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Influence of preconstructed effector loop location using a barbed unidirectional suture on leakage pressures following canine enterotomy closure

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Abstract

Objective: To evaluate the influence of preconstructed effector loop location using a barbed unidirectional suture on leakage pressures following canine enterotomy closure.

Study design: Randomized, experimental, cadaveric.

Animals or sample population: Grossly normal jejunal segments from three canine cadavers.

Methods: Jejunal segments were harvested and randomly assigned based upon effector loop location from the beginning of the incisional line. Groups (n = 12/group) included 0 mm, 5 mm, 10 mm, 15 mm, and intact controls (n = 6/group), repaired using a 3–0 unidirectional barbed suture in a simple continuous pattern. Initial leakage pressure (ILP), maximum intraluminal pressure (MIP), repair time, and leakage location were recorded.

Results: Mean ILP for 0 mm group (24.42 ± 8.43 mmHg) was lower ($p \leq .001$) compared to all experimental groups with ILP ~40% lower. There was no difference in MIP among experimental groups ($p = .239$). Repair time increased ($p < .0001$) as the distance of the effector loop increased ≥5 mm from the beginning of the incisional line. Leakage location differed among groups ($p < .001$) with leakage in the 0 mm group from the incisional line (75%), compared to leakage from predominantly from the suture holes in other groups, respectively.

Conclusion: Effector loop location influenced ILP and leakage location. Effector loops placed at the beginning of the incisional line (0 mm) decreased ILP compared to loops placed at 5, 10, and 15 mm.

Clinical significance: Effector loop location using a unidirectional barbed suture should be placed ≥5 mm from beginning of the incisional line for enterotomy closure. Further in vivo studies are necessary to determine the clinical significance of these findings.

1 | INTRODUCTION

Surgical enterotomy is a commonly performed procedure in canine patients to remove foreign body obstructions, biopsy the small bowel or for enteral feeding tube placement.[1] The most common complications following enterotomy closure include dehiscence and resultant leakage that typically occurs 3–5 days following surgical intervention and is a significant cause of surgical morbidity.[2] Enterotomy leakage with ensuing septic peritonitis is the most common complication following gastrointestinal tract surgery in dogs.[1,3] Previous studies have reported the rate of small intestinal dehiscence in dogs to be 3–28%.[3–5] Enterotomy closure techniques using hand-sewn and stapled techniques have been widely reported in dogs,[6,7] with no difference in leakage reported in cadaveric canine jejunal models.[8–11] Following enterotomy closure, establishing a water-tight seal to resist physiologic pressures encountered during active peristalsis is of the upmost importance. In healthy anesthetized dogs without known gastrointestinal disease, physiologic intraluminal pressures are reported to be 15–25 mmHg.[12]

Barbed suture is manufactured using either a unidirectional and bidirectional design that creates barbs that interact with and anchor within apposed tissues.[13] Barbed suture was originally developed for use in minimally invasive surgery due to its knotless design to allow ease of intracorporal suturing.[13] A preconstructed effector loop through which the suture needle passes after the initial suture bite is taken creates an anchor point that provides initial suture security, thus negating the need for knot placement at the initiation of the incisional line.[9,13] Suture knotting reduces the tensile strength of monofilament suture associated with stretching and thinning of the suture material.[9] Barbed polyglyconate is unidirectional in nature meaning that suture passage through intestinal tissues is easily accomplished in a single direction only. Unidirectional barbed suture has resulted in a significant reduction in closure times by 25% for jejunal anastomosis and 32% for total hip and knee arthroplasty closure compared with monofilament suture use in human patients.[14,15] Barbed suture is advantageous for enterotomy closure due to its ability to equally distribute applied force along the entirety of the suture line.[9,10,13–15] When intraluminal pressure is applied to the suture line used for enterotomy closure, barbs grasp the surrounding tissue preventing suture pullout, while evenly distributing tension along the length of the incision,[16] until the force to overcome the barb-tissue interaction is exceeded. The tensile strength is equivalent to those of a barbless suture of the same material that is the same or 1 USP size smaller.[17,18] As barbed suture is passed through jejunal tissues, the suture hole may be greater in size than an equivocally sized monofilament suture. This is due to barbs being wider than the core suture shaft, potentially causing iatrogenic tissue damage.[18] Investigators recently demonstrated that sutured hand-sewn anastomosis using barbed suture showed no difference in initial leakage pressures compared to hand-sewn techniques using monofilament suture and stapled functional anastomosis techniques.[8] In open surgery, barbed sutures have been used for applications in gastrointestinal, urogenital, and tendon repair in prior small animal studies.[8–10,19–22] For laparoscopic application in dogs, barbed suture for the gastrointestinal closure in vivo, demonstrated no difference compared to conventional suture use regarding mean burst pressures and leak pressure assessment at 3, 10, and 21 days following surgery.[23] Although use of barbed suture has gained widespread popularity for use in gastrointestinal surgery, studies have reported that barbed suture should be continued for at least 1–3 bites beyond the termination of the incisional line.[9] At the present time studies differ regarding instituted methods for the initial start location of the preconstructed effector end loop at the beginning of the incisional line.[9,21,24] Canine studies have described effector loop placement at 0 mm,[9] 1 mm,[21] and 5 mm[24] from the beginning of the incisional line for closure of cystotomy and enterotomy incisions. The initial location of the effector loop placement for enterotomy closure is of critical important to evaluate if loop location effects leakage pressures in an open setting to resist normal jejunal physiologic intraluminal pressures (15–25 mmHg).[12] This information is of critical importance to allow leak pressure assessment prior to evaluation for use during laparoscopic procedures.

The objective of this study was to evaluate the influence of preconstructed effector loop location using a barbed unidirectional suture placed at 0 mm, 5 mm, 10 mm, 15 mm from the start of the incisional line on initial (ILP) and maximum leakage pressures (MIP) and leakage location following canine enterotomy closure. Our secondary objective was to evaluate enterotomy closure times associated with different effector loop locations from the start of the incision. Our null hypothesis was that ILP and MIP would not differ among experimental groups while times to complete the simple continuous closure line would increase as the distance from the start of the enterotomy incision increased.

2 | MATERIALS AND METHODS

2.1 | Sample collection

This study was deemed exempt from requiring an IACUC protocol due to the secondary usage of cadaveric tissues.

Three young adult healthy dogs weighing between 28 and 32 kg devoid of known gastrointestinal disease were obtained following humane euthanasia from a local animal shelter. Dogs without known evidence of gastrointestinal disease that were not receiving any medications for at least 1 month were included. Gastrointestinal specimens were harvested within 2 h of euthanasia and tested within 24 h based on the results of previous studies.[24–26] Following open celiotomy the jejunum was isolated from the caudal duodenal flexure to the antimesenteric ileal vessel and the jejunum transected using straight Metzenbaum scissors. All jejunal specimens were visually inspected by a single board-certified surgeon (D.J.D) to ensure no evidence of gross gastrointestinal pathology prior to testing. Following specimen collection, the mesentery was carefully excised at a distance of 1 cm from mesenteric border of the jejunum to avoid tearing and bunching associated with specimen handling. Luminal contents were then milked from intestinal segments and the lumen flushed repeatedly with room temperature (21°C) isotonic 0.9% sodium chloride (NaCl). Jejunal samples were then sharply transected using straight Metzenbaum scissors into 10 cm segments using a surgical ruler (Surgical Ruler, Medline, Northfield, Illinois). Following collection, specimens were mixed and stored in 0.9% sodium chloride (NaCl) in an impervious container prior to testing.

2.2 | Experimental groups

Fifty-four jejunal segments were randomly assigned to four equally sized treatment groups ($n = 12$/group) using a random number generator (https://www.randomizer.org). Six jejunal specimens were randomly selected (two segments/cadaver) to act as a control group to validate our test methodology and to evaluate for ILP and MIP in intact segments. All procedures were performed at room temperature (21°C) under surgical lighting. Segments were occluded with atraumatic straight Doyen intestinal forceps held by a single investigator (Y-J.C). Jejunal segments were treated using a full-thickness enterotomy that was created by making an initial stab incision with an #11 scalpel blade that was then extended to 3 cm using Metzenbaum scissors. (Figure 1A) Enterotomies were performed alongside a mm ruler (Surgical Ruler, Medline, Northfield, Illinois) placed along the antimesenteric border of the jejunal segment.

Residual air or fluid was manually evacuated from the intestinal lumen prior to performance of each assigned closure technique. Enterotomy incisions were then closed using a simple continuous, single-layer appositional pattern using conventional instrumentation in an open surgical setting. All enterotomy closures were performed using 3–0 barbed Polyglyconate (Polyglyconate, V-Loc 180 Absorbable Wound Closure Device, Medtronic) using a swaged V-20 26 mm ½ circle taper needle. The suture line was first secured by passing the needle full thickness through the jejunal tissue, equidistant with the start of the incisional line (0 mm—Figure 1B). The suture needle was then passed through the pre-constructed end loop at which point manual tension was placed on the suture to draw the effector loop tight against the serosal surface of the jejunal segment. Sutures were passed full thickness to ensure engagement of the submucosa. A simple continuous pattern was then performed with suture bites placed 2–3 mm apart and 2–3 mm from edge of the incision. At the termination of the suture line, three additional suture bites were taken as recommended[9] before the suture was cut to a length of 4 mm. All enterotomy closures, were performed by a single board-certified surgeon (D.J.D) familiar with the use of barbed suture aided by a single trained investigator (Y-J.C). Although subjectively assessed, even tension was applied during enterotomy closure to remove suture slack while avoiding iatrogenic crush injury to the intestinal tissues. The time to complete each enterotomy was recorded in seconds (s) using a stopwatch. Four groups were evaluated with the effector loop placed at the start of the incision 0 mm (Figure 1B), 5 mm (Figure 1C), 10 mm (Figure 1D), and 15 mm (Figure 1E) from the beginning of the enterotomy incisional line, respectively.

2.3 | Leakage pressure evaluation

Following enterotomy closure, leakage pressures were evaluated as previously described.[24,27] Two 18-gauge, 1.16-in IV catheters (Insyte, BD Vialon Material, Franklin Lakes, New Jersey) were inserted from the antimesenteric border into the jejunal lumen at an angle of ~45°. One catheter was then connected to a 5 L bag of Hartmann's solution (Vetivex Hartmann's Solution, Dechra, Overland Park, Kansas) mixed with 15 ml of methylene blue dye (Kordon LLC, Hayward, California) connected by a fluid line (Lifeshield Primary Plumset, Hospira, Lake Forest, Illinois). A fluid line primed with 0.9% sodium chloride (NaCl) was connected to a pressure transducer (Logical, Smiths medical, Dublin, Ohio) with the other end attached to the second preplaced catheter. The pressure transducer was connected to a multi-parameter pressure monitor (Passport 2, Mindray North America, Mahwah, New Jersey) and force zeroed at the same height and level as each jejunal segment. During each test, fluid was infused at a rate of 500 ml/h based on the results of prior studies[24,28] while the incisional line and serosal surface was monitored from above for leakage by a single study investigator (D.J.D). A single study investigator (Y-J.C) manually recorded the pressure readings when extraluminal leakage of fluid was observed. ILP was defined as the intraluminal pressure at which dyed fluid was first observed to leak from the jejunal segment. MIP was defined as the maximum intraluminal pressure measured during each test. Leakage location was recorded at the time of testing and included from the preconstructed effector loop, suture holes, or along the length of the incisional line. Control specimens were tested using the same methodology for validation of intraluminal pressure readings and overall assessment of jejunal specimen integrity.

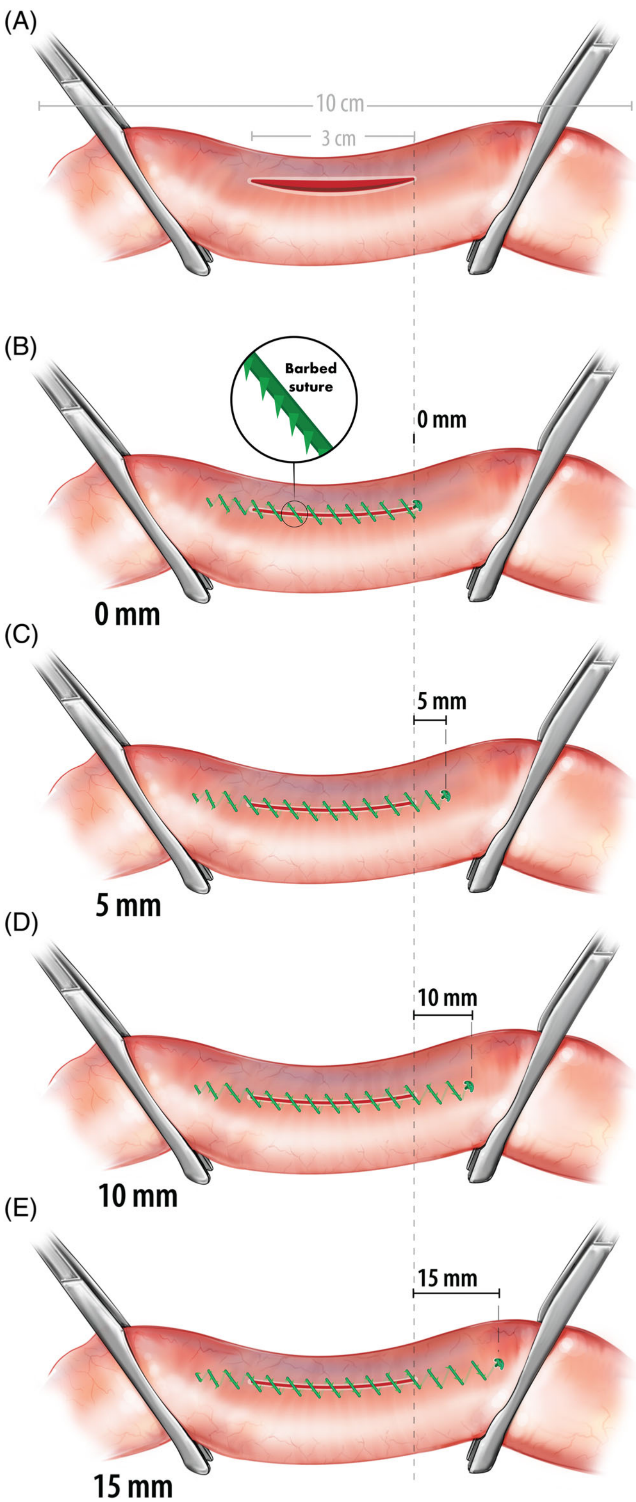

FIGURE 1 Diagrammatic illustration showing enterotomy closure in representative cadaveric canine jejunal segments using 3–0 barbed polyglyconate unidirectional suture. A simple continuous pattern was performed with suture bites placed 2–3 mm apart and 2–3 mm from the edge of the incisional line, and three additional suture bites placed at the termination of the incisional line. (A) A 3 cm incision was performed on the antimesenteric border of the 10 cm long canine cadaveric jejunal segment. The effector loop was placed after the initial tissue bite at a measured distance of (B) 0 mm (equidistant with the start of the incisional line), (C) 5 mm, (D) 10 mm, and (E) 15 mm from the beginning of the incisional line

2.4 | Statistical analysis

A pilot study was performed to determine and refine the method for specimen collection, enterotomy creation, intestinal closure and intraluminal leakage pressure evaluation. A priori power analysis was performed that determined that a sample size of ≥10 jejunal segments/group was required to detect a mean difference of 20 ± 5 mmHg between study groups using an 80% power and an alpha error rate of 5%. Results for ILP (mmHg), MIP (mmHg) were reported as mean ± SD. Distribution of data was assessed for normality using the Shapiro–Wilk test. Experimental group means regarding ILP, MIP, and repair time were compared using a one-way ANOVA. Pairwise comparisons were performed using Sidak-adjusted significance levels. Leakage location was evaluated using a Fisher's exact test. Statistical analysis was performed using commercially available software (Stata/SE, v.15.0, StataCorp, College Station, Texas) with a p value of $\leq .05$ considered statistically significant.

3 | RESULTS

3.1 | Leakage pressure data

ILP differed among experimental groups ($p < .0001$; Table 1). Effector loop location at 0 mm had ILP that were lower compared to effector loops placed at 5 mm ($p = .01$), 10 mm ($p < .0001$), and 15 mm ($p < .0001$) from the beginning of the incisional line, respectively (Figure 2). There was no difference when effector loops were placed at a distance

TABLE 1 Comparisons of the mean ± SD (mmHg) initial leakage pressure (ILP), and maximal intraluminal pressure (MIP) and repair time (s) for jejunal enterotomy closure using 3–0 barbed polyglyconate with the preconstructed effector loop placed at a distance of 0, 5, 10, and 15 mm from the beginning of the incisional line

Experimental group	ILP (mmHg)	MIP (mmHg)	Repair time (s)
0 mm	24.42 ± 8.43[a]	86.58 ± 18.18[a]	142.08 ± 7.53[a]
5 mm	40.75 ± 10.12[b]	97.58 ± 23.04[a]	161.58 ± 9.16[b]
10 mm	48.25 ± 13.94[b]	100.17 ± 19.63[a]	184.33 ± 9.61[c]
15 mm	49.75 ± 14.08[b]	100.83 ± 12.08[a]	213.83 ± 12.63[d]
Control	403.00 ± 80.84[c]	468.33 ± 43.13[c]	N/A

Note: Data for intact control specimens are shown. Different superscript letters denote significant differences between groups for ILP ($p \leq .001$), MIP ($p \leq .001$), and repair times ($p \leq .001$), respectively.

of 5 and 10 mm ($p = .565$), 10 and 15 mm ($p = 1.000$), and 5 and 15 mm ($p = .355$) from the beginning of the enterotomy incision, respectively. ILP for control specimens was 403.00 ± 80.84 mmHg which were greater compared to all other experimental groups ($p < .0001$).

There was no difference in MIP among groups regardless of effector loop distance from the start of the incisional line ($p = .239$; Table 1). MIP of control specimens was 468 ± 43.13 mmHg, which was greater compared to all experimental groups ($p < .0001$).

3.2 | Observed leakage location

Leakage location differed between groups ($p < .001$) based on the distance of effector loop from the beginning of the incisional line. The majority of jejunal sections in the 0 mm group leaked from the initiation of the incisional line (9/12, 75%) under the effector loop. Leakage from the incisional line was observed in 4/12 (33.3%), 1/12 (8.3%), and 0/12 (0%) jejunal segment when the effector loop was positioned at 5, 10, and 15 mm from the beginning of the incisional line, respectively. Leakage occurred from suture holes in 8/12, (66.7%), 11/12 (91.7%), and 12/12 (100%) in the 5, 10, and 15 mm groups, respectively. For control specimens, leakage occurred in 3/6 (50%) following serosal tearing and tissue rupture. The remaining 3/6 (50%) of control segments did not demonstrate evidence of leakage, leading to maximal readings observed on the pressure monitor (500 mmHg).

3.3 | Repair time

There was a difference in repair times among all groups ($p < .0001$). As the distance of effector loop location increased from the start of the incisional line, repair time also increased (Table 1).

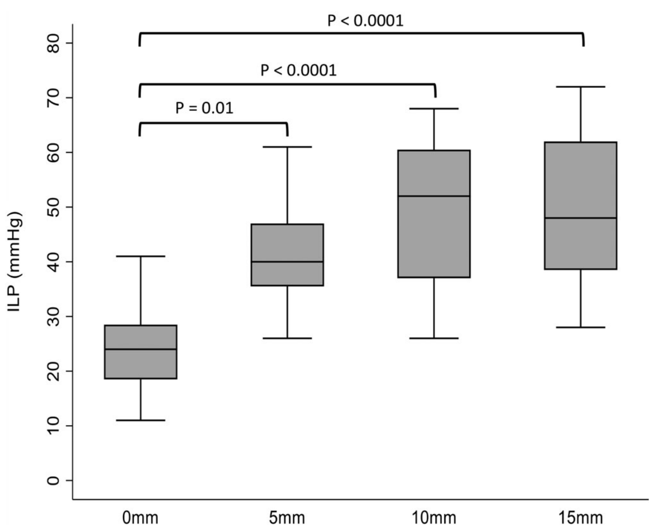

FIGURE 2 Box and whisker plot illustrating the initial leakage pressure (ILP, mmHg) following canine jejunal enterotomy closure using 3–0 barbed unidirectional polyglyconate suture with the preconstructed effector loop placed at a distance of 0, 5, 10, and 15 mm from the beginning of the incisional line. There was a difference in ILP in when the preconstructed end loop was placed at 0 mm compared with other experimental groups ($p \leq .01$). Bars represent significant differences between experimental groups

4 | DISCUSSION

Effector loop location influenced ILP and the location of observed leakage. Effector loops placed at the initiation of the incision line (0 mm) decreased ILP compared to loops placed at 5, 10, and 15 mm from the beginning of the incisional line and increased the incidence of leakage from the incisional line. Effector loop location had no effect on MIP. We therefore rejected our null hypothesis.

In our study, mean ILP among the 5, 10, and 15 mm experimental groups exceeded reported peak physiologic intraluminal pressures, except in the 0 mm group, in which six jejunal segments leaked <25 mmHg. Given our results of ILP occurring at lower than physiologic intraluminal pressure, we conclude that barbed sutured closures may not be able withstand the normal processes of peristalsis thus increasing the risk of intestinal dehiscence.[8,12,29] These results support the placement of the effector loop ≥5 mm from beginning of the incisional line for enterotomy closure when using a unidirectional barbed suture.

To the best of the authors' knowledge, there is currently no consensus regarding the location for the initial location of effector loop at the beginning of the incisional line. In previous studies Kieves et al.,[21] and Duffy et al.,[22] placed effector loops 1 and 5 mm from the beginning of cystotomy incisions in canine and ovine models, respectively.[21,22] For canine enterotomy closure, Ehrhart et al., placed the effector at the beginning of the incisional line (0 mm), however, it should be noted that the effector loop in this study was placed intraluminally with only a limited description of how the barbed suture line was initiated. In studies by Duffy et al.,[24] and Sinovich et al.,[30] investigators placed effector loops at 5 mm from the beginning of the incisional line in dogs and horses, respectively.[22,30] In the present study, mean ILPs in the group 5, 10, and 15 mm were significantly higher than the 0 mm group. This demonstrates that effector loop location is a factor affecting intraluminal leakage pressure assessment. Accordingly these findings may play an important role following enterotomy closure and may inform the methodology of future ex vivo studies.[3,8,29] It should be noted that due to the ex vivo nature of this study the effect of early fibrin seal development and biological factors conferring early resistance to leakage were not assessed.

The canine gastrointestinal tract is typically a low pressure system under normal physiologic conditions with MIP recorded in vivo in the jejunum of normal dogs rarely exceeding 40 mmHg.[12] In our study, MIP values did not differ between experimental groups irrespective of effector loop location from the beginning of the incisional line. Although MIP was lower (86–100 mmHg) than recorded control group values in our study (468.33 ± 43.13 mmHg), recorded MIP in all groups were approximately double that of maximum physiologic pressure during active peristalsis.[12] We hypothesize that these findings may be due to the relatively high rate of fluid infusion into jejunal segments which prevents extraluminal leakage of dyed solution at the same rate through suture holes or from the incisional line. It should be noted that mean MIP among all experimental groups was higher than pressures reported in vivo.[31] Previous studies using barbed suture in a simple continuous pattern were 185.2 ± 67.9 mmHg and 116 mmHg MIP following jejunal enterotomy closure in ex vivo and in vivo canine studies, respectively.[9,10] Differences observed between studies may relate to the rate of fluid infusion used during testing. In the present study, an infusion rate of 500 ml/h was used to infuse jejunal segments compared to rates of 900 ml/h[25] and 999 ml/h[10] used in the aforementioned studies which could account for the observed differences in MIP. The faster the rate of fluid infusion the greater the magnitude of change in MIP that is affected by compliance of the jejunal wall and accommodation of fluid within the luminal space. When comparing our results to those of other investigators using similar methods for intraluminal fluid infusion techniques, results for MIP were in agreement. Variability in MIP seen between studies may be attributable to techniques of anastomotic creation, methods of pressure assessment and rates of fluid infusion into intestinal specimens. These findings, however, highlight the need for species specific research and assessment of procedural methods utilized for future leak pressure studies.

In our study, leakage occurred from the suture holes in 83.3% and 91.7% in the 10 and 15 mm groups, respectively. These observed leakage locations are in agreement with those of prior investigators using barbed suture for canine jejunal enterotomy closure and anastomosis.[8,10,24] These results are also similar to leakage locations reported for smooth suture use for jejunal enterotomy closure.[8,10,27] In our study, the location of leakage differed depending on the initial location of the preconstructed loop. Unlike the 10 and 15 mm groups, the predominant leakage location in the 0 mm group was from the beginning of the incisional line in 75% of enterotomy closures. The cause of these observed findings in the 0 mm group likely relate to the fact that barbed polyglyconate is devoid of barbs immediately adjacent to the pre-constructed end loop, representing a point of uneven tension distribution.[22,32] It should be noted that in the 5 mm group leakage occurred predominantly from the suture hole associated with the preconstructed loop. Use of bidirectional suture material, which eliminates the end-loop configuration, may also obviate the observed pattern of leakage seen in this study and is an area for future investigation.

Not surprisingly, repair times in our study increased as the distance of the pre-constructed loop was placed at greater distance from the beginning of the incisional line. This information is clinically relevant as there is no benefit regarding enterotomy leakage to positioning the preconstructed end loop >5 mm from the beginning of the incisional line.

Limitations of this study include its ex vivo nature and the nonphysiologic method of leakage pressure assessment. Use of ex vivo modeling precludes a true understanding of barbed suture behavior and intestinal healing in vivo. It is plausible that different results may be obtained in vivo due to the regenerative response of the intestinal wall and rapidity of fibrin seal development following repair. Although histopathological assessment to confirm absence of microscopic disease was not performed due to visually normality of jejunal segments. We acknowledge that leakage pressure testing may lead to different results in canine jejunum affected by neoplastic, inflammatory or infiltrative disease or enterotomy closure using different suture patterns such as the modified Gambee. Various factors may be associated with the postoperative dehiscence in clinical cases, and surgeons are advised to assess other variables such as preoperative peritonitis, intestinal foreign body obstruction, and serum albumin concentration < 2.5 g/dl.[3] In clinical cases enterotomies are routinely reinforced using techniques such as serosal patching or omental wrapping,[33] which have previously been shown to increase ILP following simple continuous enterotomy closure, however these techniques were not examined.

In conclusion, the location of the preconstructed effector loop influenced ILP and the location of observed leakage. Effector loops placed at the initiation of the incisional line (0 mm) decreased ILP compared to loops placed at 5, 10, and 15 mm from the beginning of the incisional line. For enterotomy closure the preconstructed end loop using a unidirectional barbed suture should be placed at a distance of ≥5 mm from beginning of the incisional line. Future studies investigating barbed suture use as an intracorporeal device for enterotomy closure are warranted to determine the clinical significance of these findings and the effectiveness and practicality of this barbed suture in a clinical setting.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Chang, Y.J., BVetMed, MS: Contributions included acquisition of data, interpretation of the data, writing and revising the manuscript, and approval of the final version to be published. Duffy, D.J., BVM&S (Hons.), MS, FHEA, MRCVS, DACVS-SA, DECVS: Contributions include design of study performed and study methodology, construct suturing, acquisition of data, analysis and interpretation of data, writing and revising the manuscript, and approval of the final version to be published. Moore, G.E., DVM, PhD, ACVIM (SAIM): Contributions includes statistical analysis, review of the manuscript and approval of the final version to be published.

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