaker HO, Zuidema J, Ploeg RJ (2011) Protection of stapled colorectal anastomoses with a biodegradable device: the C-Seal feasibility study. The American Journal of Surgery 201(6):754–758. https://doi.org/10.1016/j.amjsurg.2010.04.014
25. Bakker IS, Morks AN, Hoedemaker HO, Burgerhof JG, Leuvenink HG, Ploeg RJ, Havenga K (2012) The C-seal trial: colorectal anastomosis protected by a biodegradable drain fixed to the anastomosis by a circular stapler, a multi-center randomized controlled trial. BMC Surg 12:23. https://doi.org/10.1186/1471-2482-12-23
26. Morks AN, Havenga K, ten Cate Hoedemaker HO, Leijtens JW, Ploeg RJ (2013) Thirty-seven patients treated with the C-seal: protection of stapled colorectal anastomoses with a biodegradable sheath. Int J Colorectal Dis 28(10):1433–1438. https://doi.org/10.1007/s00384-013-1724-7
27. Bakker IS, Morks AN, Ten Cate Hoedemaker HO, Burgerhof JGM, Leuvenink HG, van Praagh JB, Ploeg RJ, Havenga K (2017) Randomized clinical trial of biodegradeable intraluminal sheath to prevent anastomotic leak after stapled colorectal anastomosis. Br J Surg 104(8):1010–1019. https://doi.org/10.1002/bjs.10534
28. Puntambekar SP, Gandhi NM, Attar MAA, Bharambe S, Sathe R, Panse M, Chitale M, Manerikar K, Inampudi S, Puntambekar A (2023) Intersphincteric resection and coloanal anastomosis in the treatment of distal rectal cancers. Laparosc Endosc Robot Surg 6(2):57–62. https://doi.org/10.1016/j.lers.2023.04.001
29. Song Z, Huang X, Dai S, Tong Y, Cai X (2022) A stent-based diverting technique after low anterior resection of rectal cancer: our preliminary experience. Langenbecks Arch Surg 407(4):1751–1756. https://doi.org/10.1007/s00423-022-02433-8
30. (2023) The safety and efficiency of stent-based diverting technique versus ileostomy in rectal cancer patients: a prospective, multicenter, open-label, non-inferiority, randomized controlled study. https://clinicaltrials.gov/study/NCT06204497
31. Kim IY, Kim BR, Kim YW (2015) The impact of anastomotic leakage on oncologic outcomes and the receipt and timing of adjuvant chemotherapy after colorectal cancer surgery. Int J Surg 22:3–9. https://doi.org/10.1016/j.ijsu.2015.08.017
32. Kingham TP, Pachter HL (2009) Colonic anastomotic leak: risk factors, diagnosis, and treatment. J Am Coll Surg 208(2):269–278. https://doi.org/10.1016/j.jamcollsurg.2008.10.015
33. Law WI, Chu KW, Ho JW, Chan CW (2000) Risk factors for anastomotic leakage after low anterior resection with total mesorectal

excision. Am J Surg 179(2):92–96. https://doi.org/10.1016/s0002-9610(00)00252-x
34. Platell C, Barwood N, Dorfmann G, Makin G (2007) The incidence of anastomotic leaks in patients undergoing colorectal surgery. Colorectal Dis 9(1):71–79. https://doi.org/10.1111/j.1463-1318.2006.01002.x
35. Konishi T, Watanabe T, Kishimoto J, Nagawa H (2006) Risk factors for anastomotic leakage after surgery for colorectal cancer: results of prospective surveillance. J Am Coll Surg 202(3):439–444. https://doi.org/10.1016/j.jamcollsurg.2005.10.019
36. Vignali A, Gianotti L, Braga M, Radaelli G, Malvezzi L, Di Carlo V (2000) Altered microperfusion at the rectal stump is predictive for rectal anastomotic leak. Dis Colon Rectum 43(1):76–82. https://doi.org/10.1007/bf02237248
37. Lucarini A, Guida AM, Orville M, Panis Y (2024) Indocyanine green fluorescence angiography could reduce the risk of anastomotic leakage in rectal cancer surgery: a systematic review and meta-analysis of randomized controlled trials. Colorectal Dis 26(3):408–416. https://doi.org/10.1111/codi.16868
38. Choi HK, Law WL, Ho JW (2006) Leakage after resection and intraperitoneal anastomosis for colorectal malignancy: analysis of risk factors. Dis Colon Rectum 49(11):1719–1725. https://doi.org/10.1007/s10350-006-0703-2

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