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INVITED REVIEW

WILEY

Intestinal surgery in small animals: historical foundations, current thinking, and future horizons

Gary W. Ellison DVM, MS, Diplomate ACVS | **J. Brad Case DVM, MS, Diplomate ACVS-SA** | **Penny J. Regier DVM, MS, Diplomate ACVS-SA**

Department of Small Animal Clinical Sciences, College of Veterinary Medicine, University of Florida, Gainesville, Florida

Correspondence
Gary W. Ellison, Box 100126 Health Science Center, University of Florida, Gainesville Florida, 32610.
Email: ellisong@ufl.edu

Abstract

Intestinal wounds require precise closure after intestinal biopsy, enterotomy, or enterectomy in small animals. Preexisting factors such as intra-abdominal sepsis and hypoalbuminemia as well as poor surgical technique increase the risk of intestinal dehiscence, with considerable negative impact on patient morbidity and mortality. Live dog studies have demonstrated the dangers of mucosal eversion especially in the septic abdomen. Approximating patterns preserve luminal diameter, heal optimally, and have equal bursting strength compared with inverting patterns after 24 hours. Simple interrupted and simple continuous suture patterns and disposable skin staples are established alternatives for manual wound closure. Knotless quilled suture currently used in laparoscopic gastropexy techniques shows bursting strength equal to monofilament sutures in dog cadaveric intestine. Dehiscence rates with hand sewn vs titanium automated stapling anastomosis are similar in uncomplicated cases; however, auto stapling devices may be the preferred method of anastomosis when preexisting abdominal sepsis is present and when patient size allows it. Regardless of the technique, current standard of care involves leak testing and omental wrapping, followed by early postoperative feeding. The past decade has ushered in an exciting new era of laparoscopic assisted techniques that have the potential to reduce postoperative pain and patient morbidity. An understanding of these applications will establish the future of minimally invasive small animal intestinal surgery for veterinary specialists. In summary, surgeons have a variety of methods at their disposal for optimal clinical outcome in small animal intestinal surgery.

1 | INTRODUCTION

Modern veterinary intestinal surgery has evolved in response to time-tested traditional human surgical principles, many of which were based on experimental canine studies. In 1812, after the many failures of anastomosis up to that time, Travers[1] tested an end-to-end suture pattern in dogs and declared that "union of the divided bowel requires the contact of the cut extremities in their entire circumference." Lembert[2] in 1826 suggested that serosa-to-serosa contact was required for proper intestinal healing after performing an inverting anastomosis in dogs. Halstead[3] pointed out in 1887 that the submucosa is the "single tough layer of bowel that must be penetrated by sutures," a principle still adhered to today. In 1951, Gambee[4] described an approximating pattern that engaged the submucosa twice and preserved lumen diameter. Hamilton[5] discovered that dog intestine could be narrowed by 54% with two-layer inverted techniques, by

39% with a single-layer inverted pattern, by 4% with the Gambee, and by 3% with the everted horizontal mattress. The double-layered anastomosis also had poorer bursting strength than either the approximating or the single-layer inverting patterns during the critical lag phase of healing.[5] Inverted anastomosis in dogs was found to create a good serosal seal but also an internal cuff of tissue that initially reduced lumen diameter but after 5 days usually sloughed.[6] Conversely, everted anastomosis caused increased adhesions, delayed wound healing, and, ultimately, did not maintain lumen diameter as well as single-layer inverting patterns.[6] Leak pressures in everting anastomosis were significantly lower than either inverting or approximating patterns immediately after surgery in dogs. The inverting patterns' wound strength was equal to the approximating patterns' strength after 24 hours.[7] In 1967, a single-layer simple interrupted "crushing pattern" was described for use in man.[8] The crushing pattern caused tissue ischemia, mucosal eversion/overlap between sutures, and increased adhesions around the circumference of the anastomosis when tested in dogs.[9] In 1973, Dehoff[10] described a simple interrupted noncrushing approximating technique, which remains popular with small animal surgeons today. In 1981, Jansen and colleagues[9,11] verified that anatomic approximation of the serosa, muscularis, submucosa, and mucosa in dog jejunums allowed for optimal rapid healing characterized by "primary intestinal wound healing."

2 | INTERRUPTED VS CONTINUOUS PATTERNS

Both interrupted and continuous suture patterns are used for intestinal surgery in small animals, but there are few studies comparing the methods. In Hardy's classic dog study,[12] he placed interrupted sutures 2 to 18 mm apart and ran continuous sutures 2 to 14 mm apart. He observed no leakages in the continuous group and noted that, regardless of pattern, the best healing occurred with suture placement no more than 3 mm apart and 3 to 4 mm from the wound edge. Nonomentalized interrupted crushing, interrupted approximating, and continuous approximating suture patterns were compared by using fluorescein dye, micro angiography, and histopathology in dogs.[9] At 72 hours, there was statistically more tissue ischemia with the crushing technique (Figure 1A,B) compared with the appositional techniques (Figure 2A,B). The most consistent tissue apposition occurred with the simple continuous pattern, which allowed for mucosal re-epithelialization and early formation of well-vascularized collagen between the submucosa, muscularis, and serosa.[9] The simple continuous pattern had 40% of its circumference covered with adhesions compared with 70% for the interrupted and 72% for the crushing techniques.[9] The use of continuous patterns was further supported in a retrospective clinical study of 83 intestinal anastomoses.[13] The leakage rate for simple continuous suture was 2%, which was lower but not statistically different from the simple interrupted patterns, which leaked at a rate of 4%.[13]

Recently, four methods of enterotomy closure—simple interrupted, simple continuous, modified Gambee and disposable skin staples—were tested in an ex vivo canine jejunal model. The Gambee took the longest to perform but had statistically higher leak pressure compared with the stapled closure. All constructs exceeded physiologic pressure.[14]

Intestinal wound sites should undergo leak pressure testing at greater than peak normal intestinal peristaltic pressure of 25 mm Hg. Appropriate leak pressures were tested after 6-mm Baker punch biopsy closures in 38 live dogs. Occlusion of a 10-cm length of bowel and injection of 16 to 19 mL of saline with digital compression or 12 to 15 mL of

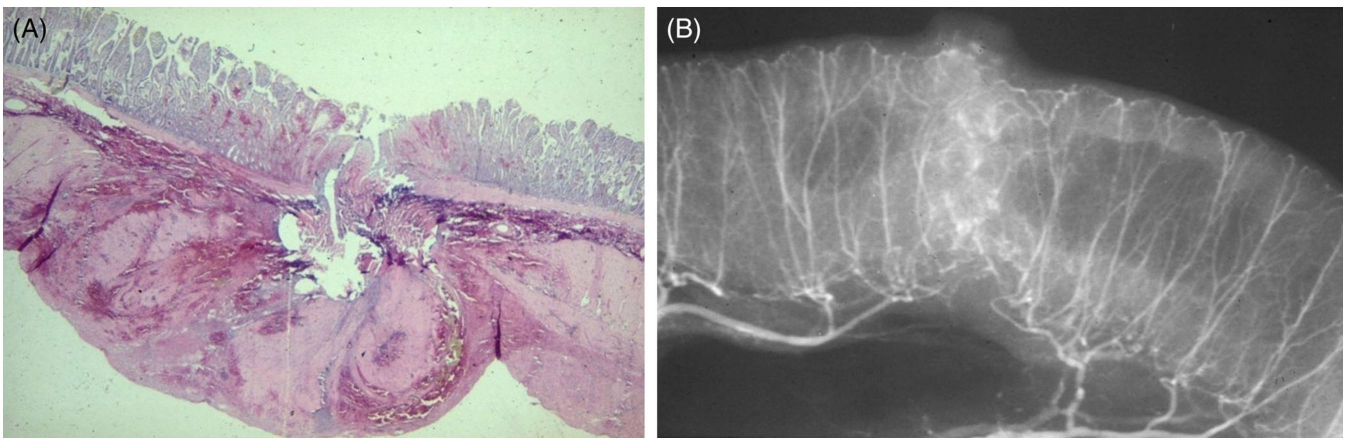

FIGURE 1 **A,** Photomicrograph of a hematoxylin and eosin-stained intestinal wound closed with interrupted crushing suture 7 days postoperatively. Note the continued hemorrhage and necrosis within the muscularis and incomplete establishment of mucosal integrity. **B,** Corresponding microangiography illustrates continued extravastion of contrast material at the anastomosis site

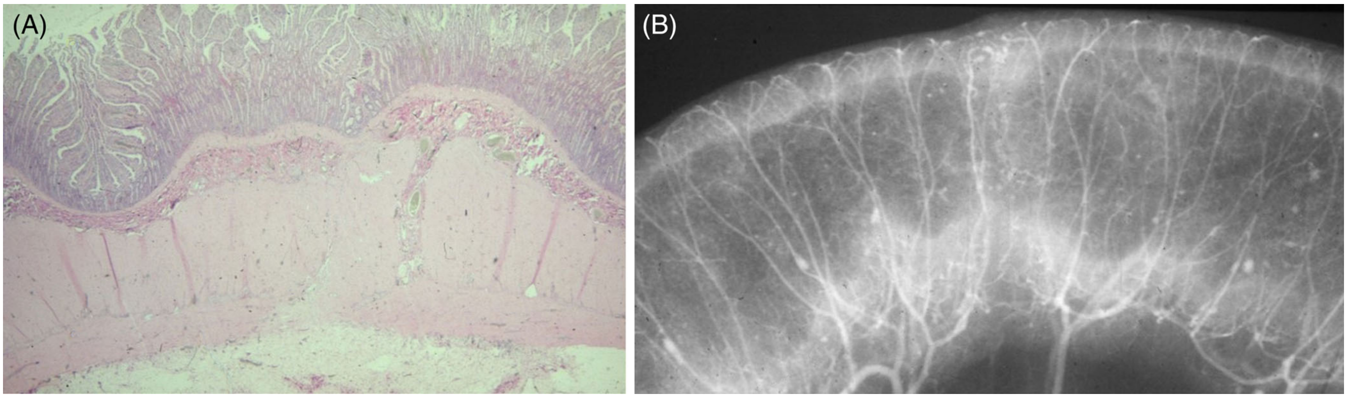

FIGURE 2 **A,** Photomicrograph of a hematoxylin and eosin-stained intestinal wound closed with a continuous appositional suture pattern 7 days postoperatively. Note the rapid reestablishment of mucosal continuity and anatomic alignment of the submucosa. **B,** Corresponding microangiography illustrates good reestablishment of flow across the anastomosis site

FIGURE 3 Leak testing of the anastomosis. Doyen forceps are placed 10 cm apart. Injection of 12 to 15 mL of saline creates intraluminal pressures exceeding 25 mm Hg

saline with Doyen forceps occlusion produces intraluminal pressures of 34 mm Hg[15] (Figure 3).

3 | IMPORTANCE OF OMENTUM IN INTESTINAL HEALING

After experiments in dogs, Senn[16] declared in 1888 that the "omentum should be used to protect intestinal anastomoses," and, in 1906, Morison[17] coined the term "abdominal policeman." A vascularized omental pedicle helps to seal the wound edge, restore blood supply, and facilitate lymphatic drainage.[18] However, free nonvascularized omental grafts are detrimental. In experimental anastomosis of devitalized small intestine in dogs, 11 of 14 dogs with vascularized omental pedicle grafts survived, whereas 15 of 17 dogs with free omental grafts died of anastomotic breakdown.[18] More striking are results of studies in which the omental resection and everting anastomoses were performed. Abramowitz[6] reported that only one of 10 dogs survived with an everted anastomosis, whereas 10 of 10 dogs survived with omentectomy and inverting anastomosis.

When omentum is unavailable or contaminated due to preexisting septic peritonitis, serosal patching will bolster the anastomosis.[19] It was found that placement of serosal patch around a small intestinal anastomosis increased the leak pressure from 28 mm Hg to 82 mm Hg in a canine cadaveric study.[19] A jejunal serosal patch was compared to a jejunal pedicle flap for repair of 50% circumferential duodenal defects in 10 dogs.[20] The vascularized pedicle flap was created by isolating a free segment of jejunum, opening it on its antimesenteric border and suturing its edges to the duodenal defect. The jejunal donor site was then reestablished with anastomosis. Both techniques maintained lumen diameter, but the pedicle flap healed with less inflammation due to mucosa-to-mucosa apposition rather than serosa-to-mucosa apposition characterizing the serosal flap. As an application of this technique, a jejunal patch flap was recently reported for the clinical repair of a large duodenal defect secondary to a foreign body in a dog.[21]

4 | FACTORS AFFECTING INTESTINAL HEALING AND DEHISCENCE

4.1 | Etiology of obstruction, preexisting peritonitis, and hypoalbuminemia

Leakage occurred in 13 of 90 dogs but in 0 of 25 cats in a retrospective study of 115 cases of intestinal anastomosis in dogs and cats.[22] In that study, dogs with preoperative peritonitis, intestinal foreign body, and serum albumin concentration ≤2.5 g/dL were most likely to have leakage of the intestinal wound. In another study of 198 dogs, foreign bodies were protective for intestinal wound failure, with negative survival being associated with hypoalbuminemia ≤2.5 g/dL, hypoproteinemia, and preexisting septic peritonitis.[23] Although albumin is not an essential element of wound healing, it serves as a marker for disease and nutritional status, maintains oncotic pressure, and binds proteins and other substances critical for wound healing[23]

4.2 | Ischemic tissue and massive resection

The classic intraoperative methods for evaluation, including color, temperature, mesenteric arterial pulsations, and the "pinch test for intestinal peristalsis," are not always reliable. Fluorescein dye[9] and surface oximetry[24] have been used experimentally to identify viable tissue within strangulated segments of bowel. If massive intestinal resection is required, the remaining bowel accommodates by luminal dilation, increase in height of the mucosa villi, and slowed peristaltic rate.[25] As little as 50% resection can reportedly lead to short bowel syndrome in some clinical cases,[25] but long-term survival after 85% removal of the small intestine has been reported in dogs,[26] and, likewise, cats can tolerate resections of up to 81%.[27] The single catheter method for removal of linear bodies may obviate the requirement for massive enterectomy in some cats (Figure 4).[28]

4.3 | Effects of early feeding

Early or immediate postoperative feeding via oral, nasoesophageal, esophageal, or gastric tubes is currently considered the postoperative standard of care in small animals. Amino acids provided via enteral nutrition help synthesize hexosamines, proteoglycan polymers, nucleic acids, and structural proteins such as actin, myosin, collagen, and elastin. Bursting pressures and collagen levels of ileal and colorectal anastomosis were compared in beagles fed enteral diets vs those fed only electrolytes and water for 4 days. Dogs that were fed enteral diets had nearly twice the bursting strengths of the control group and nearly double the amount of both immature and mature collagen at the wound site.[29] Conversely, total parenteral nutrition does not appear to improve intestinal healing.[30]

FIGURE 4 A urinary catheter has been sutured to a linear foreign body allowing the foreign body to be disengaged from the mucosa and removed with a single enterotomy

5 | SELECTION OF CLOSURE METHOD

5.1 | Suture material

There are surprisingly few studies in which the efficacy of different suture materials for intestinal closure in small animals have been compared. Chromic gut rapidly loses its tensile strength due to collagenase and dissolves rapidly in the gut lumen.[31] Silk harbors bacteria in its interstices.[31] Monofilament nonabsorbable sutures such as polypropylene create little inflammation and are resistant to contamination.[9] However, polypropylene was associated with plant foreign body adherence in one case series.[32] Synthetic monofilament polyglycolic acid copolymers do not harbor bacteria, are absorbed by hydrolysis, and, therefore, are unaffected by contaminated environment. Absorbable suture materials commonly used include polydioxanone (PDS II; Ethicon, Somerville, New Jersey), polyglactin (Maxon; Medtronic, Minneapolis, Minnesota) Glycomer 631 (Biosyn; Medtronic), and poliglecaprone 25 (Monocryl). Comparative estimated tensile strengths at 2 weeks are 80% for polydiaxanone and polyglactin, 50% for Gylcomer™ 631, and 20% for poliglecaprone 25.[33] Polyglactin 910 (Vicryl; Ethicon) remains 50% tensile at 14 days but is braided and possesses significant tissue drag. However, in one study, polyglactin 910 created less tissue reaction compared with polydioxanone in dog enterotomy closures.[34] Size 4-0 suture material on an RB1 needle or equivalent has been used in cats and small dogs, and 3-0 suture on an SH or SH1 needle is used in larger dogs. Studies comparing leak rates for hand-sewn anastomosis on the basis of suture size alone are lacking in the veterinary literature.

5.2 | Barbed knotless sutures

V-Loc™ (V-Loc wound closure device; Medtronic), Quill™ (Quill knotless tissue-closure device; Surgical Specialties, Wyomissing, Pennsylvania), and Stratafix™ (Stratafix spiral knotless tissue control device; Ethicon) have unidirectional or bidirectional protruding spurs along the surface of monofilament suture with end loops or anchors to obviate knot tying (Figure 5). The spurs engage the tissue throughout the suture line and maintain apposition more consistently compared with smooth suture and provide for more even distribution of tension along wound edges.[35-37] Because of these advantages, barbed suture has gained more widespread interest and use in veterinary medicine. Barbed sutures are used almost exclusively for most intracorporeal laparoscopic gastropexy applications.[38-40] Continuous barbed closures were performed more rapidly and had equal burst pressures compared with similarly sized Glycomer™ 631 sutures in canine jejunum in two in vivo studies in which gastrointestinal (GI) incisions were evaluated.[41,42]

5.3 | Disposable skin staples

Appose ULC disposable skin staplers (Medtronic) have been successfully used in dogs and cats as an alternative to sutured enterotomy[43] or enterectomy.[44] For enterotomy closure, the wound is tensioned on each end with stay sutures, and staples are applied every 2 to 3 mm in linear fashion.[43] For anastomosis, the intestine is triangulated with three stay sutures, and staples are placed every 2 to 3 mm around the perimeter of the wound.[44] In vivo dog studies demonstrate that stapled anastomosis are performed more rapidly than hand-sewn anastomosis with similar bursting strengths.[44] Disposable staplers were used for intestinal anastomosis in 63 dogs in a recent clinical review, and there was a dehiscence rate of only 4.5%.[45] Linear GI incisions were closed in 333 dogs, with a dehiscence rate of rate of only 1.2%. However, the staples anchored a linear foreign body in two cases.[46] The method was also used to close GI incisions in 29 cats without apparent dehiscence.[47]

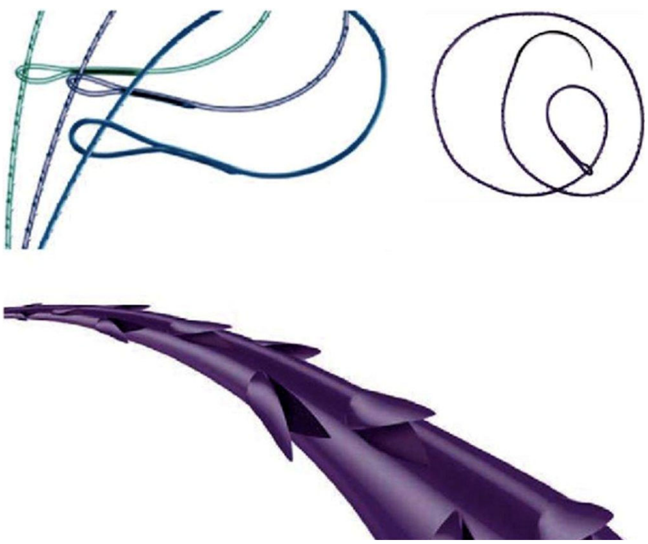

FIGURE 5 The V-Loc wound closure device. The end loop allows a knotless anchor point, and one-way barbs anchor the tissue more securely than monofilament suture and prevent tissue slippage. Image used with permission from Medtronic, Minneapolis, Minnesota

5.4 | Auto stapling applications

Functional end-to-end stapled anastomosis uses a combination of GI anastomosis (GIA) and thoracoabdominal (TA) auto staplers (Medtronic) and is commonly performed in dogs with compromised intestinal tissue. A staple length of 3.8 mm (blue cartridge) is a standard size for use in canine intestinal surgeries and fires a double overlapping row of titanium staples.[48-51]

Reports describe the TA line or the GIA and TA intersection as the highest risk sites for dehiscence (Figure 6).[49-52] For this reason, it is recommended to offset the two GIA staple lines when placing the TA staple line.[53] The GIA line is an inverting closure, whereas the TA line is an everting closure, which is less ideal for mucosal healing

FIGURE 6 Intraoperative image of a completed auto stapled functional end-to-end stapled anastomosis with 3.8mm-GIA and 3.5mm-TA cartridges. The everted mucosa within the TA staple line is the area that is most likely to leak. GIA, gastrointestinal anastomosis; TA, thoracoabdominal

and leads to a prolonged inflammatory response.[54] It has been noted in previous studies that edematous intestines in dogs can be thickened beyond the capacity of the 3.5-mm staples and lead to staple line failure, which is also seen in people suffering traumatic injuries.[55] Staple line oversew is also recommended if staples cannot compress to their closed staple size or compress to a thickness less than the closed staple size.[56] For this reason, some surgeons will reinforce the TA line with a suture oversew in dogs with preoperative peritonitis to protect the TA staple line, as performed in a recent study.[57] The apex of the side-to-side GIA staple line also known as the *crotch area* has also been reported as a high-risk area, and it is recommended to place a suture in this area to reduce tension; however, one study did not see dehiscence in the crotch area.[49]

5.5 | Sutured vs stapled anastomosis

No significant difference was found in dehiscence rates between hand-sewn anastomosis (16%) and stapled anastomosis (11%) in a recent retrospective study in dogs, but a significant difference was found in surgery duration, with a mean duration of 140 minutes for hand-sewn anastomosis and 108 minutes for stapled anastomosis.[58] In another study, the odds for dehiscence were significantly greater for sutured anastomosis (13%) than for stapled anastomosis (5%), and dogs that had surgery for intestinal dehiscence were more likely to have a subsequent dehiscence with a hand-sewn anastomosis.[59] There are a number of proposed advantages of the stapled technique compared with sutured techniques, including short surgical time, consistent staple placement, minimal tissue trauma, preserved blood supply, ease of use for inexperienced surgeons, and the ability to accommodate for lumen disparity.[48-50,56,58,59] Potential disadvantages to using stapling devices are the expense, limited applicability for small dogs and cats, and reports of secondary foreign body obstructions at the previous staple lines.[58]

6 | LAPAROSCOPIC AND LAPAROSCOPY-ASSISTED APPLICATIONS

Laparotomy has long been considered the gold standard for both diagnostic and therapeutic abdominal exploratory surgery. However, laparotomy has been associated with greater morbidity because of longer incisions and postoperative pain compared with comparative techniques with endoscopic approaches in human surgery[60] and in some veterinary reports.[61-63] Concerns regarding ability to access and assess GI tissues in man have been overcome by advances in technology and experience. Laparoendoscopic GI surgery has become the preferred method in many human GI procedures.[64,65] Dogs and cats with obstructive or nonobstructive intestinal disease can likewise benefit from exploratory laparoscopy, which can be performed safely if the minimally invasive surgeon is thorough and possesses sound decision-making ability, including willingness to convert to laparotomy if indicated.[66-72]

6.1 | Patient selection contraindications and conversion rates

Important contraindications to laparoscopic surgery in man include intolerance to pneumoperitoneum, septic peritonitis, linear foreign bodies, and the presence of intra-abdominal adhesions.[60] Adhesions tether bowel to the mesentery, to other bowel segments (enteroenteral adhesions), and to the peritoneum (enteroparietal adhesions), which results in the inability to safely exteriorize and examine bowel.[66,68]

A number of recent reports describe the use of diagnostic and therapeutic laparoscopy-assisted techniques in small animals to explore the GI tract and report excellent outcomes with few complications. Conversion rates reported in these series ranged between 0% and 23%.[66-72] Reported reasons for conversion include linear foreign bodies, foreign bodies involving the ileocecocolic and gastroduodenal regions, hemorrhage, peritoneal effusion, and requirement for additional surgical procedures.[66-72] Low preoperative total solids, presence of a solitary liver tumor, and diagnosis of neoplasia were associated with a conversion rate of 21% in another study.[73] An intestinal lesion diameter of less than 5 cm is thought to be a reasonable upper limit when a laparoscopy-assisted approach is considered in most dogs and cats.[67] In addition to intestinal diameter, the anatomic region of the affected bowel also appears to be important. Dogs and cats with GI lesions affecting the stomach, orad duodenum, or bowel aborad to the ileocolonic junction (ICJ) were not initially thought to be good candidates for a laparoscopy-assisted approach.[66,67,69] However, a recent report describing the addition of a minilaparotomy after single-incision laparoscopic exploratory may represent a compromise approach that may allow access to the stomach and duodenum as part of the extracorporeal assessment.[72]

6.2 | Gastrointestinal exploratory techniques

Both multiple- and single-port laparoscopy-assisted techniques (SILS; Medtronic) are described for GI surgery in dogs and cats. Intracorporeal exploration of the liver, gall bladder, pancreas, stomach, descending duodenum, and colon is followed by extracorporeal evaluation of the jejunum, ileum, and ICJ. (Figure 7A-C)[66,67,69-71] Patient repositioning is required for intracorporeal evaluation of the descending duodenum and colon.[69,73] Extracorporeal evaluation of the

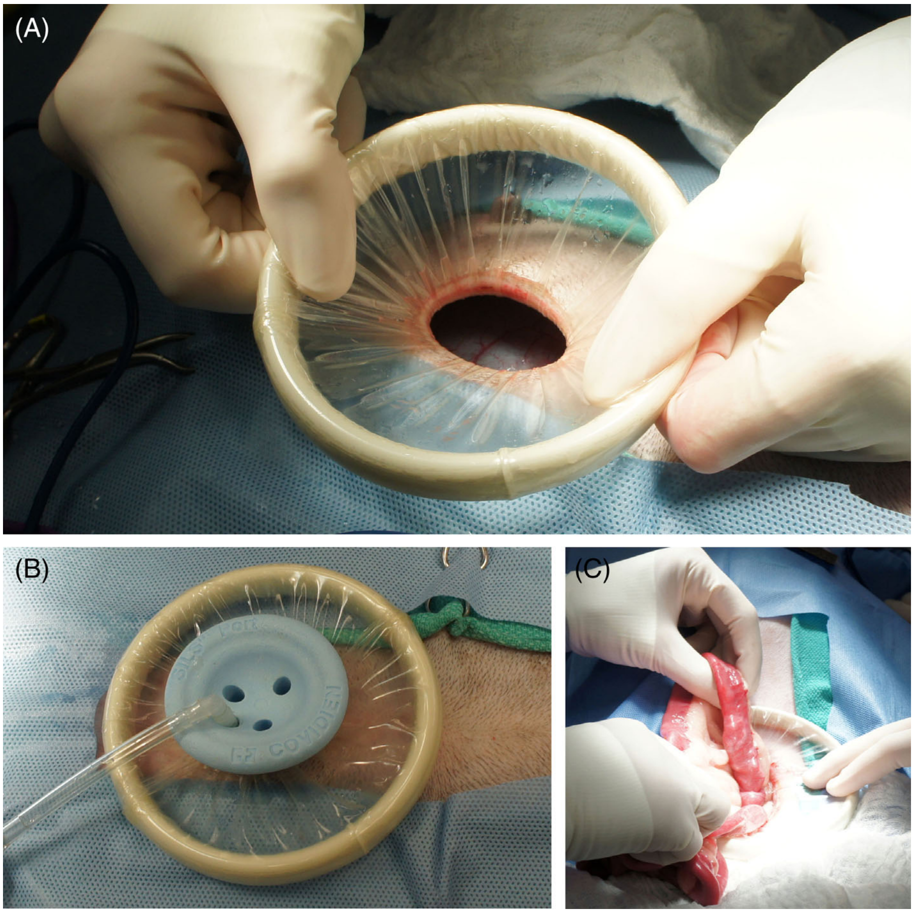

FIGURE 7 **A,** Placement of a small polyester abdominal retractor to facilitate laparoscopic assisted procedures. **B,** A multiport laparoscopic device can be placed into the retractor for insufflation and intracorporeal exploration of the abdomen. **C,** The area of involved intestine can be exteriorized for examination and surgical manipulation

viscera is most often facilitated by the use of polyurethane wound retractors (Figure 7C), although small Gelpi retractors and absence of retractors has also been reported.[66-71] A second variation involves a planned miniature laparotomy with a large wound retractor (5-9 cm), which helps facilitate hand-assisted palpation of cranial abdominal viscera such as the stomach and duodenum.[72] Ten of 13 dogs were successfully treated for intestinal obstruction with this method without operative complications, and surgical time was 75 minutes on average. Three dogs were converted to a laparotomy because of the presence of adhesions and peritoneal effusion. This compares favorably to an earlier study without a planned miniature laparotomy in which average surgical time was 115 minutes for seven dogs, five of which had intestinal obstruction and three of which required minimal enlargement of the incision to facilitate enterotomy or enterectomy.[67] No significant operative complications occurred, and clinical outcome was excellent in both groups. The time required to explore the GI tract was compared by using a single-port approach to laparotomy in 16 dogs in a recent prospective study.[69] Average laparoscopic exploratory time was 36 minutes vs 12 minutes for the open exploratory technique, although exploratory time improved significantly over the course of the study, suggesting a learning-curve effect. Average incision length was only 5 cm vs 16 cm for the laparotomy group. Therefore, although a planned miniature laparotomy (5-9 cm) is larger on average than the single- or three-port techniques, it is still significantly smaller than that reported for exploratory laparotomy.[67,69,72]

Complete intracorporeal exploration is sometimes challenging in obstructive conditions with dilated bowel due to the loss of working room, but is usually possible for nonobstructive enteropathies. It is also well suited for cats and small dogs. An intracorporeal three-port method was used by Mitterman and colleagues[68] to biopsy the stomach and bowel by enlarging one of the cranial portals after the exploratory procedure. In the Mitterman et al[68] study, 85% of the patients were cats with nonobstructive enteropathy; no operative complications occurred, and average surgical time was 95 minutes. Cats with nonobstructive enteropathy were treated with extracorporeal intestinal exploratory surgery in two other studies; complications were rare, and surgical times averaged 65 minutes[71] and 80 minutes.[70] Extracorporeal intestinal exploration is technically easier and faster than intracorporeal exploration, which may account for the reported difference in average surgical time between studies.

7 | SURGICAL PROCEDURES

7.1 | Laparoscopic and laparoscopy-assisted gastrotomy

Intracorporeal laparoscopic gastrotomy for the removal of gastric foreign bodies was described in 20 clinical dogs.[74] In this study, a midline, three-port technique was used, and gastrotomy was closed in a single inverted pattern or with an endoscopic surgical stapler. Foreign bodies were removed by using an endoscopic retrieval bag, and contamination was minimal. Clinical outcome was good in all dogs, with no complications reported. Laparoscopy-assisted gastrotomy has also been reported for gastric biopsy and gastrostomy tube placement.[67,70,71]

7.2 | Enterotomy

Laparoscopy-assisted enterotomy with either multiport[66,68,71] or single-port techniques has been described.[67-69] After intracorporeal exploratory surgery, a segment of jejunum is exteriorized, and the small intestine is run through, eventually leading to extracorporeal isolation of the affected segment of bowel. The assist incision may require minimal enlargement with a polyurethane wound retractor or a planned miniature laparotomy to facilitate exteriorization and to prevent mesenteric strangulation. The affected bowel is isolated and packed off by using laparotomy sponges during the extracorporeal enterotomy. Use of a polyurethane wound retractor is also recommended in cases of GI neoplasia to minimize the risk of incision site metastasis.[66,68,72]

7.3 | Enterectomy and anastomosis

Laparoscopy-assisted intestinal resection and anastomosis is performed in man for small bowel obstruction of various causes including, small bowel tumors, inflammatory bowel disease, and postoperative adhesion formation. In most instances, resection and anastomosis is performed extracorporeally by using standard techniques after the affected bowel has been exteriorized via assist incision. Laparoscopy-assisted enterectomy and anastomosis is performed for small intestinal intussusception, foreign body obstruction, and neoplasia[64,65,70] and can be performed with both hand-sewn or auto stapling techniques.

7.4 | Laparoscopic intestinal biopsy

Dogs and cats with nonobstructive enteropathy represent ideal candidates for laparoscopy-assisted exploratory surgery and biopsy. Three recent reports have documented that diagnostic quality biopsies can reliably be obtained by using laparoscopy-assisted techniques.[68,70,71] Although mostly cats were evaluated in these studies, similar efficacy has been demonstrated in dogs.[67,68,72] Reported diagnostic-quality samples include stomach, duodenum, jejunum, ileum, mesenteric lymph nodes, pancreas, liver, and gall bladder, with no difference in complications compared with open techniques.

7.5 | Complications and outcomes

Reported complications associated with laparoscopic GI surgery in man are limited to inability to evaluate specific regions of the intestinal tract and requirement for conversion to laparotomy (13%)[64,65] or minor incisional alteration (38%).[65] In a retrospective study of intestinal surgery in dogs, hospitalization times between open and laparoscopic groups were no different, but pain was not evaluated.[72] Cats undergoing laparoscopy-assisted exploratory surgery were compared with those with open GI exploration in a recent prospective randomized trial.[71] Complications were rare and similar between groups, but postoperative pain was significantly reduced in cats in the laparoscopic group compared with cats in the open group at 6, 12, and 24 hours after surgery,[71] which is similar to results in cats after gonadal surgery.[61-63] Accuracy and exploratory time between laparoscopic and open techniques in dogs with GI obstruction was compared in another prospective study.[69] Pain was not evaluated, but a significantly shorter incision of 4 vs 16 cm was documented in the laparoscopic group.[69]

In conclusion, small animal surgeons have numerous time-tested and newer options at their disposal to perform intestinal surgery successfully. With hand suturing, adherence to established surgical principles including incorporation of the submucosa, minimization of mucosal eversion, and avoiding over tightening of sutures remains important. Continuous patterns seem to outperform interrupted patterns in most clinical studies but meta-analysis comparing the two is not available. Recent experience with knotless barbed sutures as well as disposable skin staples provides evidence of a potential for reduced surgery time. Leak rates with hand-sewn vs auto stapled anastomosis are similar in most studies, but it appears that automated stapling devices may be the preferred method of anastomosis when preexisting abdominal sepsis is present. Laparoscopy-assisted intestinal techniques offer the potential of a smaller incision size and reduced postoperative pain for small animals that meets inclusion criteria for their use.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest relevant to this Invited Review.

REFERENCES

1. Travers B. *An Inquiry Into the Process of Nature in Repairing Injuries of the Intestines: Illustrating the Treatment of Penetrating*

Wounds, and Strangulated Hernia. London: Longman, Hurst Rees, Orme, and Bacon; 1812.
2. Lembert A. Memoire sur penterorrhaphic. *Rep Gen d'Anat et de Physiol Pathol.* 1826;2:101.
3. Halstead WS. Circular suture of the intestine: an experimental study. *Am J Med Sci.* 1887;94:436-461.
4. Gambee L. A single-layer open intestinal anastomosis applicable to the small as well as the large intestine. *West J Surg Obstet Gynecol.* 1951;59:1-5.
5. Hamilton JE. Reappraisal of open intestinal anastomoses. *Ann Surg.* 1967;165:917-924.
6. Abramowitz HB, Butcher HR Jr. Everting and inverting anastomoses: an experimental study of comparative safety. *Am J Surg.* 1971;121:52-56.
7. Loeb MJ. Comparative strength of inverted, everted, and end-on intestinal anastomoses. *Surg Gynecol Obstet.* 1967;125:301-304.
8. Poth EJ, Gold D. Intestinal anastomosis, a unique technique. *Am J Surg.* 1968;116(5):643-647.
9. Ellison GW, Jokinen MP, Park RD. End to end approximating anastomosis in the dog: a comparative fluorescein dye, angiographic and histopathologic evaluation. *J Am Anim Hosp Assoc.* 1982;18(4):729-736.
10. DeHoff WD, Nelson W, Lumb WV. Simple interrupted approximating technique for intestinal anastomosis. *J Am Anim Hosp Assoc.* 1973;9(5):483-489.
11. Jansen A, Becker AE, Brummelkamp WH, Keeman JN, Klopper PJ, et al. The importance of the apposition of the submucosal intestinal layers for primary wound healing of intestinal anastomosis. *Surg Gynecol Obstet.* 1981;152(1):51-58.
12. Hardy KS. Suture anastomosis: an experimental study using limited suturing of the small bowel in the dog. *Arch Surg.* 1968;97(4): 586-589.
13. Weisman DL, Smeak DD, Birchard SJ, Zweigart SL. Comparison of a continuous suture pattern with a simple interrupted pattern for enteric closure in dogs and cats: 83 cases (1991-1997). *J Am Vet Med Assoc.* 1999;14(10):1507-1510.
14. Kieves NR, Krebs AI, Zellner EM. A Comparison of ex vivo leak pressures for four enterotomy closures in a canine model. *J Am Anim Hosp Assoc.* 2018;54(2):71-76.
15. Saile K, Boothe HW, Boothe DM. Saline volume necessary to achieve predetermined intraluminal pressures during leak testing of small intestinal biopsy sites in the dog. *Vet Surg.* 2010;39:900-903.
16. Senn N. An experimental contribution to intestinal surgery with special reference to the treatment of intestinal obstruction. *Ann Surg.* 1888;1:1-1:21.
17. Morison R. Remarks on some functions of the omentum. *Br Med J.* 1906;1:76.
18. McLackin AD, Denton DW. Omental protection of intestinal anastomosis. *Am J Surg.* 1973;125:134-140.
19. Hansen LA, Monnet EL. Evaluation of serosal patch supplementation of surgical anastomoses in intestinal segments from canine cadavers. *Am J Vet Res.* 2013;74(8):1138-1141.
20. Zialian B, Hosseinzadeh M, Nikravesh B, et al. Assessing two methods of repair of duodenal defects, jejunal serosal patch and jejunal pedicled flap, (an experimental animal study). *J Pak Med Assoc.* 2014;64(8):907-910.
21. Putterman AB, Trumpatori BJ, Mathews KG. Successful vascularized jejunal patch graft to treat severe orad duodenal injury secondary to foreign body obstruction in a dog. *Vet Surg.* In press.
22. Ralphs SC, Jessen CR, Lipowitz AJ. Risk factors for leakage following intestinal anastomosis in dogs and cats: 115 cases (1991-2000). *J Am Vet Med Assoc.* 2003;223(1):73-77.
23. Grimes JA, Schmiedt CW, Cornell KK, Radlinski MA. Identification of risk factors for septic peritonitis and failure to survive following gastrointestinal surgery in dogs. *J Am Vet Med Assoc.* 2011;238(4):486-494.
24. Erikoglu M, Kaynak A, Beyatli EA, Toy H. Intraoperative determination of intestinal viability: a comparison with transserosal pulse oximetry and histopathological examination. *J Surg Res.* 2005;128(1):66-69.
25. Kouti VI, Papzoglou L, Rallis TS. Short-bowel syndrome in dogs and cats. *Compendium.* 2006;28(3):1-10.
26. Chatworthy HW, Saleby R, Lovingood C. Extensive small bowel resection in young dogs: its effect on growth and development. *Surgery.* 1952;32:341.
27. Gorman SC, Freeman LM, Mitchell SL, Chan DL. Extensive small bowel resection in dogs and cats: 20 cases (1998-2004). *J Am Vet Med Assoc.* 2006;228(3):403-407.
28. Anderson SA, Lippincott CL, Gill PJ. Single enterotomy removal of gastrointestinal linear foreign bodies. *J Am Anim Hosp Assoc.* 1992;28(6):487-490.
29. Braga M. Early postoperative enteral nutrition improves oxygenation and reduces costs compares with total parenteral nutrition. *Clin Nutr.* 2001;29:242-248.
30. Peter JV, Moran JL, Phillips-Hughes J. A meta-analysis of treatment outcomes of early enteral versus early parenteral nutrition in hospitalized patients. *Crit Care Med.* 2005;33(1):213-220.
31. Van Winkle W Jr, Hastings JC. Considerations in the choice of suture material for various tissues. *Surg Gynecol Obstet.* 1972; 135:113-126.
32. Milovancev M, Weisman DL, Palmisano MP. Foreign body attachment to polypropylene suture material extruded into the small intestinal lumen after enteric closure in three dogs. *J Am Vet Med Assoc.* 2004;225(11):1713-1715.
33. House A. So many pieces of string—how to choose appropriate suture material. Presented at: The 40th World Small Animal Veterinary Association *Congress*; May 15-18, 2015; Bangkok, Thailand.
34. Kirpensteijn J, Maarschalkerweerd RJ, van der Gaag I, Kooistra HS, van Sluis FJ. Comparison of three closure methods and two absorbable suture materials for closure of jejunal enterotomy incisions in healthy dogs. *Vet Q.* 2001;23(2):67-70.
35. Matarasso A. Introduction to the barbed sutures supplement: the expanding applications of barbed sutures. *Aesthet Surg J.* 2012;33 (3S):7S-11S.
36. Ruff G. Techniques and uses for absorbable barbed sutures. *Aesthet Surg J.* 2006;26:620-628.
37. Paul MD. Bidirectional barbed sutures for wound closure: evolution and applications. *J Am Col Certif Wound Spec.* 2009;1:51-57.
38. Spah CE, Elkins AD, Wehrenberg A, et al. Evaluation of two novel self-anchoring barbed sutures in a prophylactic laparoscopic gastropexy compared with intracorporeal tied knots. *Vet Surg.* 2013;42:932-942.
39. Arbaugh M, Case JB, Monnet E. Biomechanical comparison of Glycomer 631 and Glycomer 631 knotless for use in canine incisional gastropexy. *Vet Surg.* 2013;42:205-209.
40. Imhoff DJ, Cohen A, Monnet E. Biomechanical analysis of laparoscopic incisional gastropexy with intracorporeal suturing using knotless polyglyconate. *Vet Surg.* 2015;44:39-43.

41. Ehrhart NP, Kaminskaya K, Miller JA, Zaruby JF. In vivo assessment of absorbable knotless barbed suture for single layer gastrotomy and enterotomy closure. *Vet Surg*. 2013;42:210-216.
42. Miller J, Zaruby J, Kaminskaya K. Evaluation of a barbed suture device versus conventional suture in a canine enterotomy model. *J Invest Surg*. 2012;25:107-111.
43. Coolman BR, Ehrhart N, Marretta SM. Use of skin staples for rapid closure of gastrointestinal incisions in the treatment of canine linear foreign bodies. *J Am Anim Hosp Assoc*. 2000;36(6):542-547.
44. Coolman BR, Ehrhart N, Pijanowski G, et al. Comparison of skin staples with sutures for anastomosis of the small intestine in dogs. *Vet Surg*. 2000;29(4):293-302.
45. Rosenbaum JM, Coolman BR, Davidson BL, et al. The use of disposable skin staples for intestinal resection and anastomosis in 63 dogs: 2000 to 2014. *J Small Anim Pract*. 2016;57(11):631-636.
46. Schwartz Z, Coolman BR. Disposable skin staplers for closure of linear gastrointestinal incisions in dogs. *Vet Surg*. 2018;47(2):285-292.
47. Schwartz Z, Coolman BR. Closure of gastrointestinal incisions using skin staples alone and in combination with suture in 29 cats. *J Small Anim Pract*. 2018;59(5):281-285.
48. White RN. Modified functional end-to-end stapled intestinal anastomosis: technique and clinical results in 15 dogs. *J Small Anim Pract*. 2008;49:274-281.
49. Jardel N, Hidalgo A, Leperlier D, et al. One stage functional end-to-end stapled intestinal anastomosis and resection performed by nonexpert surgeons for the treatment of small intestinal obstruction in 30 dogs. *Vet Surg*. 2011;40:216-222.
50. Ullman SL, Pavletic MM, Clark GN. Open intestinal anastomosis with surgical stapling equipment in 24 dogs and cats. *Vet Surg*. 1991;20:385-391.
51. Ullman SL. Surgical stapling of the small intestine. *Vet Clin North Am Small Anim Pract*. 1994;24:305-322.
52. Snowdon KA, Smeak DD, Chiang S. Risk factors for dehiscence of stapled functional end-to-end intestinal anastomoses in dogs: 53 cases (2001-2012). *Vet Surg*. 2016;45:91-99.
53. Hansen LA, Smeak DD. In vitro comparison of leakage pressure and leakage location for various staple line offset configurations in functional end-to-end stapled small intestinal anastomoses of canine tissues. *Am J Vet Res*. 2015;76:644-648.
54. Ellison GW. Wound healing in the gastrointestinal tract. *Semin Vet Med Surg (Small Anim)*. 1989;4:287-293.
55. Brundage SI, Jurkovich GJ, Hoyt DB, et al. Stapled versus sutured gastrointestinal anastomosis in the trauma patient: a multicenter trial. *J Trauma*. 2001;51:1054-1061.
56. Tobias KM. Surgical stapling devices in veterinary medicine: a review. *Vet Surg*. 2007;36:341-349.
57. Sumner SM, Regier PJ, Case JB, Ellison GW. Evaluation of suture reinforcement for stapled intestinal anastomoses: 77 dogs (2008–2018). *Vet Surg*. 2019. https://doi.org/10.1111/vsu.13274.
58. Duell JR, Thieman Mankin KM, Rochat MC, et al. Frequency of dehiscence in hand-sutured and stapled intestinal anastomoses in dogs. *Vet Surg*. 2016;45:100-103.
59. DePompeo CM, Bond L, George YE, et al. Intra-abdominal complications following intestinal anastomoses by suture and staple techniques in dogs. *J Am Vet Med Assoc*. 2018;253:437-443.
60. Litwin DE, Cahan M, Sneider EB. Laparoscopic treatment of disorders of the small bowel. In: Swanstrom LL, Soper NJ, eds. *Mastery of Endoscopic and Laparoscopic Surgery*. 4th ed. Williams, & Wilkins: Lippincott; 2014.
61. Case JB, Boscan PL, Monnet EL, et al. Comparison of surgical variables and pain in cats undergoing ovariohysterectomy, laparoscopic-assisted ovariohysterectomy, and laparoscopic ovariectomy. *J Am Anim Hosp Assoc*. 2015;51:1-7.
62. Gauthier O, Holopherne-Doran D, Gendarme T, et al. Assessment of postoperative pain in cats after ovariectomy by laparoscopy, median celiotomy, or flank laparotomy. *Vet Surg*. 2015;44:23-30.
63. Coisman JG, Case JB, Shih A, Harrison K, Isaza N, Ellison G. Comparison of surgical variables in cats undergoing single incision laparoscopic ovariectomy using a LigaSure or extracorporeal suture versus open ovariectomy. *Vet Surg*. 2014;43:38-44.
64. Khaikin M, Schneidereit N, Cera S, et al. Laparoscopic vs open surgery for acute adhesive small-bowel obstruction: patients' outcome and cost-effectiveness. *Surg Endosc*. 2007;21(5):742-746.
65. Delaney CP, Chang E, Senagore AJ, Broder M. Clinical outcomes and resource utilization associated with laparoscopic and open colectomy using a large national database. *Ann Surg*. 2008;247(5):819-824.
66. Gower SB, Mayhew PD. A wound retraction device for laparoscopic-assisted intestinal surgery in dogs and cats. *Vet Surg*. 2011;40(4):485-488.
67. Case JB, Ellison G. Single incision laparoscopic-assisted intestinal surgery (SILAIS) in 7 dogs and 1 cat. *Vet Surg*. 2013;42(5):629-634.
68. Mitterman L, Bonczynski J, Hearon K, Selmic LE. Comparison of perioperative and short-term postoperative complications of gastrointestinal biopsies via laparoscopic-assisted technique versus laparotomy. *Can Vet J*. 2016;57(4):395-400.
69. Barry KS, Case JB, Winter MD, et al. Diagnostic usefulness of laparoscopy versus exploratory laparotomy dogs with suspected gastrointestinal obstruction. *J Am Vet Med Assoc*. 2017;251:307-314.
70. Baron J, Giuffrida M, Mayhew PD, et al. Minimally invasive small intestinal exploration and targeted abdominal organ biopsy with a wound retraction device in 42 cats (2005-2015). *Vet Surg*. 2017;46:925-932.
71. McClaran JK, Skerrett SC, Currao RL, Pavia PR, Tarvin KM. Comparison of laparoscopic-assisted technique and open laparotomy for gastrointestinal biopsy in cats. *Vet Surg*. 2017;46:821-828.
72. Otomo A, Singh A, Valverde A, et al. Comparison of outcome in dogs undergoing single-incision laparoscopic-assisted intestinal surgery and open laparotomy for simple small intestinal foreign body removal. *Vet Surg*. 2018;48(S1):O83-O90.
73. Oramas A, Case JB, Toskich BB, et al. Laparoscopic access to the liver and application of laparoscopic microwave ablation in 2 dogs with liver neoplasia. *Vet Surg*. 2019;48(S1):O91-O98.
74. Lew M, Jalynski M, Brzeski W. Laparoscopic removal of gastric foreign bodies in dogs—comparison of manual suturing and stapling viscerosynthesis. *Pol J Vet Sci*. 2005;8(2):147-153.

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