

# Evaluation of three techniques for end-to-end anastomosis of the small colon in horses

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## SUMMARY

In an attempt to determine the best method for surgical removal of devitalized small colon lesions, 12 horses underwent a double small colon resection and end-to-end anastomosis. In 4 horses (study 1), an appositional single-layer (APP-1) suture pattern was compared with an inverting 2-layer (INV-2) suture pattern. In 8 horses (study 2), an appositional 2-layer (APP-2) suture pattern was compared with the INV-2 suture technique. Polydioxanone suture (size 1-0), was used.

Horses were evaluated at necropsy 3, 10, 14, 28, or 56 days after surgery. Postoperative complications (peritonitis, impaction, or excessive adhesions) were encountered in 100, 42, and 13% of the APP-1, INV-2, and APP-2 anastomoses, respectively.

Postmortem evaluation of the small colon revealed dehiscence of the anastomotic site, diffuse peritonitis, and adhesion formation in 3 of the 4 horses in which the resection line was closed with the APP-1 pattern. With the INV-2 and APP-2 techniques, more intestinal inversion was present in the nontaenial than in the taenial portion of the small colon. More postoperative impactions were found with the INV-2 ( $n = 5$ ) anastomoses than with the APP-2 ( $n = 1$ ) technique; this appeared to be the result of excessive tissue inversion. There was no difference in lumen diameter between the INV-2 and the APP-2 techniques ( $P \geq 0.05$ ). However, horses with unresponsive impactions at the INV-2 site had a smaller luminal diameter compared with the INV-2 anastomoses that did not impact or that impacted and resolved with therapy ( $P \leq 0.001$ ). Difference in adhesion formation between the INV-2 and the APP-2 techniques was minimal.

Bursting pressure studies (7 APP-2, 7 INV-2, and 14 control) were performed in study 2. All segments consistently burst away from the anastomotic site along the mesenteric or antimesenteric taenial band. Differences in bursting pressure ( $P \geq 0.05$ ) were not evident between the 2 groups.

Histologic evaluation revealed the APP-1 pattern had no intestinal inversion. However, a wide full-thickness

deposition of dense fibrous connective tissue in the submucosal and muscular layer was evident. The INV-2 and the APP-2 patterns had pronounced inversion of the anastomotic layers along the nontaenial portion of the anastomoses, with minimal deposition of fibrous connective tissue between the anastomotic layers. The inversion formed a protruding ridge into the lumen that was more pronounced in the INV-2 than in the APP-2 anastomoses. At 28 days, the inverted tissues were held firmly together by maturing fibrous connective tissue that was covered by a mucosal layer. The inverted tissues were as pronounced at 56 days as they were at 3 days. In light of these findings, we concluded that an APP-2 pattern was the preferred surgical technique.

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Complications associated with intestinal resection and anastomosis are a major cause of death in horses requiring surgery because of abdominal disease.<sup>1</sup> In many species, the frequency of breakdown and leakage of intestinal content is greatest in the terminal colon, compared with other intestinal segments.<sup>2-5</sup> Passage of solid feces through a narrow lumen, as well as problems in the bowel wall (increased bacterial concentrations, poor blood supply, strong muscular activity, and increased tissue collagenase activity), have been cited as reasons for this poor healing.<sup>3,6-8</sup> The objective of many experimental comparisons of colon anastomoses patterns and layers has been to identify and to promote a technique that is superior under these adverse conditions. In studies using human beings, rats, rabbits, and dogs, various surgical techniques, suture patterns, and materials for anastomoses of the terminal large intestine have been compared.<sup>9-24</sup> Unfortunately, there is little agreement among investigators as to which technique is the best under most circumstances.

Several investigators<sup>25-27</sup> have described suture patterns and suture materials used for anastomosis of the small intestine in horses. Placement of antiperistaltic segments of small colon, using a 2-layer inverting closure, resulted in anastomotic dehiscence and peritonitis in 2 of 5 horses and impaction in a third.<sup>28</sup> However, there are no objective experimental or clinical studies evaluating techniques for anastomosis of the small colon in horses.

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Any technique that would decrease the risk of leakage and narrowing of lumen and that would lessen the inflammatory response would decrease postoperative mortality and morbidity. In keeping with current trends, a single-layer appositional (APP-1) suture pattern, a 2-layer appositional (APP-2) suture pattern and a 2-layer inverting (INV-2) suture pattern were evaluated for small colon resection and anastomosis in horses. Criteria for evaluation included the postoperative clinical course, intra-abdominal adhesion formation, lumen diameter, bursting strength, and gross and histologic tissue response.

## Materials and Methods

### STUDY 1

**Horses**—Four healthy horses (4 females) of various breeds, ages (mean,  $6 \pm 1.4$  years), and weights (mean,  $472 \pm 13.9$  kg) were allowed to adapt to their surroundings for a minimum of 1 week before surgery. They were dewormed with ivermectin (200 µg/kg of body weight, PO) 2 weeks before conditioning. Only horses in good body condition were used.

Starting 48 hours before surgery, each horse was given 2 L of mineral oil and 60 ml of a surfactant every 12 hours for 3 treatments.<sup>a,b</sup> Hay and grain were withheld for 12 hours before surgery, but continuous access to water was allowed.

The horses were anesthetized and positioned in dorsal recumbency, the skin was prepared for aseptic surgery, and impervious surgical drapes were applied. Sodium ampicillin (20 mg/kg) in 500 ml of physiologic saline solution was administered IV. An 18- to 20-cm ventral midline skin incision was made through the linea alba, just rostral to the umbilicus. Hemorrhage was controlled by electrocoagulation. The small colon was exteriorized. The sites for resection and anastomosis were approximately 1 m and 2 m distal to the transverse colon. The small colon segments resected were midway between 2 anastomotic loops of the left colic artery and vein.

Ingesta were manually stripped aborally past both proposed anastomotic sites into the rectum. The lumen of the bowel was temporarily occluded with a loop of soft rubber tubing to prevent return of ingesta to the anastomotic site. The mesenteric vessels supplying the bowel segment to be removed were ligated with size 1 polydioxanone sutures. Crushing forceps were placed across the bowel wall at a 60° angle to the antimesenteric border of the small colon. The exposed segments of the small colon were covered with moistened sterile towels. Ten centimeters of small colon was resected by transection along the crushing forceps. Gauze sponges were folded over the exposed intestinal lumen to minimize contamination.

Two stay sutures of size 0 polydioxanone were placed through the cut ends of the mesenteric and antimesenteric borders of the small colon. Hemostats placed on the ends of the stay sutures were held under slight tension by an assistant to maintain apposition of the cut ends of the small colon during the anastomotic procedure. The surgeries were ordered so that the type of anastomosis on the proximal and distal small colon was alternated.

At 1 anastomotic site, the defect was closed with 1-0 polydioxanone in an APP-1 pattern of simple interrupted sutures placed full thickness through the colon wall. These sutures were placed 5 mm apart and 3 mm from the wound edges. Approximately 35 to 40 sutures were placed to complete the anastomosis. The anastomotic site was tested for leaks by passing ingesta past the anastomosis. The anastomosis was then cleansed and all contaminated equipment, drapes, and gloves were dis-

carded. The defect in the mesocolon was closed with a continuous Lembert pattern, using size 2-0 polydioxanone suture.

The other anastomotic site was closed in an INV-2 continuous pattern, using size 1-0 polydioxanone suture. The first layer was a continuous Connell, with suture bites placed 5 mm apart and 3 mm from the wound edges. The intestine was cleansed and all contaminated equipment and drapes were discarded. The second layer was a continuous Cushing pattern, using size 1-0 polydioxanone suture. The sutures of both layers were tied at the midpoint of the circumference of the colon to lessen the pursestring effect on the intestine. The sutures were placed 5 mm apart and 2 mm from the junctional edge of the first layer. The anastomotic site was evaluated for any evidence of leakage by passing ingesta past the anastomosis and then was cleansed. The defect in the mesocolon was closed with a continuous Lembert pattern of size 2-0 polydioxanone suture.

The abdomen was rinsed with 10 L of warm physiologic saline solution containing 10 IU of sodium heparin/ml and 1,000 IU of potassium penicillin/ml. A perforated polyvinyl drain<sup>c</sup> was placed in the abdomen and was exteriorized 5 cm rostral to the skin incision. The drain was heparinized and closed until further abdominal fluid was drained with the horse standing.

The linea alba was apposed with simple continuous sutures of a double strand of size 2 polygalactin 910 suture. The subcutaneous tissues were apposed with simple continuous sutures of size 2-0 polygalactin 910. A continuous interlocking pattern of size 0 polymerized caprolactam suture was used to appose the skin.

Procaine penicillin G, gentamicin sulfate, and sodium heparin were administered for 3 days after surgery (22,000 IU/kg, IM, q 12 h; 2.2 mg/kg, IV, q 8 h; and 40 IU/kg, IV q 8 h, respectively). Flunixin meglumine (1 mg/kg, IV) was administered immediately after surgery and at a reduced dosage (0.5 mg/kg, IV) thereafter as needed for control of abdominal pain. Lactated Ringer solution (20 L) was given IV during the first 12 hours after surgery, after which water and alfalfa hay were provided ad libitum. Rectal temperature, pulse, respiration, fecal output, and evidence of abdominal pain were recorded every 2 hours for the first 12 hours, and then every 4 hours until resolution of any abdominal pain. Mineral oil (4 L) was administered to horses that had no fecal output after the first 24 hours or those in which a small colon impaction could be palpated per rectum. This was continued daily until feces were observed. Postmortem examination of the anastomotic sites and abdominal viscera was performed at 3, 14, or 56 days after surgery. The anastomoses were then resected and were evaluated by histologic examination.

### STUDY 2

Eight healthy horses (2 males, 6 females) of various breeds, ages (mean,  $14.8 \pm 2.5$  years), and weights (mean,  $447 \pm 17.9$  kg) were subjected to the same conditioning period and preoperative evaluation as that described for study 1. A double small colon resection was done in all horses as described for study 1. An additional inverting layer was performed over the APP-1 anastomosis (APP-2). The second layer consisted of a continuous Cushing pattern, using size 1-0 polydioxanone. The continuous suture also was interrupted at one half the circumference of the colon to lessen a pursestring effect on the intestine. The sutures were placed 5 mm apart and 2 mm from the first-layer knots.

Seven horses were euthanatized according to schedule at 3 days (horses 6 and 8), 14 days (horses 11 and 12), 28 days (horses 5 and 10), and 56 days (horse 7) after surgery. Horse 9 was euthanatized prematurely, 10 days after surgery. Evaluations of the anastomoses were identical to those for study 1.

**Determination of lumen diameter**—Each end of the removed segments of small colon was placed over the bulb of a 75-ml

<sup>a</sup> Mineral oil, Chevron, Gainesville, Fla.

<sup>b</sup> Diocytate oral solution, The Butler Co, Columbus, Ohio.

<sup>c</sup> Redi-Vacette, Bio Med, Bourbon, Ind.

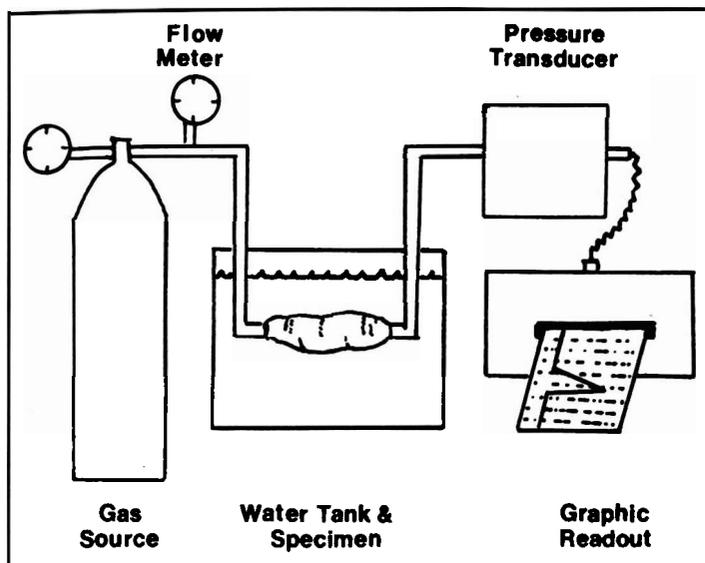


Fig 1—Bursting pressure apparatus for evaluation of anastomosis strength. Gas is infused to one end of the small colon specimen while immersed in water. A pressure transducer attached to a calibrated physiograph records intraluminal pressure.

Foley catheter that had been placed through the cut end of a 60-ml syringe casing. The catheter bulbs were distended with air until the small colon was sealed with the inside of the casing.

The bowel was distended with air through 1 Foley catheter while a mercury manometer attached to the opposite Foley catheter was used to measure the pressure within the intestinal lumen. Each segment was distended to 15 mm of Hg internal pressure, as this best represented the normal size of the small colon and did not easily collapse when positioned for radiography. The lateral radiographic projection of the small colon measured the intraluminal diameter between the 2 taenial bands. The mesenteric-antimesenteric projection measured the intraluminal diameter in the nontaenial portion of the anastomosis. Measurements of these 2 views were taken at the anastomosis and 4 cm proximal and distal to the anastomosis. The respective distal measurement was used as a control for each site. The degree of constriction was calculated by dividing the lumen diameter at the anastomotic site by the diameter of the lumen 4 cm distally. The lumen diameter 4 cm proximally was compared with the distal lumen diameter to evaluate the possibility of chronic obstruction of the proximal segment. A normal segment of small colon from each horse was used to compare the lumen diameter using the same inflation technique.

**Determination of bursting pressure**—Immediately after radiography, the bursting pressure of the isolated segment was determined. The technique was a modification of various similar techniques.<sup>4,10,11,14,15,18,21,29</sup> One Foley catheter was attached to a pressure transducer connected to a calibrated laboratory physiograph (Fig 1). The segment of small colon was immersed in a tank of water. Oxygen was infused into the other end of the intestine at a rate of 1.5 L/min. The bursting pressure was indicated by a simultaneous rapid decrease in the chart recording and leakage of gas bubbles into the water. Two normal segments of small colon from each horse were used as controls and were tested in the same manner.

**Statistical evaluation**—Means and SEM were calculated for each group of radiographic and bursting pressure data. Differences between the means of each group (APP-2, INV-2) were analyzed by use of the Student paired *t*-test. The level of significance chosen was  $P \leq 0.05$ .

TABLE 1—Results of small colon anastomoses

Horse No.	Surgical result	Hours until passage of feces
1	Anastomotic leakage at APP-1 Impacted at INV-2 Euthanized day 3	None passed
2	Anastomotic leakage at APP-1 Euthanized day 14	144
3	No postoperative complications	24
4	Anastomotic leakage at APP-1 Euthanized day 3	48
5	No postoperative complications	26
6	Impaction at INV-2 Euthanized day 3	None passed
7	No postoperative complications	72
8	Impaction at APP-2 Euthanized day 3	None passed
9	Impaction at INV-2 Euthanized day 10	24
10	No postoperative complications	26
11	Transient impaction, at INV-2	144
12	Transient impaction at INV-2	140

APP-1 = Full-thickness simple interrupted suture pattern. APP-2 = Full-thickness simple interrupted-suture pattern oversewn with a continuous Cushing suture pattern interrupted at 180°. INV-2 = Two-layer Connell-Cushing suture pattern interrupted at 180°.

## Results

### STUDY 1 (n = 4)

**Postoperative clinical evaluation**—Horses 1, 2, and 4 became febrile (temperature > 38.6 C), depressed, and anorectic at 24 hours. Horses 1 and 4 remained febrile and were euthanized on day 3 (Table 1). Horse 2 developed a low-grade undulating fever, with intermittent depression and anorexia, and first passed feces on day 6; however, it was euthanized on day 14 because of chronic peritonitis. Horse 3 appeared bright and alert, was normothermic, and passed feces at 24 hours; however, it had 2 episodes of mild abdominal pain (on days 15 and 35) that responded to 1 treatment of mineral oil and analgesic therapy.

**Gross pathologic findings**—Horses 1, 2, and 4 had generalized peritonitis, with fibrinous adhesions throughout the abdominal cavity. Multiple full-thickness defects of the APP-1 anastomosis 2- to 8-cm long were found about the mesenteric or antimesenteric taenial band. Horse 1 had an impaction at the INV-2 site. Horse 3, euthanized on day 56, had severe fibrous adhesions of linear segments of the small colon centered on the APP-1 anastomosis. The INV-2 anastomosis in this same horse still had considerable bowel wall inversion in the nontaenial areas of the anastomosis (Fig 2).

**Histopathologic findings**—Because of anastomotic leakage and peritonitis, only specimens from horse 3 were satisfactory. The lumen was compromised by inverted tissue only in the INV-2 specimens (Fig 3). In the APP-1 anastomosis, however, a wide defect in the submucosal and muscular layers of the taenial and nontaenial areas was filled by a wide plug of dense fibrous connective tissue (Fig 4). Sutures surrounded by granulomatous inflammation were still intact. The serosa was thickened by dense collagenous tissue, and extensive adhesions blended into the external surface.

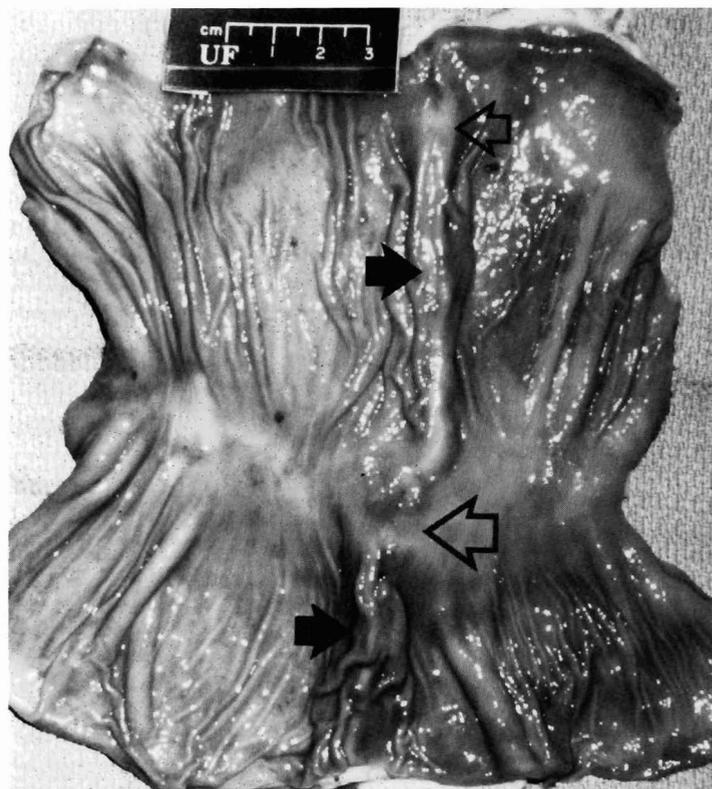


Fig 2—Two-layer inverting pattern (INV-2) in horse 3 at day 56. Tissue inversion in the nontaenial areas of colon wall is considerable (solid arrows), compared with taenial colon wall (open arrows).

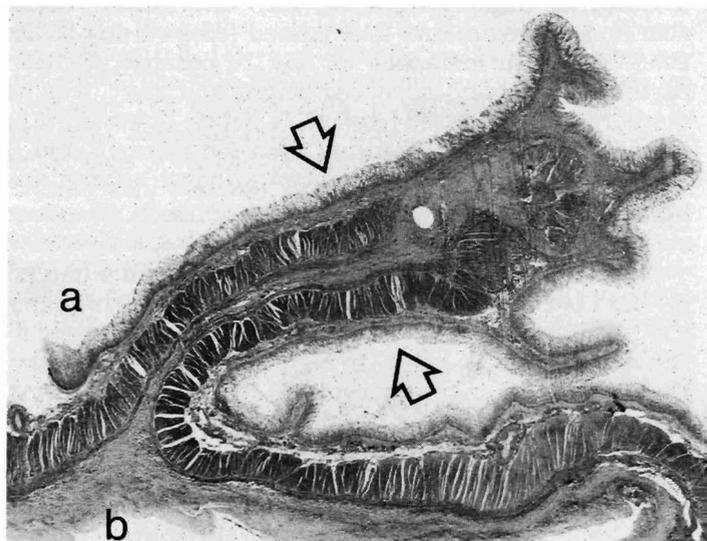


Fig 3—Section through a nontaenial portion of the INV-2 pattern from horse 3 at day 56. Inversion of all colon layers is considerable (arrows) and mucosal bridging is complete; a = mucosal surface, b = serosal surface. Masson Trichrome stain;  $\times 4.49$ . Original magnification,  $\times 7.3$ .

#### STUDY 2 (n = 8)

**Postoperative clinical evaluation**—Horses 5, 7, and 10 were bright and alert at 24 hours and were fed full rations by 48 hours (Table 1). For these 3 horses, the first passage of feces was observed at a mean of 41 hours. Horses 11 and 12 developed small colon impactions, 1 of which (in horse 12) was palpable at the distal INV-2 anastomotic site. An impaction could be palpated only when it in-

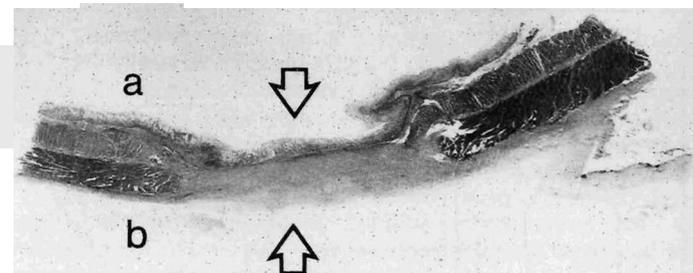


Fig 4—Section through anastomosis of the APP-1 pattern (arrows) from horse 3 at day 56. Notice wide dense collagen scar and complete mucosal bridging; a = mucosal surface, b = serosal surface. Masson Trichrome stain;  $\times 4.09$ . Original magnification,  $\times 7.3$ .

TABLE 2—Adhesions to the intestinal anastomotic sites expressed as percentage of anastomotic circumference

Horse No.	Days after surgery	APP-2	INV-2
6	3	0	0
8	3	0	0
9	10	30	0
11	14	50	40
12	14	0	40
5	28	12*	0
10	28	0	0
7	56	5†	12‡

\* Pedunculated adhesion 1  $\times$  9 cm from antimesenteric taenial band to paralumbar fossa. † Small omental adhesion. ‡ Pedunculated adhesion 1  $\times$  9 cm from antimesenteric taenial band to 18th rib.

APP-2 = Full-thickness simple interrupted-suture pattern oversewn with a continuous Cushing suture pattern interrupted at 180°. INV-2 = Two-layer Connell-Cushing suture pattern interrupted at 180°.

involved the distal small colon anastomotic site. These impactions resolved with IV fluid therapy and oral administration of a hydroscopic agent.<sup>d</sup> Periodic analgesic therapy was necessary in these 2 horses. Horses 6, 8, and 9 developed small colon impactions that did not resolve. Horses 6 and 9 had impactions at the INV-2 anastomosis and horse 8 had an impaction at the APP-2 site. Periodic analgesic therapy was necessary in these 3 horses to alleviate moderate abdominal pain. The horses were euthanatized because of unresolving impactions. Clinical evidence of anastomotic leakage had not been found.

**Gross pathologic findings**—Adhesions were related to the APP-2 anastomosis in 4 horses, and to the INV-2 anastomosis in 3 horses (Table 2). Adhesions of the mesocolon onto the INV-2 anastomosis did not disrupt the linear nature of the small colon. Fibrous adhesions of the APP-2 technique to other segments of small colon also did not disrupt the longitudinal anatomy of the small colon. Fibrinous adhesions were not found in horses 6 and 8, evaluated at 3 days. Horse 9, evaluated at 10 days, had 30% of the APP-2 anastomosis covered by adhesions, whereas the INV-2 anastomosis had none. Adhesions were most developed by day 14 and were minimal in horses 5, 10, and 7 evaluated at days 28 and 56. The APP-2 anastomosis of horse 11 (14 days) had multiple adhesions to 50% of the rest of the small colon and they disrupted the normal outflow pattern. At 28 days, one APP-2 site in horse 5 had a pedunculated 9-cm adhesion from the antimesenteric

<sup>d</sup> Gen Fiber, Goldline Laboratories, Fort Lauderdale, Fla.

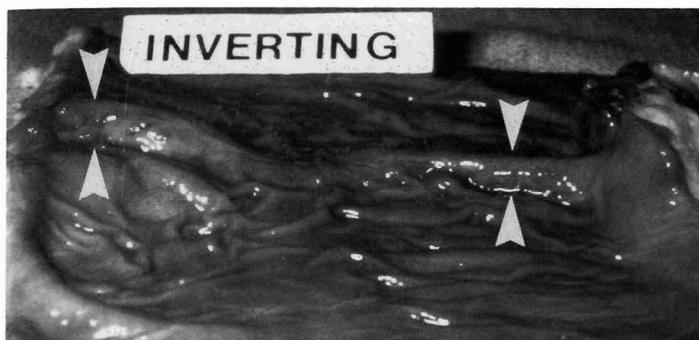


Fig 5—Colonic segment from horse 12 at day 14 after anastomosis with INV-2 technique. Inversion of the nontaenial portion of the wall (between facing arrow heads) is considerable.



Fig 6—Colonic segment from horse 12 at day 14 after anastomosis with APP-2. Inversion of the wall (between arrow heads) is minimal.

TABLE 3—Anastomotic diameters (mm)\* according to suture techniques in study 2

Horse No.	Days after surgery	APP-2	Control APP-2	INV-2	Control INV-2
6	3	42.4	65.4	36.2	66
8	3	37.7	54.1	57.6	77.6
9	10	59.4	63.7	41.3	61.5
11	14	50.1	50.1	43.2	61.1
12	14	42.2	53.9	46.9	63.5
5	28	54.9	66.1	59.5	68.7
10	28	60.0	68.5	57.2	65.4
7	56	61	71.0	52.2	72.8
Mean		45.3 ± 6.4†	54.9 ± 7.2	44.0 ± 5.9‡	60 ± 7.3

\* Mean of lateral and mesenteric-antimesenteric radiographic measurements. † APP-2 diameter smaller than APP-2 control ( $P < 0.01$ ). ‡ INV-2 diameter smaller than INV-2 control ( $P < 0.01$ ).

APP-2 = Full-thickness simple interrupted-suture pattern oversewn with a continuous Cushing suture pattern interrupted at 180°. INV-2 = Two-layer Connell-Cushing suture pattern interrupted at 180°.

border to the left paralumbar fossa. At 56 days, horse 7 had a pedunculated adhesion (1 × 9 cm) attaching the antimesenteric taenia of the INV-2 site to the medial aspect of the left 18th rib. An 8.5-cm segment of omentum was attached to the antimesenteric taenial band at the APP-2 site. Considerable full-thickness inversion of the small colon between the mesenteric and antimesenteric taenial bands was found in all INV-2 anastomoses (Fig 5). Inversion was minimal at this with the APP-2 technique (Fig 6).

**Lumen diameter**—A mean lumen diameter was determined from both radiographic measurements for all APP-2 and INV-2 anastomoses (Table 3). The means of all INV-2 and APP-2 surgical anastomoses were smaller than their

TABLE 4—Small colon bursting pressures (mm of Hg) in study 2

Horse No.	Day after surgery	INV-2		APP-2		Normal* small colons	
		Proximal	Distal	Proximal	Distal		
6	3	138			168	150	149
8	3	192			224	186	220
9	10	ND			ND	ND	ND
11	14	158			162	130	138
12	14		312	220		180	203
5	28		203	207		198	200
10	28		228	193		190	250
7	56		139	199		165	160

\* Normal values determined by measurements of 2 small colon segments at a considerable distance from the anastomotic sites.

ND = Not determined.

corresponding controls ( $P < 0.01$ ). The mean APP-2 anastomosis diameter (83% of control) was larger than the INV-2 mean diameter (73% of control). However, the difference was not statistically significant. The horses with unresponsive impactions at the INV-2 anastomosis had a 38.7-mm mean lumen diameter vs a 52.7-mm lumen diameter for those INV-2 anastomoses that did not impact or that impacted and resolved ( $P \leq 0.05$ ).

**Bursting strength**—Twenty-eight segments of small colon (7 APP-2, 7 INV-2, and 14 controls) were evaluated for bursting strength (Table 4). None of the surgical small colon segments burst at the colonic anastomosis site. All but 1 of the specimens (horse 6, INV-2) burst at the edge of the mesenteric or the antimesenteric taenial band. Since the anastomosis did not fail, strengths and differences between the APP-2 and INV-2 techniques could not be evaluated. Various groups were developed to determine whether technique or location affected bursting strength. Five sets of data were developed with determination of mean values and SEM: (1) all INV-2 segments, ( $195.7 \pm 23.2$  mm of Hg); (2) all APP-2 segments, ( $196.1 \pm 9$  mm of Hg); (3) all proximal segments, ( $186.7 \pm 10.8$  mm of Hg); (4) all distal segments, ( $205.1 \pm 21.7$  mm of Hg); and (5) all control segments ( $179.9 \pm 9$  mm of Hg). There was no statistically significant difference in the bursting pressures among these groups.

#### HISTOPATHOLOGIC FINDINGS

**Clinically normal small colon**—Along the taenial band, the inner circular and outer longitudinal smooth muscle bundles were prominent, of equal width, and were separated by a distinct band of dense fibrous connective tissue. Along the nontaenial band area the outer longitudinal muscle layer was much thinner and was discontinuous in some areas. The circular muscle layer was similar to that seen in the taenial band; however, the serosa and intermediate fibrous band appeared to be less compact. The outer longitudinal muscle bundles became abruptly more narrow at the junction of the taenial band with the nontaenial portion of the small colon. The outer longitudinal muscle bundles of the taenia were distinct and separate from those of the nontaenial areas.

**Anastomotic healing sites**—At day 3, all cut edges were apposed by a layer of fibrin, red cells, neutrophils, and necrotic fragmented smooth muscle. The tissues were congested. Submucosal and serosal veins adjacent to the incision were thrombosed. Many sutures were displaced

during preparation of the specimens; however, those that remained were surrounded by pyogranulomatous inflammation. The sutures along the mucosa were coated with bacteria and plant material. Young granulation tissue with vascular buds, and thickening of the submucosa and serosa was apparent in some specimens. The granulation tissue was more prominent at day 10 and was heavily infiltrated with macrophages and neutrophils.

A thick serosa and patchy adhesions closed the anastomotic defect externally at day 14. This layer was composed of tissues ranging from young granulation tissue consisting of proliferating fibroblasts and capillary buds, to maturing granulation tissue with collagen deposition, to dense fibrous connective tissue. The mucosa did not cover the lumen of the anastomosis at day 14. Similar changes had occurred in the submucosa, but the maturation process lagged behind that of the serosa.

At day 28, the mucosa covered the internal surface in all sections examined, bridging the narrow defect with a single layer of epithelial cells. Inverted smooth muscle bundles were joined by a band of maturing fibrous connective tissue. Sutures in this part of the wall were surrounded by a thin rim of epithelial macrophages and fibrocytes. The serosa and submucosa were thick and composed of dense, well-vascularized connective tissue.

Histologic differences between samples collected at days 28 and 56 were associated mostly with the maturation process. The anastomosis line had filled in with maturing granulation tissue and dense fibrous tissue. The serosa was thick and composed of well-vascularized, dense fibrous tissue. The suture material was still identifiable at day 56.

*Comparison of the two surgical techniques*—Inversion of the gut wall along the incision lines of the INV-2 and the APP-2 techniques was most pronounced in the nontaenial areas. The inversion formed a ridge protruding into the lumen around most of the circumference (Fig 7). The inversion was more pronounced in the INV-2 specimens. Within the taenial bands, a slight inversion of the serosa and smooth muscle caused moderate focal thickening of the wall. In nontaenial parts of the wall, inversion was substantially greater (Fig 8). Mucosa covered this fold almost completely by day 28, and the inverted serosal surfaces were held firmly together by maturing fibrous connective tissue. The cut ends of the mucosa and submucosa, at the tip of the fold, were apposed by a thick plug of fibrous connective tissue. The folds varied in height from area to area and from horse to horse but were as pronounced at day 56 as at day 3.

## Discussion

The APP-1 anastomosis was used to evaluate a technique that minimally narrows the lumen of the small colon. Others have used this technique successfully in colonic anastomoses of dogs<sup>15</sup> and human beings.<sup>9</sup> However, the appositional pattern was difficult to perform without some mucosal eversion, which retards healing and delays formation of a fibrin seal, thereby delaying full-thickness healing.<sup>29</sup> Tissue necrosis and disruption of the vasculature has been seen histologically in dogs in which the crushing technique was used. The suture was

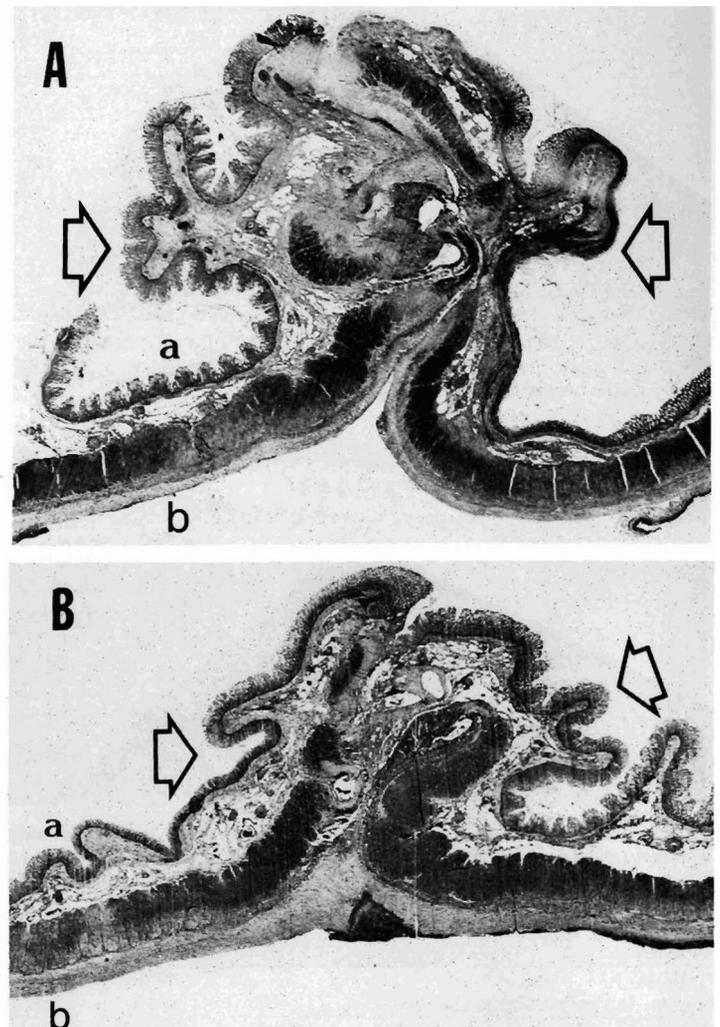


Fig 7—Tissue sections from horse 9 at day 10. A—INV-2 pattern. Notice excessive and uneven inversion of the tissue layers (arrows).  $\times 4.45$ . Original magnification,  $\times 7.3$ . B—APP-2 pattern. Notice moderate tissue inversion (arrows) with apposition better than that in the INV-2 pattern; a = mucosal surface, b = serosal surface. Masson Trichrome stain;  $\times 4.09$ . Original magnification,  $\times 7.3$ .

not applied in a crushing technique in our study because it was difficult to crush the suture loop through the muscular layers of the small colon without breaking the suture and causing excessive mucosal eversion. Because the anastomoses were performed in a highly contaminated area (compared with the small intestine), we chose to use a monofilament absorbable suture with an extended holding strength, as compared with a coated multifilamentous absorbable suture. Nonabsorbable sutures were thought not to be indicated, since the risk of fistula formation might have been greater. Leakage and peritonitis precluded further investigation of this surgical technique.

Inverting techniques are the traditional methods of closure for small intestinal resection and anastomosis,<sup>26,27</sup> but serious complications have been reported with this technique in the small colon.<sup>28</sup> Since the INV-2 and the APP-2 anastomoses ensure an adequate seal of the colon, the technique with the least narrowing of the lumen is preferred. The APP-2 anastomosis resulted in a consistently sealed anastomosis, with considerably fewer im-

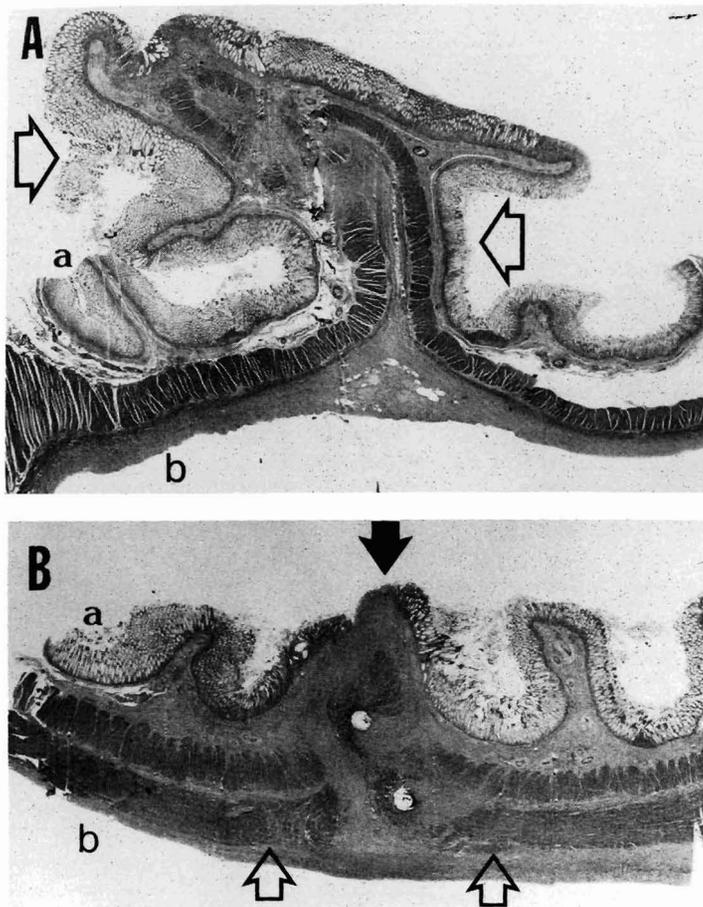


Fig 8—Tissue sections from horse 5 at day 28. A—INV-2 pattern (nontaenial portion of colon wall). Inversion (arrows) is still excessive.  $\times 4.16$ . Original magnification, 7.3. B—INV-2 pattern (taenial portion of colon wall). Inversion (solid arrow) is minimal. Notice the precise apposition of the tissue layers and the thick longitudinal muscle fiber layers forming the taenial band (open arrow); a = mucosal surface, b = serosal surface. Masson Trichrome stain;  $\times 4.27$ . Original magnification,  $\times 7.3$ .

pactions after surgery. Excessive inversion of the colon, resulting in impaction, was the reason for failure of the INV-2 anastomosis.

Compromise of lumen diameter at the anastomotic site is expected to be of more importance in the small colon, given its greatly reduced lumen and its firmer fecal consistency, compared with that of the large colon. Stenosis at the anastomosis can cause postoperative complications by restricting the passage of feces, resulting in abdominal pain, ileus, and an increase in intraluminal pressure, leading to leakage and dehiscence. Excessive tissue inversion created postoperative complications at 42% of the INV-2 anastomosis sites, compared with a 13% incidence of complications at the APP-2 anastomosis sites.

There was little difference in the frequency of adhesion formation between the APP-2 and the INV-2 techniques. However, most of the adhesions of the INV-2 anastomoses were between the anastomotic line and the adjacent mesentery, whereas the APP-2 adhesions were between adjacent loops of small colon. Most adhesions were observed within the first 14 days after surgery. Only small mature pedunculated adhesions were found later in the course of the investigation. Some adhesions may have remodeled and diminished in the later phase of the experiment. Fol-

lowing scar tissue maturation, remodeling of the fibrous reaction with resolution of the adhesions has been recorded.<sup>21,30</sup> Normal intestinal motility, combined with elaboration of collagenase during the maturation phase of wound healing, may be responsible for remodeling of the fibrous adhesions.<sup>30</sup> None of the adhesions with the APP-2 and INV-2 techniques appeared to interfere with the passage of feces.

Histologic examination of the APP-1 suture pattern at day 56 (horse 3) revealed a wide area of dense fibrous connective tissue resulting in poor apposition of the muscular and submucosal layers of the taenial and nontaenial areas. Horse 3 had 2 episodes of mild abdominal pain on days 13 and 35. Other horses did not experience abdominal pain this late in the study. The APP-2 and INV-2 patterns were histologically similar, although inversion of the nontaenial bowel wall was greater with the INV-2 technique. Maturing fibrous connective tissue bridged the apposed bowel ends with both techniques.

Bursting pressures were chosen as strength indicators of the anastomotic site in this and similar studies because the applied pressure represents a constant stress applied evenly to the anastomotic site.<sup>3,4,10,11,14,15,18,21,29,31</sup> In our study, the small colon burst away from the anastomotic line in all specimens. As a result, the bursting pressures did not accurately evaluate the anastomotic strength. Normal colon segments burst at pressures and locations similar to those for the anastomotic segments. In normal small colon, histologic evidence of abrupt separation of the longitudinal muscle fibers at the taenial band junction, with thinning of the fibrous band, may account for failure at this site. As the colon is distended, circular tension is twice as great as longitudinal tension.<sup>32</sup> Circular tension increases proportionally, whereas longitudinal tension is less altered. By virtue of the restraint on the anastomotic ring, caused by the sutures and fibrous healing of the anastomosis, there is a limit to the expansion and therefore circular wall tension in that area.<sup>32</sup> The bowel then ruptures at the weakest area in normal tissues, some distance away from the anastomosis. Tensile testing of a representative fixed width of bowel harvested across the anastomotic line was considered for evaluating bowel strength. However, we believed the choice of taenial or nontaenial bowel wall and the random distribution of strengthening adhesions and weaker inflamed areas would have complicated assessment of bowel strength by this method.

A direct comparison of the 2 anastomoses in each horse eliminated the possibility of variability among subjects. A potentially important variable with this experimental model was the proximal vs distal position for anastomosis. In human surgery there is a higher frequency of anastomotic failure with high, rather than low, colonic anastomosis.<sup>2,9,33</sup> In our study, this difference was obviated by alternating the types of anastomoses between the proximal and distal positions.

The numbers reported in this study were small, but we were able to contrast the major features of the 3 anastomosis techniques. The APP-2 and INV-2 suture patterns gave favorable results, whereas the APP-1 did not. There was little difference between the INV-2 and the APP-2 techniques with regard to adhesions, histologic evaluation of healing, and breaking strength up to day 56. However, the higher frequency of impactions and greater tissue

inversion in the INV-2 group indicates that the APP-2 anastomosis may be the most suitable technique to use in horses.

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