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Research progress on intestinal anastomosis technology and related devices

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Highlights

- Continuous suturing in traditional manual suturing shortens operation time and reduces infection risk. Absorbable sutures are preferred for intestinal suturing and anastomosis to minimize foreign body reactions.
- Mechanical anastomosis with linear and circular metal staples offers distinct advantages, while new biodegradable staples demonstrate good performance.
- Magnetopressure anastomosis, leveraging magnetic attraction, has shown success in specific scenarios, providing innovative approaches to intestinal anastomosis.
- Radio frequency energy tissue welding technology enables rapid, seamless intestinal anastomosis, with fewer complications and holds strong potential for future applications.
- The support method for intestinal anastomosis, particularly the “degradable internal stent anastomosis” using a simple support method, shows significant promise in animal studies.

Abstract

This review comprehensively examines current intestinal anastomosis techniques. Traditional manual suturing methods, including intermittent and continuous sutures, provide high flexibility but but vary in infection risk and operation time. Continuous suturing is particularly effective in reducing operative time and infection risk. Suture materials include non-absorbable sutures, absorbable sutures, and natural materials, with absorbable sutures the most preferred for intestinal anastomosis. Mechanical anastomosis has gained widespread adoption, featuring both linear and circular metal staplers. Linear staplers are simple to operate, while circular staplers better align with physiological structures. Materials used in staplers include non-degradable metals (e.g., titanium, titanium alloy) and biodegradable anastomosis (e.g., magnesium alloy). Metal nail anastomosis often results in fewer complications than manual suturing in specific surgeries. Magnetic pressure anastomosis, relying on magnet attraction, has been successfully applied in clinical scenarios following extensive research. The adhesive-based approach involves medical adhesives such as cyanoacrylate and fibrin glue, offering auxiliary support for anastomosis. Energy tissue welding encompasses laser and radio frequency energy tissue welding. While laser welding poses a risk of thermal damage, radio frequency welding offers significant advantages, including faster, seamless anastomosis with reduced complications. The support method for intestinal anastomosis is a novel concept, involving the addition of support materials to the original anastomosis. It can be divided into composite and simple support methods. The simple support method, as evidenced by the “degradable internal scaffold method for digestive tract anastomosis” developed by Cai et al. in China, has demonstrated promising results in animal experiments. In conclusion, selecting the appropriate intestinal anastomosis technique depends on clinical scenarios to optimize surgical outcomes and reduce complications. The diverse technological advancements reviewed here present valuable opportunities for enhancing the quality and safety of intestinal surgery.

Keywords: Intestinal anastomosis technique, manual suture, mechanical anastomosis, magnetic pressure anastomosis, support anastomosis

I Introduction

Intestinal anastomosis is a fundamental surgical procedure that every general surgeon must master. It is among the most common procedures in abdominal surgery. Various methods of

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intestinal anastomosis have evolved, including manual suture, metal nail device anastomosis, and "seamless closure technology". Despite advancements, these techniques cannot entirely eliminate complications such as anastomotic leakage and stenosis [1]. Moreover, with the advent of the "minimally invasive era" in modern surgery, higher standards for intestinal anastomosis have been established [2, 3].

Manual suturing remains a cornerstone technique in intestinal anastomosis, relying heavily on the surgeon's skill to accurately align and suture the intestinal tissues. The two primary suturing methods are interrupted and continuous suture. Interrupted suturing offers high flexibility, allowing adjustment to accommodate the wound's specific characteristics and facilitating effective wound observation during the healing process. However, this method is often time-consuming and more prone to infection. Conversely, continuous suturing reduces operative time, lowers infection risk, evenly distributes tissue tension, and minimizes the formation of dead spaces [4]. The selection of suture material is also critical to the success of manual suturing. Available materials include non-absorbable and absorbable sutures, as well as natural options. Each material offers distinct properties that influence the efficacy of the anastomosis and the patient's recovery trajectory [5].

However, traditional manual stitching is not without limitations. The procedure is relatively complex, necessitating a high level of technical proficiency and experience. Furthermore, it is time-consuming and associated with an increased risk of intraoperative bleeding, which increases the complexity and risk of the operation. To address these challenges, mechanical anastomosis methods, particularly metal staplers, have been developed, marking a significant advancement in intestinal anastomosis [6]. Mechanical anastomosis instruments include linear and circular staplers. Linear staplers are known for their simplicity and efficiency, while circular staplers are designed to align with the intestine's physiological structure, reducing the risk of anastomotic stenosis. The use of staplers has demonstrated clear benefits over traditional suturing techniques, including shorter operation times, fewer postoperative complications, and reduced patient discomfort [7]. Furthermore, the development of biodegradable staples offers new possibilities for improving intestinal anastomosis [8].

Despite the acknowledged benefits, mechanical anastomosis also has drawbacks. For instance, permanent titanium staples may induce inflammatory responses and lead to severe complications [9]. Consequently, exploring innovative anastomosis techniques has emerged as a focus in intestinal surgery research. Magnetopressure anastomosis utilizes magnetic attraction to create an intestinal anastomosis, thus eliminating the need for permanent foreign bodies and introducing a novel approach to this procedure. The intestinal adhesion method, involving medical adhesives such as cyanoacrylate and fibrin glue, serves as a supplementary technique to enhance anastomosis strength and reduces the risk of anastomotic leakage [10, 11]. Energy tissue welding technology, including laser welding and radio frequency (RF) energy tissue welding, employs energy sources such as light and electricity to achieve seamless anastomosis. Additionally, the concept of support-based anastomosis methods, which includes both composite and simple support techniques, offers an innovative strategy for intestinal anastomosis with promising potential.

Despite significant advancements in intestinal anastomosis technology, several challenges remain. Key research areas include improving anastomosis quality and safety to reduce postoperative complications and optimizing the selection of anastomosis methods and materials based on individual patient needs. This article aims to provide a comprehensive review of the current status and research progress of intestinal anastomosis technology. It evaluates the advantages and disadvantages of various techniques and offers insights into both research and clinical practice. The ultimate goal is to drive the continuous development and refinement of intestinal anastomosis methods, contributing to improved patient outcomes.

II Review progress

Traditional manual stitching

Traditional intestinal suture methods

Intestinal anastomosis is a critical step in surgical procedures, with the successful healing of the anastomosis significantly influencing surgical outcomes. Contemporary suturing techniques primarily include interrupted and continuous suture methods.

Interrupted sutures vs. continuous sutures

The history of manual suturing dates back to ancient China, where the renowned physician Hua Tuo is believed to have invented Ma Boiling Powder to aid in patient recovery. Since the

19th century, research on manual sutures for intestinal anastomosis has progressed rapidly [12]. Interrupted suturing is considered a classic method due to its high flexibility. Each stitch is independent, allowing for adjustments based on the wound's specific conditions. Furthermore, it can be applied to wounds of various sizes and shapes and facilitates better observation of the healing process, enabling early detection and treatment of complications. However, a notable drawback is its susceptibility to infection, as dirt and debris can accumulate between knots, necessitating regular cleaning. Additionally, intermittent suturing is more time-consuming than continuous suturing since each knot must be tied individually.

To enhance efficacy and reduce operative time, the continuous suture method was developed. This method not only shortens the operation time but also maintains an intestinal patency rate comparable to that of interrupted sutures. Sert et al. conducted a comparative study, demonstrating that continuous suturing could reduce operation time by 50% [4]. The benefits of this method mainly include even distribution of tissue tension and tighter incision closure.

Suture material

A wide variety of sutures is used in manual suturing, all of which must meet specific criteria. First, sutures must be universal, sterile, non-electrolytic, non-allergenic, and non-carcinogenic to prevent bacterial growth. Second, sutures should be easy to handle, provide secure knotting without wear or cutting, and maintain adequate tension and strength. Third, for intestinal suturing, the material should be absorbed by the body, triggering only a mild biological response or no response [13].

Non-absorbable sutures

Non-absorbable sutures provide long-term support for tissues requiring sustained reinforcement, such as in cardiac or macrovascular surgeries. However, their use in intestinal anastomosis is limited due to the risk of chronic inflammation and foreign body granulomas formation. Nylon, a synthetic polyamide known for its high strength and durability is associated with a significant tissue reaction. Polyester, a synthetic polyethylene terephthalate, offers strength and longevity but also provokes a large tissue reaction.

While non-absorbable sutures offer advantages in scenarios requiring long-term support, their propensity to trigger substantial tissue reaction makes them less suitable for intestinal suturing. This limitation is primarily due to their foreign body response, a characteristic that restricts their broader application in this context.

Absorbable sutures

Absorbable sutures are designed to be absorbed by the body gradually, reducing the risk of long-term foreign body reactions. They are particularly recommended for intestinal anastomosis. VicrylPlus™, developed by Zhao et al. in 2008, contains triclosan, an antimicrobial agent, effectively inhibiting bacterial growth around the sutures [14]. Biosutures, synthesized by Pascual et al. in 2008, is a novel suture that uses adipose-derived mesenchymal stem cells for cladding, promoting intestinal healing through stem cell differentiation [15]. V-LocTM, featuring a barbed design that introduced in 2009 by Demyttenaere et al., eliminates the need for knotting, thereby reducing the risk of anastomosis disruption by knotting. This design facilitates the suturing operation under laparoscopic or robotic assisted suturing, enhancing the ease and efficiency of the procedure [5, 16].

Natural materials

While synthetic materials dominate modern surgical sutures, natural materials continue to hold clinical value in specific contexts. Silk, composed of silk fibroin, a protein with high tensile strength offers durability but are associated with a significant tissue reaction. Additionally, its rapid water absorption nature can lead to swelling, limiting its use in contemporary intestinal anastomosis. Catgut (Gut), made from animal tendon collagen, is absorbable; however, its short absorption time and propensity to elicit tissue reactions have reduced their frequency of use in modern practice. Recent innovations have introduced multifunctional sutures. For instance, antimicrobial-coated sutures, coated with substances like triclosan, can significantly reduce the risk of wound infection, making them suitable for surgeries with a high risk of contamination. Smart sutures, which integrates nanotechnology and shape memory materials, enable real-time monitoring of wound conditions and can release medications on demand, promoting targeted and accelerated healing.

Intestinal mechanical anastomosis

Metal nail stapler

Metal nail staplers are designed to apply pressure to deploy staples that reconnect tissues

through staple deformation, achieving tissue anastomosis. Different structural types, including linear and circular staplers, are developed to match the physiological characteristics of specific anatomical sites.

Linear staplers

The conventional manual suturing techniques are often time-consuming, with a higher risk of intraoperative bleeding. In recent years, gastrointestinal staplers, particularly linear staplers, have become increasingly popular for lateral anastomosis or when tissue resection and anastomosis are required. Common applications include: gastrointestinal bypass procedures (e.g., gastrojejunal anastomosis) to create a wide anastomosis; partial intestine resection with posterior anastomosis to prevent intestinal lumen narrowing; and rectal stump closure during low anterior rectal resection. The mechanism of action of linear staplers involves inserting two rows of interlaced staples into the intestinal wall, facilitating efficient and neat anastomosis. They are simple to operate, enabling quick anastomosis and producing a clean anastomotic line. The selection of stapler depends on the intestinal diameter and specific surgical requirements. For instance, in colon surgery, a linear stapler with a longer staple chamber and wider stich spacing may be more suitable to accommodate the larger diameter of the colon.

Circular staplers

Circular staplers are frequently used for the end-to-end anastomosis of the intestine, offering distinct advantages in specific surgical scenarios, including esophagogastric anastomosis, colorectal anastomosis (especially in cases of narrow pelvic space), and ileal pouch-anal anastomosis to maintain mucosal alignment integrity. The mechanism of action involves a nail seat and a nail bin, where the broken ends of the intestine are secured. Upon firing, a circular stapler anastomosis is achieved in a single step. The primary benefit of circular staplers is their ability to create a round anastomotic connection that closely matches physiological structures, thereby reducing the risk of anastomotic stenosis.

However, it is important to note that circular staplers are not without limitations. For instance, there is a potential for for incomplete anastomosis or leakage if not properly aligned. Besides, the cost of circular staplers is relatively high, which increases the overall cost of surgery.

Anstomosis Material

Traditional non-degradable anastomoses

Titanium and titanium alloys are widely used in traditional non-degradable anastomoses, offering several advantages for gastrointestinal anastomosis. Titanium, with a density of approximately 4.5 g/cm³ at room temperature, provides the ideal balance of strength and lightness, allowing anastomosis nails to remain in the body long-term without adding undue stress. The non-magnetic nature of titanium alloys renders them well-suited for gastrointestinal anastomoses, especially in scenarios involving magnetic resonance imaging environments. The low elastic modulus of titanium alloys enables the material to deform under external forces, which is critical for forming anastomotic pinching and reducing the risk of postoperative leakage. Titanium alloys exhibit excellent resistance to erosin by biological fluids, including intestinal fluid, which ensures long-term durability. Furthermore, high mechanical strength and toughness can maintain the structural stability and functionality of anastomosis nails in complex human environments. Titanium alloys such as Ti-3Al-2.5V and Ti-6Al-4V exibit enhanced mechanical properties while retaining the excellent biocompatibility and corrosion resistance of pure titanium by adding aluminium and vanadium. In the domain of general surgery gastrointestinal reconstruction, titanium alloys are extensively utilised in the fabrication of anastomosis nails, aiding in reliable tissue fixation and effective reduction of postoperative complications. However, the permanent presence of titanium in the human body is associated with certain drawbacks, such as imaging artifacts in CT, which could potentially lead to misdiagnosis, and postoperative complications like congestion, inflammation, and the risk of developing hepatic granulomas [9, 17, 18].

Biodegradable anastomoses

Magnesium alloys have a long history of biomedical exploration, with the earliest documented use dating back to 1907. Zheng et al. implanted tubular magnesium connectors in the stomach and intestines of dogs, demonstrating the preliminary feasibility of magnesium-based implants in the gastrointestinal tract [19]. Nevertheless, the support duration and degradation rate of these implants were highly dependent on their anatomical position and size. Consequently, the utilisation of magnesium alloy in clinical settings necessitates careful consideration of the clinical titanium

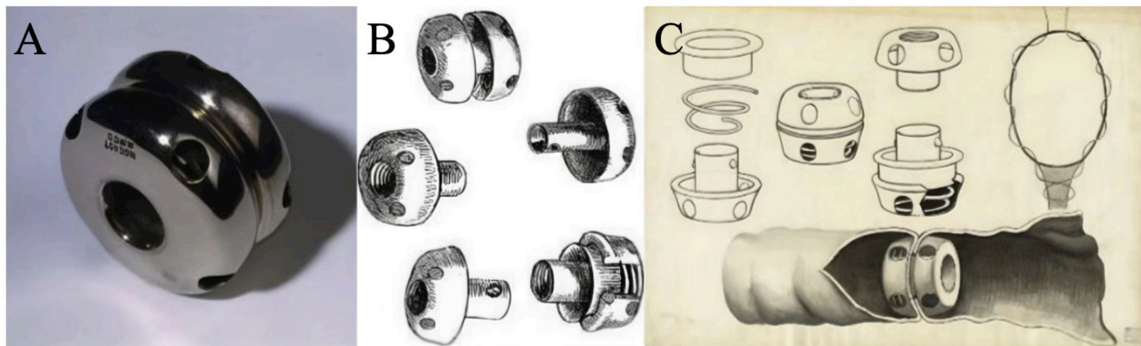

Figure 1. Murphy Button and its operational functionality. (A) Murphy Button in general; (B) Exploded view of the Murphy Button; (C) Schematic diagram of the Murphy Button at work. This figure is adapted from [31].

staple diameter of 0.3 mm, balancing the challenge between effective tissue engagement and optimal device degradation time. Modern advancements in magnesium alloys processing have revitalized interest in their clinical applications, particularly in gastrointestinal anastomosis. Research has focused on enhancing the mechanical strength and biodegradability of high-purity (HP) Mg and its alloys. In 2016, Wu et al. developed a novel HP Mg anastomostomosis device [7]. Qu et al. evaluated the biocompatibility and degradation behaviour of HP Mg staples in small intestinal anastomosis, showing reduced inflammatory responses [20]. Xu et al. reported that adjusting local Mg^{2+} ion concentrations could potentially support anti-tumor therapy [21]. These reports highlight an innovative application of biodegradable magnesium-based materials with numerous benefits.

Recent studies suggest that there is no difference in the complication rate between metal nail anastomosis and manual suturing in gastrointestinal anastomosis, small intestine anastomosis, and colonic anastomosis [6, 22-25]. However, the complication rate of esophagogastric anastomosis and ileocolic anastomosis is lower with metal nail anastomosis than that with manual suturing, which may be related to the improvement of stapler manufacturing processes [26, 27].

Pressurized anastomosis

Regardless of whether manual suturing or mechanical stapling is used, both methods introduce foreign materials to close the intestinal tube, leading to the presence of a foreign body at the anastomosis [28]. In contrast, compression anastomosis; the third generation of anastomosis techniques, offers a method that potentially reduces foreign body residues. This technique is particularly advantageous in intestinal stricture or complex anatomical structures, where avoiding foreign body presence is crucial. Common applications include low recto-anal anastomosis, duodenal, and jejunal anastomosis.

The origins of compression anastomosis date back to the early 20th century, with early experiments involving compression rings for intestinal anastomosis. In 1826, Lambert et al. pioneered the use of compression anastomosis rings, demonstrating the feasibility of this approach [29]. Denan subsequently achieved a seamless intestinal anastomosis using a compression ring in late 19th century. In 1892, Murphy invented the "Murphy Button," a metal anastomosis ring that applied pressure to the anastomotic wall, causing tissue atrophy and necrosis, and allowing the compression ring to eventually detach and enter the intestinal lumen [30]. While effective, the high cost and complexity of the procedure limited its widespread adoption (**Figure 1**) [31]. In the 1980s, research shifted towards magnetic compression anastomosis rings for intestinal anastomosis [32]. The feasibility and effectiveness of this technique were demonstrated in studies [33]. In 1984, the "AKA-2" compression anastomosis ring was developed by Kanshin et al. and gained clinical acceptance [34]. Material science advancements in the 1990s led to the creation of the Valtrac BAR, a biodegradable compression anastomosis ring (**Figure 2A**) [31]. Its anastomosis principle is similar to that of the "Murphy button", but with notable improvements: reduced tissue ischemia and necrosis as well as low incidence of anastomotic stenosis. However, the Valtrac BAR technique is technically demanding. Surgeons must accurately select the size of the anastomosis ring based on intestinal tube diameter and intestinal wall thickness. The gap between the rings must be adjusted manually, relying heavily on the surgeon's experience.

The development of memory alloy pressurized

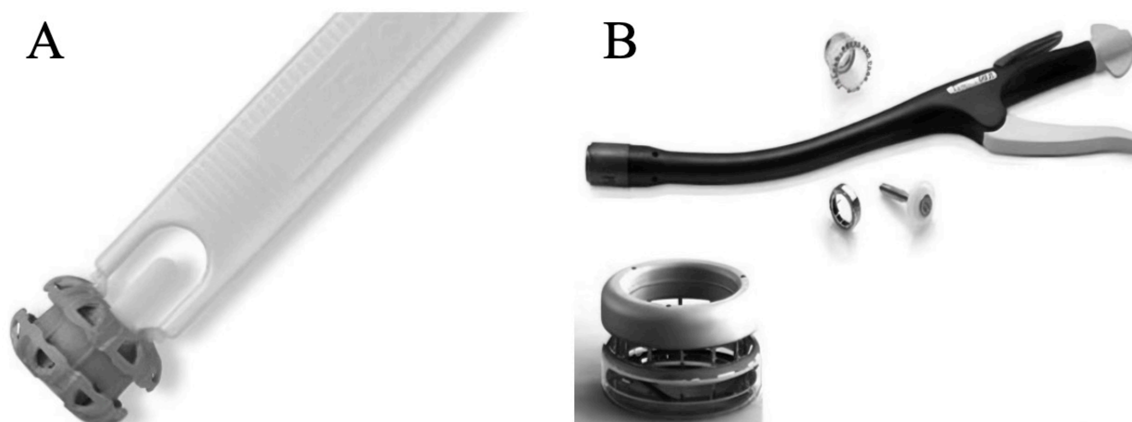

Figure 2. Several typical pressurized anastomosis devices. (A) Valtrac BAR; (B) Ni-Ti memory alloy pressurized anastomosis ring. This figure is adapted from [31].

anastomosis rings represents a significant advancement in compression anastomosis technology. The Nitinol memory alloy pressurized anastomosis ring (**Figure 2B**) was authorised by the China Food and Drug Administration for clinical application [31]. Fudan University Cancer Hospital successfully completed the first clinical anastomosis in Asia using this technology. The Nitinol ring remained in the body for 12-18 days, effectively reducing the risk of anastomotic inflammation [35].

Despite its advantages, the pressurized stapler technique presents several technical challenges, particularly related to the precise alignment of magnets. The dynamic peristalsis of the intestines poses a significant obstacle to the accurate placement of magnets within the internal environment. One potential solution is to employ advanced imaging techniques, such as intraoperative real-time ultrasound imaging, to enhance the visualization of magnet positioning, promoting more accurate alignment during anastomosis procedures. Additionally, the variability in intestinal anatomy, such as curvature and thickness, affect the effective alignment of the magnetic field. To address this, developing magnet systems capable of adjusting magnetic strength and field direction could accommodate anatomical variations among patients, thereby improving the success rate of pressurized stapler anastomosis.

Intestinal adhesion method

Medical adhesives used in intestinal anastomosis can be broadly categorized into two main types: chemical glue (primarily α-cyanoacrylate adhesives; e.g., OB and EC glues) and biological glue (e.g., fibrin sealants).

Cyanoacrylate adhesives

The binding mechanism of cyanoacrylate adhesives involves interaction with proteins present in all cellular structures. Organic amines act as catalysts in the polymerisation of cyanoacrylate monomers, allowing for rapid curing at room temperature. The natural moisture in the body further accelerates the curing process. Conversely, due to its nature as an ester compound, cyanoacrylate demonstrates reduced bonding strength in wet conditions, limiting its use in organs with secretory functions, such as the digestive tract. Currently, α-cyanoacrylate is used solely as an adjunct to manual suturing or instrumental anastomosis, serving primarily to reinforce anastomosis and reduce the risk of anastomotic leakage [10, 36].

Fibrin gule

Fibrin glue is primarily composed of fibrinogen and thrombin, which work together to form a fibrin network upon application to intestinal tissues. When thrombin activates fibrinogen, this network traps surrounding cells and tissues, forming a stable adhesive structure that bonds effectively with the intestinal tissue. The fibrin glue offers several advantages, such as reducing operation time and complexity and minimising tissue damage. However, it is important to note that fibrin glue does have certain drawbacks. Firstly, the adhesive strength of fibrin glue is low compared to traditional suture methods, making it unsuitable for high-tension applications. Secondly, it is more expensive and requires special storage and handling conditions. Currently, fibrin glue is primarily used as an adjuvant in intestinal anastomosis. Subsequent to manual suturing or instrumental anastomosis, it reinforces the anastomosis and helps reduce the risk of anastomotic leakage. In recent years, there have also been reports of "seamless" intestinal anastomosis using fibrin glue-coated collagen patches or fleece [11, 37].

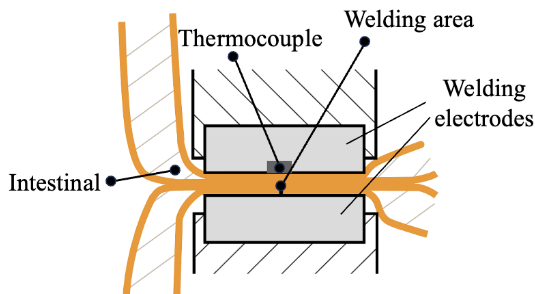

Figure 3. Radiofrequency energy tissue welding.

Energy tissue welding

Energy tissue welding anastomosis involves applying heat energy to tissues using light, electricity, and other energy forms. This process alters the molecular structure of tissue proteins, enabling tissue connection. Two primary methods in this domain are laser welding and RF energy tissue welding.

Laser welding

Laser energy was among the first energy-based methods explored for tissue welding. Compared to conventional manual sutures and mechanical anastomosis, laser welding produces a smoother intestinal wall surface and eliminates foreign body residues, reducing the likelihood of postoperative complications [38]. In the 1960s, Yahr proposed the concept of laser tissue welding [39]. Subsequent research by Cochrane demonstrated that laser anastomosis in rat colons achieved anastomotic strength comparable to manual sutures within 7 days post-surgery [40]. Yamada conducted intestinal closure tests on sick cats and dogs using various laser types, and optimal results were observed at laser power settings of 6-10 W [41]. To boost anastomotic strength, researchers developed techniques to apply biological coatings to the anastomosis site during laser welding. These coatings, such as proteins, help regulate laser energy release by providing feedback signals [42]. Huang et al. used elastin as a binding agent to laser weld the ruptured porcine small intestine, and the experimental results showed that the use of elastin significantly improved the tensile strength and burst pressure of the welded intestinal tissue [43].

Ultrasound energy

Ultrasound energy involves sound waves with frequencies above 20 kHz, which transmit energy through mechanical vibrations. When ultrasound is applied to biological tissues, it produces mechanical, thermal, and physicochemical effects, contributing to tissue cutting and anastomosis. The mechanisms of action include the following asepects. Oscillatory movement: ultrasound induces vibrations that lead to the vaporization of water molecules in tissues; the protein structure is disrupted, acilitating tissue cutting and mechanical separation. Thermal effect: Tissues absorb ultrasonic energy, leading to a temperature increase, which causes denaturation and recoagulation of extracellular matrix proteins, promoting tissue bonding. Physicochemical effect: this enhances protein synthesis, blood vessel formation, and injury repair and healing; the physicochemical changes contribute to stable tissue adhesion, aiding the anastomosis process.

However, the uneven transmission of ultrasonic energy during tissue welding presents a significant challenge in achieving precise control over the welding depth and width, affecting the stability of the anastomosis site. Current ultrasound-anastomosed tissues do not meet the biomechanical demands of normal physiological functions, limiting clinical applicability. In future research, the research direction should focus on developing technologies to ensure uniform distribution of ultrasonic energy, enhancing control over welding precision. Concurrently, new materials that improve the effectiveness of tissue welding and enhance biomechanical strength are also a promising research focus.

RF energy tissue welding

RF energy tissue welding employs electric current to heat biological tissues, a mechanism similar to laser welding. When tissues are heated to a specific temperature range, protein denaturation occurs. By maintaining a uniform and stable temperature, protein reaggregation is prevented, promoting the formation of stable protein linkages and enabling tissue incision anastomosis (**Figure 3**).

In RF tissue welding, the frequency of the RF current is typically 450-500 kHz [44, 45]. Radiofrequency tissue welding, employed in devices like LigaSure (Medtronic), was first used for vascular anastomosis [46, 47]. Building on the success of radiofrequency energy in the domain of vascular anastomosis, researchers have explored its application in intestinal anastomosis. Tu et al. investigated the impact of various control parameters (power, time interval, terminal impedance) on intestinal anastomosis using radiofrequency energy, and employed two indicators, burst pressure and thermal injury, to assess the quality of intestinal anastomosis [48]. The findings revealed that when the power

was set at 100 W, the time interval was 2000 ms, and the terminal impedance was 50 Ω, the maximum burst pressure could reach approximately 8.46 kPa following intestinal anastomosis. Pan et al. conducted intestinal closure experiments on 18 pigs using radiofrequency energy (LigaSure, Valleylab), with traditional manual suturing and mechanical anastomosis serving as control groups [49]. Histological examination showed collagen fibers filling the muscular layer gaps in the RF-welded anastomosis, in comparison to the control groups, indicating superior tissue fusion. Wang et al. used custom RF platform with adjustable voltage, action time, and applied pressure, to assess the effect of RF energy-based anastomosis in the small intestine [44]. The anastomosis quality was evaluated based on burst pressure and microstructure observations. The results demonstrated that maintaining impedance between 61.0 and 86.2 Ω yielded satisfactory anastomosis quality. Lacitignola et al. used RF-based laparoscopic vascular occlusion devices to test small intestine closure in pigs, and demonstrated that the burst pressure of the RF-closed small intestine reached approximately 40 mmHg, demonstrating robust anastomotic strength [50].

RF energy tissue welding technology facilitates rapid and seamless anastomosis of tissues and organs, exhibiting notable advantages, including the absence of foreign body intervention, high initial tensile strength, expedited postoperative healing with minimal complications. This technique holds considerable clinical research value and surpasses alternative anastomosis techniques.

Intestinal anastomosis by the support method

Intestinal anastomosis by the support method is a novel concept involving the placement of a supportive material within the intestinal wall to reinforce anastomosis during traditional anastomotic procedures [29]. This approach is categorized into composite support anastomosis and simple support anastomosis.

Composite support method

The healing process of intestinal anastomosis involves restoring intestinal wall continuity, balancing intraluminal pressure and intestinal wall pressure. From a biomechanical perspective, maintaining this pressure balance is crucial to prevent anastomotic leakage. The principle underpinning this method is that as long as the intestinal wall force at the anastomosis site exceeds the intraluminal pressure, the risk of anastomotic leakage remains low. Traditional techniques such as manual suturing, stapling, bonding, and welding anastomosis all aim to restore this balance by reconstructing the intestinal wall's structural integrity. While not providing strong compressive force, compression anastomosis effectively resists intraluminal pressure, contributing to pressure equilibrium between the intestinal lumen and intestinal wall The composite support method enhances the original anastomosis technique by adding a layer of supportive material. While this reduces the intestinal pressure at the anastomosis to a certain extent, it concomitantly increases the intestinal wall pressure.

Simple support method

The simple support method of intestinal anastomosis represents a significant innovation in traditional anastomotic techniques. This method uses two binding lines (or alternative methodologies) to secure the intestinal wall and support material, thereby establishing a “zero pressure zone” within the intestinal healing region between the two binding lines. This pressure-neutral environment is conducive to optimal tissue healing. A similar bundle anastomosis was first documented in the late 19th century. In 1894, Abbe tied grooved glass tubes to the severed vessel ends and achieved “seamless” end-to-end anastomosis of the blood vessels [51]. In 1980, Payr refined the “Abbe method” using a magnesium ring equipped with a grooved end [52]. This innovation involved initially placing the magnesium ring on the adventitia of the blood vessel during anastomosis, followed by exteriorizing the severed vessel end to expose the intima. The procedure was completed by inserting the contralateral intima of the blood vessel into the exposed intima, thereby achieving a secure and seamless binding.

In China, Peng et al. advanced this concept through the development of the “degradable internal stent gastrointestinal anastomosis”, building upon their prior work with bundled line pancreatic anastomosis and bundled pancreatic-gastric anastomosis [53-55]. Prior animal experiment has demonstrated the safety and feasibility of this method, demonstrating its capacity to complete gastrointestinal, small intestine, and colonic anastomosis in a normal abdominal environment, but also to repair anastomotic leakage or colonic perforation in phase I of infectious environments [56, 57].

III Conclusion

The development of intestinal anastomosis

technology is crucial for advancing intestinal surgery. This paper systematically reviewed and analyzed various intestinal anastomosis techniques, demonstrating that each method has unique advantages and limitations. Selecting the appropriate technique requires careful consideration of clinical factors to optimize surgical outcomes.

(1) Traditional manual suturing constitutes the fundamental method of intestinal anastomosis. Intermittent suture offers high flexibility but is time-consuming and prone to infection. Continuous sutures reduce the operation time and the risk of infection. The selection of suture material is of paramount importance, with absorbable sutures offering distinct advantages in the context of intestinal suturing, thereby mitigating the risk of foreign body reactions. The advent of novel multifunctional sutures expands the possibilities for intestinal anastomosis. However, the technical complexity of manual suturing demands high surgical expertise, potentially limiting its effectiveness in complex surgeries.

(2) Intestinal mechanical anastomosis is a widely applied technique, and the advent of metal nail staplers has significantly improved surgical efficiency. Linear stapler is simple to operate, and the circular stapler anastomosis aligns well with physiological structure. However, there are also limitations, such as incomplete anastomosis, anastomotic leakage, and high cost. The continuous improvement of staple materials, such as the emergence of biodegradable staplers, provides a new solution to the problem of long-term retention of traditional non-degradable stasmosis staples. Nevertheless, the mechanical properties of biodegradable staples still need to be further improved.

(3) Magnetic pressure anastomosis is a novel technique that utilizes magnetic attraction to facilitate intestinal anastomosis, effectively eliminating the risk for foreign body residues at the anastomosis. This technology demonstrates significant potential in specific clinical scenarios. Nevertheless, this technology may still have certain limitations in terms of operation accuracy and scope of application, necessitating further research and clinical trials to refine the technique and expand its applicability.

The adhesion method employs medical adhesives as intestinal anastomosis adjuvants, contributing to reinforced anastomosis and a reduced risk of anastomotic leakage. However, challenges such as inadequate adhesive strength and high cost persist. Energy tissue welding technology, particularly RF energy tissue welding, offers a promising alternative. RF energy welding provides strong initial tensile strength, and no foreign body intervention, making it a viable choice for intestinal anastomosis. However, laser welding is hindered by problems such as thermal damage, which limits its application.

The the support method in intestinal anastomosis is a novel concept, offering innovative approaches through the composite support method and simple support method. For instance, the “biodegradable internal stent gastrointestinal anastomosis” has demonstrated favourable outcomes in animal experiments; however, further clinical studies are required to substantiate its safety and efficacy.

In conclusion, the field of intestinal anastomosis techniques is undergoing continuous evolution, driven by innovative research and technological advancement. The emergence of safer, more effective, and user-friendly methods is expected. These advancements will likely contribute to improved quality of care, reduced complication rates, and better surgical outcome.

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References

[1] Nandakumar G, Stein SL, Michelassi F. Anastomoses of the lower gastrointestinal tract. Nat Rev Gastroenterol Hepatol 2009;6(12):709-716.

[2] Meshikhes AW. Controversy of hand-assisted laparoscopic colorectal surgery. World J Gastroenterol 2010;16(45):5662-5668.

[3] Tavakoli A, Bakhtiari J, Khalaj AR, et al. Single-layer versus double-layer laparoscopic intracorporeally sutured gastrointestinal anastomoses in the canine model. JSLS 2010;14(4):509-515.

[4] Sert G, Aksoyler D, Kara M, et al. Comparison of total anastomosis time between four different combinations of suturing and knot tying techniques in microsurgical anastomosis. J Plast Surg Hand Surg 2023;57(1-6):240-246.

[5] Demyttenaere SV, Nau P, Henn M, et al. Barbed suture for gastrointestinal closure: a randomized control trial. Surg Innov 2009;16(3):237-242.

[6] Zhang Y, Cao J, Lu M, et al. A biodegradable magnesium surgical staple for colonic anastomosis: In vitro and in vivo evaluation. Bioact Mater 2023;22:225-238.

[7] Wu H, Zhao C, Ni J, et al. Research of a novel biodegradable surgical staple made of high purity magnesium. Bioact Mater 2016;1(2):122-126.

[8] Guo H, Hu J, Shen Z, et al. In vitro and in vivo studies of biodegradable Zn-Li-Mn alloy staples designed for gastrointestinal anastomosis. Acta Biomater 2021;121:713-723.

[9] Zhang H, Gao M, Tian X, et al. Study on Mechanical Properties and Degradation Behavior of Magnesium Alloy Vascular Clip. J Funct Biomater 2023;14(10):501.

[10] Paral J, Subrt Z, Lochman P, et al. Suture-free anastomosis of the colon experimental comparison of two cyanoacrylate adhesives. J Gastrointest Surg 2011;15(3):451-459.

[11] Stumpf M, Junge K, Rosch R, et al. Suture-free small bowel anastomoses using collagen fleece covered with fibrin glue in pigs. J Invest Surg 2009;22(2):138-147.

[12] Hardy KJ. A view of the development of intestinal suture. Part II. Principles and techniques. Aust N Z J Surg 1990;60(5):377-384.

[13] Pillai CKS, Sharma CP. Review Paper: Absorbable Polymeric Surgical Sutures: Chemistry, Production, Properties, Biodegradability, and Performance. J Biomater Appl 2010;25(4):291-366.

[14] Zhao YP. The development history, status quo and prospects of sutures in general surgery. Chin J Pract Surg 2008;28(10):789-792.

[15] Pascual I, de Miguel GF, Gómez-Pinedo U, et al. Adipose-derived mesenchymal stem cells in biosutures do not improve healing of experimental colonic anastomoses. Br J Surg 2008;95(9):1180-1184.

[16] Omotosho P, Yurcisin B, Ceppa E, et al. In vivo assessment of an absorbable and nonabsorbable knotless barbed suture for laparoscopic single-layer enterotomy closure: a clinical and biomechanical comparison against nonbarbed suture. J Laparoendosc Adv Surg Tech A 2011;21(10):893-897.

[17] Hu Y, Duan J, Yang X, et al. Wettability and biological responses of titanium surface's biomimetic hexagonal microstructure. J Biomater Appl 2023;37(6):1112-1123.

[18] Wang X, Zhang L, Zhang X, et al. Mg–6Zn alloys promote the healing of intestinal anastomosis via TGF-β/Smad signaling pathway in regulation of collagen metabolism as compared with titanium alloys. J Biomater Appl 2022;36(9):1540-1549.

[19] Zheng YF, Gu XN, Witte F. Biodegradable metals. Mater Sci Eng: R: Rep 2014;77:1-34.

[20] Qu S, Xia J, Yan J, et al. In vivo and in vitro assessment of the biocompatibility and degradation of high-purity Mg anastomotic staples. J Biomater Appl 2017;31(8):1203-1214.

[21] Xu B, Song Y, Yang K, et al. Magnesium metal and its corrosion products: Promising materials for tumor interventional therapy. J Magnesium Alloys 2023;11(3):763-775.

[22] Gao Y, Wang L, Li L, et al. Effect of stress on corrosion of high-purity magnesium in vitro and in vivo. Acta Biomater 2019;83:477-486.

[23] Guo H, Hu J, Shen Z, et al. In vitro and in vivo studies of biodegradable Zn-Li-Mn alloy staples designed for gastrointestinal anastomosis. Acta Biomater 2021;121:713-723.

[24] Anikeev SG, Kaftaranova MI, Hodorenko VN, et al. TiNi-based material with shape-memory effect for surgical treatment of diseases of small intestine in newborn and young children. J Funct Biomater 2023;14(3):155.

[25] Neutzling CB, Lustosa SA, Proenca IM, et al. Stapled versus handsewn methods for colorectal anastomosis surgery. Cochrane Database Syst Rev 2012;(2):CD003144.

[26] Xu QR, Wang KN, Wang WP, et al. Linear stapled esophagogastrostomy is more effective than hand-sewn or circular stapler in prevention of anastomotic stricture: a comparative clinical study. J Gastrointest Surg 2011;15(6):915-921.

[27] Choy PYG, Bissett IP, Docherty JG, et al. Stapled versus handsewn methods for ileocolic anastomoses. Cochrane Database Syst Rev 2011;(9):CD004320.

[28] Ore AS, Althoff A, Kull DR, et al. Comparative early histologic healing quality of magnetic versus stapled small bowel anastomosis. Surgery 2023;173(4):1060-1065.

[29] Ho YH, Ashour MA. Techniques for colorectal anastomosis. World J Gastroenterol 2010;16(13):1610-1621.

[30] Murphy J. An analysis of the cases operated upon with the Murphy Button up to date. Lancet 1895;145:1040-1047.

[31] Wang JL, Xu JK, Hopkins C, et al. Biodegradable Magnesium-Based Implants in Orthopedics-A General Review and Perspectives. Adv Sci (Weinh) 2020;7(8):1902443.

[32] Jansen A, Brummelkamp W, Davies G, et al. Clinical applications of magnetic rings in colorectal anastomosis. Surg Gynecol Obstet 1981;153(4):537-545.

[33] Jamshidi R, Stephenson JT, Clay JG, et al. Magnamosis: magnetic compression anastomosis with comparison to suture and staple techniques. J Pediatr Surg

2009;44(1):222-228.

[34] Kanshin N, Lytkin M, Knysh V, et al. First experience with application of compression anastomoses with the apparatus AKA-2 in operations on the large intestine. Vestn Khir Im I I Grek 1984;132(1):52-57.

[35] Li XX, Cai SJ, Gao J, et al. A prospective study of the application of nickel-titanium memory alloy compression anastomosis ring to intestinal reconstruction after colorectal surgery. Chin J Gastrointest Surg 2011;14(5):330-332.

[36] Bae KB, Kim SH, Jung SJ, et al. Cyanoacrylate for colonic anastomosis; is it safe? Int J Colorectal Dis 2010;25(5):601-606.

[37] Nordentoft T, Rømer J, Sørensen M. Sealing of gastrointestinal anastomoses with a fibrin glue-coated collagen patch: a safety study. J Invest Surg 2007;20(6):363-369.

[38] Alam Z, Mohan M, Pal K, et al. Albumin-PEG-based biomaterial for laser-tissue soldering and its real-time monitoring with swept-source optical coherence tomography. Lasers Surg Med 2021;53(6):815-829.

[39] YAHR WZ, STRULLY KJ, HURWITT ES. Non-occlusive small arterial anastomosis with a neodymium laser. Surg Forum 1964;15:224-226.

[40] Cochrane J, Beacon J, Creasey G, et al. Wound healing after laser surgery: an experimental study. Br J Surg 1980;67(10):740-743.

[41] Yamada E, Sumiyoshi H, Yamaga Y, et al. Bowel welding technique in dogs and cats using a diode laser: an experimental study. J Vet Med Sci 2006;68(7):669-674.

[42] Simhon D, Halpern M, Brosh T, et al. Immediate tight sealing of skin incisions using an innovative temperature-controlled laser soldering device: in vivo study in porcine skin. Ann Surg 2007;245(2):206-213.

[43] Huang H-C, Walker CR, Nanda A, et al. Laser welding of ruptured intestinal tissue using plasmonic polypeptide nanocomposite solders. ACS Nano 2013;7(4):2988-2998.

[44] Wang Y, Liu K, Xiang X, et al. The impedance analysis of small intestine fusion by pulse source. Open Life Sci 2020;15(1):808-818.

[45] Zhao L, Zhou Y, Song C, et al. Predicting burst pressure of radiofrequency-induced colorectal anastomosis by bio-impedance measurement. Physiol Meas 2017;38(3):489-500.

[46] Gentile M, Cestaro G, Velotti N, et al. Lateral internal sphincterotomy (LIS) for chronic anal fissure by LigaSure™ Small Jaws: a comparison with traditional technique. Chirurgia 2022;35(4):213-217.

[47] Dunay MP, Lipcsey Z, Arany-Tóth A, et al. Experimental assessment of three electrosurgical tissue-sealing devices in a porcine model. Acta Vet Hung 2020;68(3):318-322.

[48] Tu L, Zhou Y, Song C, et al. Preliminary study of a control algorithm for radio-frequency-induced intestinal tissue fusion. Int J Hyperthermia 2019;36(1):1296-1305.

[49] Pan H, Leung KK, Ng EKW. Tissue fusion technology versus suture and staple in porcine bowel anastomosis: An in vivo study. Braz J Med Biol Res 2020;53(5):e9305.

[50] Lacitignola L, Imperante A, Trisciuzzi R, et al. Swine small intestine sealing performed by different vessel sealing devices: Ex-vivo test. Vet Sci 2021;8(2):34.

[51] Abbe R. Sarcoma of the kidney; its operative treatment. Ann Surg 1894;19:57-69.

[52] Lee S, Wong L, Orloff MJ, et al. A review of vascular anastomosis with mechanical aids and nonsuture techniques. HNS 1980;3:58-65.

[53] Peng SY, Wang JW, Hong DF, et al. Binding pancreaticoenteric anastomosis: from binding pancreaticojejunostomy to binding pancreaticogastrostomy. Updates Surg 2011;63(2):69-74.

[54] Peng SY, Wang JW, Lau WY, et al. Conventional Versus Binding Pancreaticojejunostomy After Pancreaticoduodenectomy. Ann Surg 2007;245(5):692-698.

[55] Peng S. Binding pancreaticojejunostomy: 150 consecutive cases without leakage. J Gastrointest Surg 2003;7(7):898-900.

[56] Wang Y, Cai X, Jin R, et al. Experimental Study of Primary Repair of Colonic Leakage with a Degradable Stent in a Porcine Model. J Gastrointest Surg 2011;15(11):1995-2000.

[57] Wang Y, Cai X, Cai H, et al. Experimental study of colonic anastomosis with a degradable stent in a porcine model. Am J Surg 2010;199(6):833-839.