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EXPERIMENTAL LAB RESEARCH

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Gastrointestinal thickness, duration, and leak pressure of five intestinal anastomosis techniques in cats

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Abstract

Objective: To compare time to construct completion and resistance to leakage for five intestinal anastomosis techniques in cats and to report normal feline gastrointestinal thickness.

Study design: Experimental study.

Sample population: Grossly normal intestinal segments ($n = 120$) from 10 fresh cat cadavers.

Methods: A total of 8 cm segments of fresh feline cadaveric intestine were collected, and mural thickness was recorded. Segments were randomly allocated between a control group ($n = 20$ segments) and five treatment groups (20 segments/group with 2 segments/construct = 10 constructs per group): (1) hand-sewn anastomosis – simple interrupted (HSA-SI), (2) hand-sewn anastomosis – simple continuous (HSA-SC), (3) functional end-to-end stapled anastomosis (FEESA), (4) functional end-to-end stapled anastomosis with oversew (FEESA-O), (5) skin stapled anastomosis (SS). Time to construct completion, leakage location, initial leak pressure (ILP), and maximum intraluminal pressure (MIP) were compared.

Results: Mean mural thickness ± SD (mm) for the stomach, duodenum, jejunum, and ileum were 1.66 ± 0.28, 2.05 ± 0.18, 2.28 ± 0.30, and 2.11 ± 0.39, respectively. ILPs (mean ± SD) for HSA-SI (165 ± 122 mmHg), HSA-SC (149 ± 83), FEESA-O (63 ± 25, FEESA (84 ± 59), SS (77 ± 56), and control segments (>500) were compared. There was no statistically significant difference in ILP ($p > .08$) or MIP ($p > .084$) between any treatment groups. Nonoversewn FEESAs were 2.4 times faster to perform compared to oversewn FEESA and SS groups, and 4.7 times faster than HSA ($p < .001$).

Conclusion: All anastomosis techniques provide resistance to leakage that is supraphysiological to that of the normal maximum intraluminal pressure. HSA take longer to complete than stapled anastomoses.

Clinical significance: All anastomotic techniques may be appropriate in cats. Hand-sewn anastomoses result in a longer surgical time.

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1 | INTRODUCTION

Intestinal resection and anastomoses are commonly performed in both dogs and cats for the treatment of a variety of conditions, including gastrointestinal obstruction, linear foreign bodies, trichobezoars, focal intestinal neoplasia, feline infectious peritonitis, megacolon, irreducible intussusceptions, and for the removal of ischemic, necrotic, or fungal infected sections of intestine.[1–5]

Dehiscence is the most significant major complication following gastrointestinal (GI) surgery.[4,6] Historically, complications following GI surgery in cats have been reported at lower frequencies than in dogs.[4,6–8] Despite the low reported rate of dehiscence in cats, this complication is catastrophic when it occurs, with a reported mortality rate of 69%–80% in dogs and cats following gastrointestinal surgery.[4,9,10]

In veterinary medicine, anastomosis is generally performed by hand-suturing or via the use of stapling devices.[9,11–14] Stapled anastomoses carry the potential benefits of decreased surgical time, reduced tissue trauma, ease of addressing luminal disparity, and preservation of vascular supply.[11,14] In veterinary medicine, stapled anastomoses are traditionally performed as functional end-to-end stapled anastomoses (FEESA), a technique which utilizes a gastrointestinal anastomosis stapler (GIA).[11] In cats, smaller intestinal lumens may necessitate the use of endoscopic-GIA staplers, which can be prohibitively expensive or unavailable in some facilities.[15] Other described methods of stapled anastomoses include the use of thoracoabdominal staplers or skin staples.[11–13,16,17] Due to fixed staple height and need to adequately engage the submucosa as to not cause either leakage or necrosis of the anastomosis site, it is of utmost importance to understand normal feline intestinal thickness, which should be taken into account when selecting staple size.[11,18]

The objective of this study was to compare the initial resistance to leakage and time of construction of various methods of feline intestinal anastomosis, including traditional FEESA with TA staplers and endoscopic GIA staplers, oversewn FEESA, hand-sewn techniques, and skin staples. Additionally, samples of feline gastrointestinal tissue were collected, and the thickness of the tissues was measured at various levels of the gastrointestinal tract. We hypothesized that hand-sewn anastomoses would have higher leak pressures than stapled anastomoses, among which oversewn FEESA would have higher resistance to leakage than skin stapled or traditional FEESA. Our second hypothesis was that traditional FEESA would have a more rapid surgical time than oversewn FEESA or skin stapled techniques, and that all techniques would be faster than hand-sewn anastomoses. Finally, we hypothesized that feline gastrointestinal tissue would be thicker than that of humans and similar to canines.

2 | MATERIALS AND METHODS

2.1 | Specimens

This study was approved by the University of Florida Institutional Animal Care and Use Committee (no. 202111512). A total of 10 adult domestic shorthair feline cadavers were included in this study. All cats were subjectively similar in size, skeletally mature, and of an appropriate body condition score (4–5/9). All cats had grossly normal small intestinal and gastric tissue. The cats were obtained from a local shelter (Gainesville, Florida) and were euthanized with an IV infusion of pentobarbital-phenytoin sodium for reasons unrelated to the study. All GI samples were harvested within 6 h of euthanasia and flushed with isotonic saline (0.9% NaCl solution).

2.2 | Thickness measurements

All thickness measurements were obtained within 12 h of harvest. The stomach was transected perpendicularly to the long axis of the greater curvature at the level of the midbody. Thickness measurements were made on either side of the cut inbetween rugal folds.

Representative samples from the midpoint of the duodenum, jejunum, and ileum were also sharply transected and measured. On either side of the transection, measurements were performed at the 12, 3, 6, and 9 o'clock positions, with the 12 o'clock position correlating with the antimesenteric border. Thus, there were a total of eight measurements taken of each section. All measurements were recorded in millimeters by a single investigator (J.E.S.) using an electronic caliper (Fisher Scientific, Hampton, New Hampshire).

2.3 | Small intestinal segmentation and allocation

Twelve 8-cm long sections of jejunum were sequentially harvested from each cadaver for a total of 120 segments. All intestinal segments were stored at 4°C in 0.9% NaCl until construct assembly within 24 h of harvesting based on previous studies demonstrating consistent resistance to leakage between cooled jejunal segments and fresh specimens.[19,20]

Two segments from each cadaver were randomly assigned to a control group. The rest of the segments from each cadaver were distributed throughout each of the five treatment groups. Thus, each cadaver yielded two control segments and five anastomosed constructs:

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(1) hand-sewn anastomosis via a simple interrupted technique (HSA-SI) ($n = 10$ constructs), (2) hand-sewn anastomosis via a simple continuous technique (HSA-SC) ($n = 10$ constructs), (3) functional end-to-end stapled anastomosis with oversew (FEESA-O) ($n = 6$ constructs), (4) functional end-to-end stapled anastomosis without oversew (FEESA) ($n = 6$ constructs) and (5) skin stapled anastomosis (SS) ($n = 10$ constructs).

In intestinal samples from 4/10 cadavers, application of the Endo GIA stapler was not possible because of serosal tearing during insertion of the device into the intestinal lumen or the inability to insert the device into the lumen at all.

All anastomoses were constructed by a single, board-certified veterinary surgeon (P.J.R.). Time of construction was recorded from the time the first suture was passed through the intestine or from when the first limb of the GIA was inserted into an intestinal lumen until the last tag of suture was cut or the transverse staple line had been deployed and tissue cut along the stapler in the case of nonoversewn FEESA constructs.

2.4 | Intestinal anastomosis construction

2.4.1 | Hand-sewn anastomosis via a simple interrupted technique (HSA-SI)

Hand-sewn anastomoses were performed according to a standard surgical technique with 4–0 glycomer 631 (Medtronic, Minneapolis, Minnesota) swaged onto a CV-23 half-circle, 17-mm tapered needle in a single-layer simple interrupted appositional pattern. Starting at the mesenteric border, knots were placed every 2–3 mm. Bites were taken 2–3 mm from the transected tissue edge. Care was taken to ensure that each bite engaged the submucosa. Each knot was tied with four square throws.

2.4.2 | Hand-sewn anastomosis via a simple continuous technique (HSA-SC)

Hand-sewn anastomoses were performed according to a standard surgical technique with 4–0 glycomer 631 (Medtronic, Minneapolis, Minnesota) swaged onto a CV-23 half-circle, 17-mm tapered needle in a single-layer simple continuous appositional pattern. In these constructs, one line of suture began at the mesenteric border and a second line at the antimesenteric border. Knots were tied with four square throws at the beginning and end of each line, and bites were spaces approximately 2–3 mm apart and 2–3 mm from the transected tissue edge.

2.4.3 | Functional end-to-end stapled anastomosis with oversew (FEESA-O)

Functional end-to-end stapled anastomosis was performed by fully seating an 8-cm intestinal segment on each limb of an Endo GIA 30 mm reusable stapler (Medtronic) loaded with a purple (3, 3.5, and 4-mm) tri-staple cartridge (Medtronic). The device was positioned such that the antimesenteric borders would oppose when the device was fired with placement of six rows of staggered staples with a linear stoma established between the third and fourth rows.

A reusable stapler (TA 60; Medtronic) was loaded with a 3.5-mm staple cartridge (blue cartridge; Medtronic) and applied perpendicular to the GIA staple line approximately 0.5 cm distal to the transverse opening. The GIA staple lines were partially offset as has been previously demonstrated to elicit the highest resistance to leakage in GIA FEESA constructs.[21] The TA stapler was fired, deploying two rows of staggered staples and the excess tissue was excised with a #15 blade above the staple cartridge before release of the stapler.

The TA line was inverted with a continuous Cushing oversew pattern with 4–0 glycomer 631 swaged onto a CV-23 half-circle, 17-mm tapered needle and secured with four square throws.

No “crotch” suture was applied as has been previously described in some reports.[21,22]

2.4.4 | Functional end-to-end stapled anastomosis without oversew (FEESA)

The FEESA was constructed as noted above, but there was no oversew performed following the TA stapling.

2.4.5 | Skin stapled anastomosis (SS)

Skin stapled anastomoses were performed as previously described.[12,13,17] To appropriately oppose the intestinal segments prior to stapling, three stay sutures were placed equidistant circumferentially and secured with four square throws with 4–0 glycomer 631 swaged onto a CV-23 half-circle, 17-mm tapered needle. A disposable skin stapler (3 M, St. Paul, Minnesota) loaded with 6.7-mm staples (closed height 3.9 mm) was centered over the transected intestinal ends and deployed every 2 to 3 mm. This was repeated for each of the three segments demarcated by the stay sutures. All suture tags were cut short, leaving the three simple interrupted sutures with the stapled construct.

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2.5 | Leak-testing

All constructs and control segments were leak tested immediately following construction and within 24 h of tissue harvesting. Rochester-Carmalt forceps were used to completely occlude the lumen of both sides of each construct. A single 18-gauge, 1.25 inch, over-the-needle catheter was inserted centrally to each Rochester-Carmalt forceps at a 45° angle transmurally through the antimesenteric border and into the intestinal lumen. Thus, each construct or control had two catheters centrally directed towards the anastomosis site or the center of the control segment (Figure 1). One catheter was connected to a pressure transducer, transducer amplifier, and pressure monitoring system (AD Instruments, Sydney, Australia). The second catheter was connected to an IV fluid line, which was connected to a standard 0.5-L bag of 0.9% NaCl with a 1 to 500 dilution of methylene blue. The entire construct was suspended on a metal grate 2–3 cm above a standard white absorbent pad. Thus, as leakage occurred, blue dye was able to be visualized extruding from the leakage site and detected easily in contrast to the background of the white pad.

FIGURE 1 Photograph of a functional end-to-end stapled anastomosis during leak testing. The two free ends of the construct are clamped off with Rochester Carmalt forceps. Then 18-gauge IV catheters are introduced into the intestinal lumen at 45° angles. Methylene blue dyed 0.9% NaCl is infused, and initial leakage pressure, maximum intraluminal pressure, and initial leak location are noted.

Prior to each leak test, the pressure sensor system was calibrated. With the entire unit (construct, tubing, transducer) at the same level plane, the system was calibrated to 0 mmHg using a sphygmomanometer (Welch Allyn, Skaneateles Falls, New York). Next, an IV infusion pump (Heska, Loveland, Colorado) was used to continuously infuse the previously mentioned 0.9% NaCl solution into the intestinal lumen at the maximum rate of the pump (999 mL/h). One investigator (J.E.S) monitored the continuous pressure monitoring software, which recorded the internal pressure of the intestinal lumen as it was distended with fluid. A second investigator (M.W.) observed the construct or control segments for serosal tearing, leaking around the catheter site, or leaking through the anastomosis site. Alternatively, recording was stopped if the maximum pressure of the recording software was exceeded (>500 mmHg). The initial pressure at which the leakage was noted was recorded as the initial leak pressure (ILP). The location at which leakage occurred was also recorded. The infusion was continued until the pressure recording reached a plateau for 5 s, exceeded the maximum pressure, or sharply declined following catastrophic failure of the integrity of the anastomosis or intestinal wall. The plateau pressure or the highest noted pressure prior to decline was noted as the maximum intraluminal pressure (MIP).

2.6 | Fluoroscopic imaging

Fluoroscopy (Ziehm, Nuremberg, Germany) was used to evaluate stapled constructs for proper staple conformation. This was defined as a B-shape for GIA and TA staple lines and a rectangular D shape for skin staple lines. Orthogonal static images were obtained of each staple line and the number and location of malformed staples was recorded.

2.7 | Statistical analysis

A prestudy power analysis showed that a sample size of ≥5 constructs per group was required to detect a difference with a power of 90% and a $\alpha = .05$. Descriptive statistics were used to describe the distribution of time to construct assembly, ILP, MIP, luminal diameter at the level of the duodenum, jejunum, and ileum, and mural thickness at the level of the stomach, duodenum, jejunum, and ileum. A Kruskal-Wallis test was performed to compare time to construct assembly, ILP, MIP for all construct groups as well as luminal diameter and mural thickness at all afore mentioned sites. For all variables identified as significant, post hoc analysis with the

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Steel-Dwass method was performed for multiple comparisons. Statistical significance was set at $p \leq .05$. All statistical analyses were performed in SAS (SAS Institute, Cary, North Carolina).

3 | RESULTS

All intestinal segments were grossly normal at the time of harvest. Mean +/− SD (Table 1) and median (Table 2) time to construct completion, initial leak pressure, and maximum intraluminal pressure for all construct groups are reported. The distribution of time to construct completion, ILP, and MIP are shown in Figures 2–4. For 4 of 10 cadavers, significant serosal tearing or inability to insert Endo GIA arms into the intestinal lumen prevented construction of FEESA constructs. There was no gross difference in body size or statistically significant difference in previously measured intestinal thickness or lumen diameter between these cadaveric samples and the samples that the Endo GIA was able to be successfully used on.

The time to construct completion differed significantly with respect to multiple treatment groups. Both hand-sewn anastomoses using simple interrupted and

TABLE 1 All measured variables for control segments and five treatment groups.

Construct	Time to construct completion, mean ± SD, s	ILP, mean ± SD, mmHg	MIP, mean ± SD, mmHg
Control	-	>500	>500
HSA-SI	397 ± 70	165 ± 122	223 ± 134
HSA-SC	352 ± 51	149 ± 83	210 ± 129
FEESA-O	195 ± 13	63 ± 25	123 ± 36
FEESA	79 ± 30	84 ± 59	124 ± 75
SS	180 ± 70	77 ± 56	93 ± 64

Abbreviations: -, not applicable; FEESA, functional end-to-end stapled anastomosis; FEESA-O, functional end-to-end stapled anastomosis – oversewn; HSA-SC, hand-sewn anastomosis – simple continuous; HSA-SI, hand-sewn anastomosis – simple interrupted; ILP, initial leak pressure; MIP, maximum intraluminal pressure; SS, skin stapled anastomosis.

TABLE 2 All measured variables for control segments and five treatment groups.

Construct	Time to construct completion, median (range), s	ILP, median (range), mmHg	MIP, median (range), mmHg
Control	-	>500	>500
HSA-SI	370.5 (308–524)	99.5 (45–380)	224.5 (95–425)
HSA-SC	349 (272–458)	129.5 (62–310)	186 (63–418)
FEESA-O	197.5 (174–210)	56 (36–103)	106.5 (95–182)
FEESA	81 (42–114)	82 (4–185)	123.5 (5–225)
SS	156.5 (126–362)	85 (2–199)	88 (2–216)

Abbreviations: -, not applicable; FEESA, functional end-to-end stapled anastomosis; FEESA-O, functional end-to-end stapled anastomosis – oversewn; HSA-SC, hand-sewn anastomosis – simple continuous; HSA-SI, hand-sewn anastomosis – simple interrupted; ILP, initial leak pressure; MIP, maximum intraluminal pressure; SS, skin stapled anastomosis.

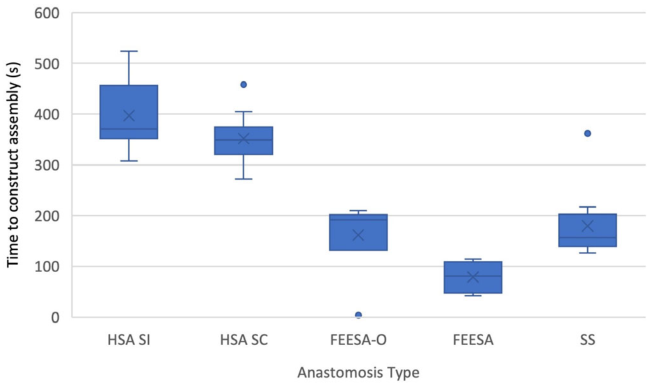

FIGURE 2 Side-by-side boxplot of time to construct assembly for all constructs. Each box represents the 25th to 75th percentiles, the horizontal line is the median, and the whiskers represent the range. The circles represent potential outliers. FEESA, functional end-to-end stapled anastomosis; FEESA-O, functional end-to-end stapled anastomosis – oversewn; HSA-SC, hand-sewn anastomosis – simple continuous; HSA-SI, hand-sewn anastomosis – simple interrupted; SS, skin stapled anastomosis.

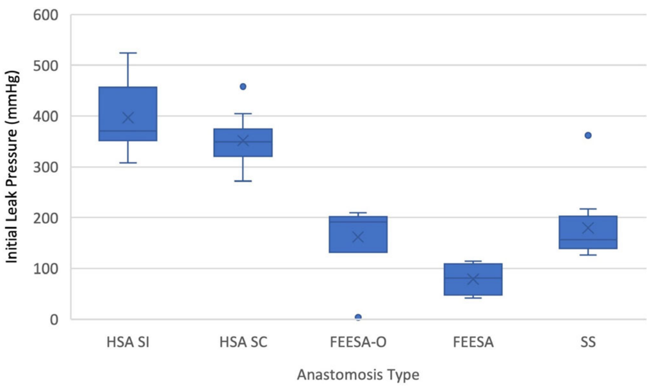

FIGURE 3 Side-by-side boxplot of initial leak pressure for all constructs. Each box represents the 25th to 75th percentiles, the horizontal line is the median, and the whiskers represent the range. The circle represents a potential outlier. FEESA, functional end-to-end stapled anastomosis; FEESA-O, functional end-to-end stapled anastomosis – oversewn; HSA-SC, hand-sewn anastomosis – simple continuous; HSA-SI, hand-sewn anastomosis – simple interrupted; SS, skin stapled anastomosis.

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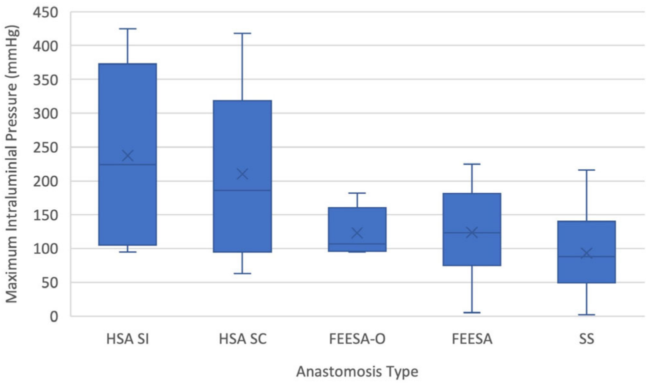

FIGURE 4 Side-by-side boxplot of maximum intraluminal pressures for all constructs. Each box represents the 25th to 75th percentiles, the horizontal line is the median, and the whiskers represent the range. FEESA, functional end-to-end stapled anastomosis; FEESA-O, functional end-to-end stapled anastomosis – oversewn; HSA-SC, hand-sewn anastomosis – simple continuous; HSA-SI, hand-sewn anastomosis – simple interrupted; SS, skin stapled anastomosis.

simple continuous techniques took the longest time to construct, with mean time to completions of 396.8 and 351.8 s, respectively. These groups were not statistically significant from each other ($p = .48$); however, they were significantly slower when compared with all FEESA groups ($p = .012$) and with skin stapled anastomoses ($p = .004$ and $p = .0114$ respectively). The next slowest anastomosis groups were skin stapled anastomoses and FEESA with oversew, with mean times to construct completion of 156.5 and 197.5 s respectively. These groups were not significantly different from each other ($p = .514$) but were statistically different from all other treatment groups ($p < .05$). The fastest anastomosis group was the FEESA without oversew group, with a mean time to construct assembly of 79 s. This group was significantly faster than all other groups ($p < .05$). No statistical difference in MIP or ILP was noted between any treatment groups upon pairwise analysis comparing each individual treatment group (Table 3).

TABLE 3 Pairwise comparisons between treatment groups.

Comparison groups		*p*-value for ILP	*p*-value for MIP
HSA-SC	HSA-SI	1.000	.9938
HSA-SC	FEESA	.6205	.8414
HSA-SC	FEESA-O	.0798	.7858
HSA-SC	SS	.3870	.1680
HSA-SI	FEESA	.7234	.6561
HSA-SI	FEESA-O	.3175	.5496
HSA-SI	SS	.4807	.0836
FEESA	FEESA-O	.9036	.9993
FEESA	SS	1.000	.7858
FEESA-O	SS	.9988	.6561

Abbreviations: FEESA, functional end-to-end stapled anastomosis; FEESA-O, functional end-to-end stapled anastomosis – oversewn; HSA-SC, hand-sewn anastomosis – simple continuous; HSA-SI, hand-sewn anastomosis – simple interrupted; ILP, initial leak pressure; MIP, maximum intraluminal pressure; SS, skin stapled anastomosis.

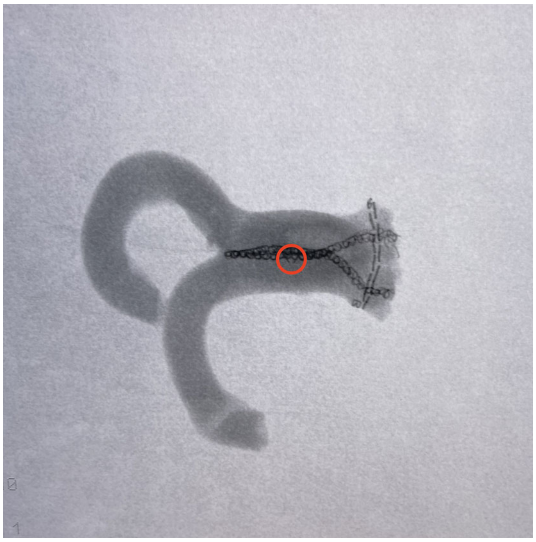

FIGURE 5 The red circled area represents a noncompressed staple seen on fluoroscopy within the vertical staple line of a functional end-to-end stapled anastomosis construct.

TABLE 4 Mural thickness and luminal diameter of 10 fresh feline cadavers.

Gastrointestinal location	Mural thickness, mean ± SD, mm	Mural thickness, median (range), mm	Luminal diameter, mean ± SD, mm	Luminal diameter, median (range), mm
Stomach (midbody)	1.66 ± 0.28	1.71 (1.17–2.09)	-	-
Duodenum	2.05 ± 0.18	2.06 (1.77–2.49)	6.11 ± 0.53	6 (5.5–7.21)
Jejunum	2.28 ± 0.30	2.29 (1.83–2.87)	6.08 ± 0.65	5.98 (4.89–7.17)
Ileum	2.11 ± 0.39	2.22 (1.21–2.53)	6.85 ± 1.36	6.56 (5.52–10.19)

Abbreviation: -, not applicable.

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TABLE 5 Location of leakage for all treatment groups.

Construct	Suture bite leakage	Vertical staple line leakage	Horizontal staple line leakage	Staple hole leakage	Punctate stream at mesenteric margin	Cut edge
Control	-	-	-	-	2	-
HSA-SI	10	-	-	-	0	0
HSA-SC	10	-	-	-	0	0
FEESA-O	0	6	0	0	0	0
FEESA	-	3	3	0	0	0
SS	-	-	-	8	0	2

Note: $n = 10$/group for HSA-SI, HSA-SC, SS; $n = 20$ for control, $n = 6$/group for FEESA-O and FEESA.
Abbreviations: -, not applicable; FEESA, functional end-to-end stapled anastomosis; FEESA-O, functional end-to-end stapled anastomosis – oversewn; HSA-SC, hand-sewn anastomosis – simple continuous; HSA-SI, hand-sewn anastomosis – simple interrupted; ILP, initial leak pressure; MIP, maximum intraluminal pressure; SS, skin stapled anastomosis.

The mean ± SD and median thickness and luminal diameters of all gastrointestinal anatomic locations is presented in Table 4. The mean thickness of the stomach was shown to be thinner than the duodenum, jejunum, and ileum ($p = .0133$, .0133, .0025 respectively). There were no differences in thickness between duodenal, jejunal, or ileal sections ($p > .05$ between all groups). There were no differences noted between any sections with respect to luminal diameter ($p = .305$).

Staple conformation was appropriate in all skin stapled anastomoses as confirmed with fluoroscopy. Two constructs in the FEESA with oversew group had a single, noncompressed staple in the vertical staple line each (Figure 5). All other staples, regardless of stapler type, size, and shape, were found to engage the submucosa at all locations.

The location of initial leakage was recorded for all anastomotic constructs in each treatment group and are recorded in Table 5. A total of 18 of 20 control segments reached the maximum pressure of the sensor system. The other two control segments exhibited serosal tearing followed by punctate streams of leakage along the mesenteric border prior to reaching maximum pressure.

4 | DISCUSSION

An ex vivo feline cadaveric model was used in this study for the evaluation of normal feline gastrointestinal mural thickness and luminal diameter, and to assess resistance to leakage and time to construct completion of five different techniques for the anastomosis of feline gastrointestinal tissue. Our first hypothesis was rejected because there was no difference in ILP or MIP between hand-sewn, FEESA, or skin stapled groups. The second hypothesis was supported because standard FEESA was determined to be quicker to construct than oversewn FEESA or skin stapled techniques, which were faster than hand-sewn techniques. The final hypothesis was partially supported because, although feline gastrointestinal thickness was determined to be thicker than that of humans throughout the duodenum, jejunum, and ileum, the stomach was thinner than human tissue.[23,24] Additionally, although feline gastrointestinal thickness was similar to that of dogs in the duodenum, jejunum, and ileum, the thickness of the stomach in cats is almost half that of the stomach in dogs.[25]

In dogs, FEESA is the most commonly applied technique for the construction of stapled anastomoses.[11] Studies have not been performed in cats to show the frequency of various anastomosis techniques. Stapled anastomoses in cats can be constructed as functional end-to end anastomoses via the use of GIA or Endo-GIA staplers with or without TA staplers or in end-to-end fashion via the use of skin staplers.[11,13,17] In prior studies, both techniques have been shown to be safe and efficacious in cats.[3,10,13,26] A study of 29 cats with gastrointestinal incisions closed with skin staples alone or in combination with suture showed excellent efficacy and safety of the method, with no evidence of intestinal dehiscence or postoperative septic peritonitis identified in any of the cats.[13] No study has directly compared dehiscence rates between stapled and hand-sewn anastomoses in cats. In dogs, there is conflicting literature on the topic. A retrospective 2015 study of 205 dogs showed no significant difference between postoperative dehiscence rates of hand-sutured anastomoses compared to stapled anastomoses; however, a similar retrospective study of 180 dogs in 2018 showed a dehiscence rate of 13% following sutured anastomoses compared to 5% following staple techniques.[9,14] In human trauma surgery, stapled anastomoses have been shown to be significantly at higher risk for dehiscence than sutured ones.[27] Thus, our study aims

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to provide insight to the veterinary surgeon regarding resistance to physiologic pressures of all commonly performed anastomotic types and inform the surgeon as to potential sources for surgical error as it pertains to surgical staple size selection.

To the authors' knowledge, this is the only study of its kind which has studied the thickness of feline gastrointestinal tissue in cadaveric tissue for the purpose of facilitation of correct staple size selection in gastrointestinal surgery. GIA and TA staple cartridges are color coded according to staple size and in human medicine, there are precise indications for the use of each color within different gastrointestinal divisions.[28] However, in veterinary medicine, such consensuses do not exist. In humans, the stomach is the thickest part of the intestine, with mean mural thickness of 2.9 mm as compared to thicknesses from the duodenum through the ileum ranging from 0.9 to 1.6 mm.[24] Our study showed mean mural thickness in the feline stomach that was 0.57 times as thick as human stomach. On the other hand, the remainder of the intestines were determined to be 1.43 times as thick as that of man.[24] Thus, to ensure appropriate engagement of the submucosa in feline gastrointestinal surgery, it may be pertinent to select green TA staples green (2.0 mm closed staple height) for use in the duodenum, jejunum, and ileum, whereas it may be more appropriate to select blue TA staple cartridges (1.5-mm closed staple height) for use on the feline stomach. This is counterintuitive to the recommendations in human surgery.[28] However, based on similar wall thickness throughout the small bowel in cats and dogs (within 0.3 mm at all division), recommendations for staple selection in these two species can reasonably be inferred to be the same.[25] Additionally, based on the findings of our study, the use of tan Endo GIA cartridges (recommended for tissue thickness ranging from 0.88 to 1.8 mm) is appropriate in the feline stomach. The remainder of the feline gastrointestinal tract has mean thicknesses very near to the purple/black GIA cartridge selection size distinction of 2.25 mm.[25] Thus, the selection of Endo GIA cartridge size for FEESA cannot be determined by gastrointestinal division alone and must be made on an individual basis depending on intestinal thickness of the patient.

To the authors' knowledge, there are no studies that evaluate the maximum intraluminal pressure of the feline gastrointestinal tract. However, a study performed in healthy, nonanesthetized dogs showed maximum intraluminal pressures induced by peristalsis to be between 15 and 25 mmHg.[29] Additionally, a study of intraluminal pressures in an experimentally induced small bowel obstruction feline model showed baseline intraluminal pressures ranging from 2 to 4 mmHg.[30] The same study demonstrated maximum pressures of 20 mmHg during activity following 72 h of intestinal obstruction.[30] It can be reasonably inferred that under normal circumstances, feline intraluminal pressures do not exceed this value. All mean values in the present study for ILP far exceeded this threshold, providing evidence that all anastomotic techniques evaluated provide sufficient resistance to leakage in healthy cadaveric tissue. However, this information cannot be directly extrapolated to live tissue, especially when considering the biological factors that influence intestinal leakage and the potential for intestinal tissue exhibiting various pathologies to behave differently to the nondiseased tissue used in this study. It should also be noted that within the skin stapled group and the FEESA group, there were two individual outliers whose ILP did not exceed physiological pressures (ILP = 2 and 4 mmHg, respectively). These findings support the practice of intraoperative leak testing and correction of leaks with interrupted sutures as is common clinical practice when performing intestinal anastomoses.[31]

Within FEESA construct groups, it was hypothesized that the oversewn group would withstand greater intraluminal pressures than its nonoversewn counterparts. The transverse staple line has repeatedly been implicated as the most common site of leakage and abscessation in FEESA constructs; thus, it stands to reason that reinforcement with suture would fortify the inherent weakness of this site.[9,14,16,18] However, in our study, no statistical difference was found between any treatment group. In the present study, 50% (3/6) of the FEESA group were noted to initially leak from the transverse stapled line, whereas 0% (0/6) of the FEESA-O group were noted to initially leak from this site. While this modification did not appear to change the pressures at which the constructs leaked, it does thus appear to provide structural support to the transverse staple line. Additionally, a recent retrospective study showed an increased rate of dehiscence among nonoversewn FEESAs as compared to oversewn ones in dogs, although this association has not been established in cats.[16]

Another important consideration for anastomotic technique selection is the amount of time that each method takes to complete. It has been repeatedly shown in the human and veterinary literature that longer time under anesthesia is an important risk factor for the development of intra- and postoperative complications.[32–34] In our study, the hand-sewn anastomosis groups took twice as long to complete as the skin stapled and oversewn FEESA groups, and four times as long to complete as the nonoversewn FEESA group. Thus, when considering the critical patient for whom reduced surgical time may be paramount in reducing complication rates, it may be pertinent for the surgeon to elect for a stapled

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anastomosis. There is not enough literature pertaining to dehiscence following FEESA in cats to make a claim as to whether oversewing the transverse line is worth the slower anastomosis in such cases. Each case should be evaluated on an individual basis with intraoperative factors and patient factors taken into account when deciding whether or not to perform a suture oversew.

In our study, only two constructs were noted upon fluoroscopic evaluation to have malformed staples. Both constructs had a single staple malformation in the vertical staple line. While both constructs were noted to initially leak from the vertical staple line, it was not possible to assess whether this was due to the malformed staple. All other constructs in this group also leaked at this location, and due to the nature of the dyed saline pooling at the dependent aspect of the constructs in addition to the small nature of the constructs, it was not possible to localize the leak to one individual staple. All skin staples and TA staples were noted to have appropriate conformations.

There are a few notable limitations to this study. The major limitation is its ex vivo nature. Cadaveric tissue may behave differently than live tissue. While prior studies have provided evidence that cooled jejunal segments have leak pressures comparable to segments tested immediately after harvest in dogs, it is possible that this differs in cats or that cadaveric tissue behaves differently than live tissue under the strain of leak testing.[19,20] Dehiscence is a multifactorial process, much of which is based on biological factors such as the environment of the abdomen (peritonitis), inflammatory and debridement components of healing, and vascular compromise to the anastomosed tissues, none of which was assessed in the present study.[31] In addition, the FEESA groups in our study had a smaller sample size due to tearing of the serosa when trying to insert the Endo GIA arms into the relatively small feline intestinal lumens in 4/10 cadavers. This may represent a concern for the use of Endo GIA staplers in practice or may be a limitation of our cadaveric study. It is unknown whether the elasticity of the intestinal wall is comparable between live, body temperature tissue and cadaveric, room temperature tissue. Additionally, it has been established that in dogs, addition of a "crotch" suture at the junction of the antimesenteric borders where the GIA staple line ends increases resistance to leakage.[22] This was not performed in our study due to previous literature uncommonly implicating this as a site of leakage; however, the addition of a crotch suture may have increased resistance to leakage within our FEESA groups.[21] In practice, a major advantage to the use of GIA staplers is the fact that they have been demonstrated to have similar outcomes when used by novice versus experienced surgeons.[35] In contrast, hand-sewn anastomoses require a significantly greater level of skill. In our study, all hand-sewn anastomoses were constructed by a board-certified surgeon with extensive skill and experience in the field of gastrointestinal surgery. It is possible that HSAs constructed by amateur surgeons, such as is frequently done in clinical practice, would have had significantly lower ILPs or more evidence of failure to engage the submucosal layer. Finally, although all groups demonstrated supraphysiological ILPs, it is the opinion of the authors that in recognition of the complex biological factors that contribute to dehiscence and intestinal leakage in live tissue, skin stapled anastomoses, which appear more likely to cause vascular compromise or mucosal eversion than other, more precise anastomotic techniques that have been designed specifically with gastrointestinal tissue in mind (i.e., GIA staplers), should be used with caution.

In conclusion, there was no difference in ILP or MIP between all five treatment groups and the mean ILP exceeded the maximum intraluminal pressure generated by peristalsis. Hand-sewn anastomoses took four times as long to construct as FEESA without oversew. FEESA with oversew and skin stapled anastomoses took twice as long as FEESA without oversew. The mural thickness of feline stomach is less than that of dog and man, and the mural thickness of duodenum, jejunum, and ileum are greater than that of man and equivalent to that of the dog. These findings may guide surgeons in the appropriate selection of staple sizes.

AUTHOR CONTRIBUTIONS

Sanders, JS, DVM: Study design, data collection, manuscript composition; Regier PJ, DVM, MS: Study design, data collection, manuscript composition; Waln M, BS: Data acquisition, manuscript review; Colee J, PhD: Study design, data interpretation, manuscript review.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest related to this report.

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