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A COMPARISON OF GAMBEE AND EVERTED STAPLED ANASTOMOSES IN THE JEJUNUM OF THE HORSE

By

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ABSTRACT

A COMPARISON OF
GAMBEE AND EVERTED STAPLED ANASTOMOSES
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Complications from prolonged anesthesia and intestinal anastomosis increase mortality due to obstruction of the small intestine in the horse. Anastomosis with automatic stapling shortens operating time, decreases tissue handling, reduces contamination and should decrease mortality. Gambee and everted, stapled anastomoses of the distal jejunum were each performed during one operation in eight horses and four ponies. Gross and microscopic characteristics of healing were quantitated and compared at 42 to 52 days after operation. The Gambee anastomosis resulted in significantly less constriction ($p<.01$), proximal dilatation ($p<.05$) and alteration of mucosal rugae ($p<.01$). Microscopically there was less distance between severed muscle layer ends ($p<.01$), less bowel wall thickening ($p<.05$), better alignment of muscular layers ($p<.01$), less inflammation ($p<.01$), and better architecture of the mucous membrane ($p<.05$). No significant differences between techniques were found for adhesions and serosal thickening. Several gross and microscopic defects peculiar to the stapled anastomoses were noted. Inferiority of the stapled anastomosis seemed related to eversion.

TO

ALBERT A. GABEL

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INTRODUCTION

1.1 Intestinal Obstruction in the Horse and Its Complications

The horse has a marked tendency toward abdominal distress.[120] Distress initiated in the small intestine is due primarily to normal anatomical and physiological characteristics and to parasitism.[14,34]

The larvae of Strongylus vulgaris migrate to and develop in the wall of the cranial mesenteric artery, the major blood supply to the small intestine.[14] These parasites frequently cause thromboembolic lesions in the artery and its branches thus impairing blood flow to all or parts of the small intestine resulting in ischemia of the intestinal wall.[14,66,120] Aneurysms in the root of the artery caused by these larvae may impinge upon the adjacent and surrounding celicomesenteric ganglion and plexus, the only nervous supply to the small intestine, and disrupt gut motility by interfering with the function of this ganglion and plexus.[14,35,103,120]

Passage of ingesta is slowed at the duodenal loop and impaction occasionally results.[66] Impactions also occur at the terminal ileum where it constricts proximal to the cecum.[66] The end of the ileum is partially telescoped into the cecum and cecal orifice is surrounded by a thick, muscular ileal sphincter.[35,58,66] This feature predisposes the horse to ileocecal intussusception and incarceration of the terminal ileum.[58,66]

There is an average of 20 meters of small intestine suspended on a mesentery 50 cm in length.[35,121,149] For this reason the small intestine is prone to rotation about its mesenteric attachment and other types of displacement.[35]

The small intestine of the horse has strong peristaltic movements and a rapid emptying rate (20-30 minutes) which predisposes the horse to spasmodic colic and intestinal intussusception.[14,120] This vigorous peristalsis also results in rapid intestinal distension secondary to obstruction and aggravates the associated pain.[66]

Operations on the small intestine of the horse are almost always for some form of obstructive lesion.[97] Complete obstruction is more common than partial obstruction.[97] Strangulation is defined as displacement of intestine causing obstruction to the movement of ingesta and partial or complete obstruction of the circulation to the affected part.[97] Some non-strangulating obstructions from impactions, stenosis and adhesions also require surgical intervention. More than 90 percent of small intestinal obstructions are strangulated.[139] A 20 percent survival rate was found for horses operated for intestinal strangulation.[127]

Specific types of small intestinal strangulation include those due to: (1) volvulus, a twisting of loops of small intestine on their own mesentry; (2) a pedunculated lipoma, normally limited to horses over age ten; (3) bowel entrapment through holes in the mesentery of the small intestine; (4-6) umbilical, inguinal and ventral hernias; (7) herniation through surgical incisions, (8) diaphragmatic hernia (rare); (9) fibrous bands and adhesions (from peritonitis, parasites, abscesses and previous operation); (10) entrapment of bowel through

the epiploic foramen; (12-14) holes in the omentum, mesocolon, and broad ligament of the uterus (a result of injury sustained during pregnancy or parturition); and (15) intussusception, of which terminal ileum or ileocecal intussusceptions are most common.[32,63,96,97,127,148,149,153,154,155]

Complete obstruction results in distended bowel. The bowel becomes progressively paralyzed due to local neuromuscular pressure and feedback inhibition of the vagus nerve.[22] Distension of the bowel results in abnormally high intraluminal pressure which inhibits fluid absorption but not intestinal secretion.[21] Further distension thus occurs and retrograde filling of the stomach follows.[34,148] The horse is unable to vomit due to an unusually muscular cardiac sphincter and a multi-folded gastric mucosa at the cardiac orifice which can occlude the opening.[27,35,58,66] Therefore, pathologic changes due to obstruction of the small intestine occur more rapidly in the horse than in other species.

Ischemic necrosis of the bowel wall results from increased intraluminal pressures.[21] Mesenteric thrombosis due to parasitic migration causes primary ischemic necrosis and obstruction due to ileus of the involved segment.[14,18,120] Constriction of mesenteric vasculature during strangulation results in venous thrombosis, vasocongestion and ischemia.[66,149] Because of bowel wall degeneration secondary to obstruction, resection of the involved segment and anastomosis of the divided ends is the required treatment.[97,154]

The horse with obstruction of the small intestine is susceptible to shock.[149] Stasis of intestinal contents and degeneration of the gut wall enhance endotoxin absorption which is associated with catecholamine

release. Increased catecholamine levels augment peripheral vascular resistance and secondary capillary pooling.[25,26] The results are cellular changes due to hypoxia causing a loss of plasma fluids into interstitial spaces and the abdominal cavity.[21,34,42] Blood lactate increases due to poor perfusion of tissues and the resultant anaerobic metabolism.[27,41,43] The outcome is metabolic acidosis.[34,57,148] If these processes continue, the loss of intravascular fluid leads to a fall in arterial blood pressure, central venous pressure, cardiac output and eventual cardiac failure.[26,57] The horse presented for laparotomy for intestinal obstruction is usually in the later stages of endotoxic shock and is a poor anesthetic risk.[148,155]

Abdominal operations in the horse are physically tiring and time-consuming due to the animal's large size and anatomy. Manipulation of most of the intestinal tract for visual inspection or palpation is necessary for a thorough examination.[149] The cecum and large colon may exceed 24-30 cm in diameter, 5 m in total length and 150 liters in capacity.[103] The small intestine is about 22 m long. It averages 6 cm in diameter, making anastomosis a lengthy and tedious procedure.[58] Fluid or gas distended intestines require delicate handling.[149,154] The deep barrel of the horse complicates aseptic technique and adds to the physical difficulty of the operation.

Postoperative complications are intestinal ileus, peritonitis, metabolic and respiratory acidosis, electrolyte and fluid imbalance, hemodynamic derangements, cardiovascular shock and pulmonary atelectasis.[27,149,156] Prolonged anesthesia increases the incidence and severity of these complications.[72,96,97,99,149] Most sedative and anesthetic drugs induce undesirable physiological changes, notably decrease of heart rate, blood

pressure, cardiac output, respiratory rate and tidal volume.[133,155] These changes produce hypoxemia and hypercapnea. The latter can result in myocardial depression and respiratory acidosis which can lead to cardiac dysrhythmias.[155]

Complications caused by the heavy weight of the horse are aggravated by prolonged recumbency during anesthesia. The weight of the thoracic and abdominal viscera contributes to pulmonary atelectasis and passive congestion.[129] The heavy mass of the animal and lack of movement of the limbs decrease blood flow to peripheral dependent skeletal muscles producing ischemic necrosis of the muscle cells and subsequent myositis and azoturia.[69,129,149] This heavy mass also compresses nerves, resulting in partial paralysis of various types.[129,149] The position of dorsal recumbency required for most celiotomies is more deleterious than lateral recumbency.[84] The dorsal position increases the severity of cardiac disturbances, pulmonary atelectasis and arterio-venous shunts, ventilation-perfusion imbalance, acidosis, myositis of the gluteal muscles and partial hindleg paralysis.[72,84,99,152]

Intestinal spillage, trauma to the bowel, ischemia of the bowel and leakage from the anastomosis contribute to peritonitis and ileus.[19] Adhesions can form secondary to peritonitis and ischemia of bowel wall.[49] Ischemia, leakage and chronic inflammation at the anastomosis can result in stenosis of the lumen.[106,153] Late complications of intestinal anastomosis are repeated episodes of abdominal pain and obstruction caused by stenosis, abcess or adhesions.[66,104,149,153]

Development of new intestinal surgical techniques in the horse should be aimed at lowering the incidence and severity of complications. Reduction of anesthetic duration should reduce complications as well as

alleviate fatigue for the surgeon and result in a more painstaking conclusion of the operation. Complications would be decreased by lessening intestinal spillage, trauma to the bowel, ischemia of the bowel, leakage from the anastomosis and chronic inflammation at the anastomosis.

1.2 Advantages of Automatic Stapling

Automatic stapling techniques appear to have many features desirable for anastomosis of the small intestine in the horse. Automatic stapling instruments are reported to have the following advantages associated with their use compared to the use of conventional suturing techniques:[3,16,36,109,110,117,135,136,147]

1. Decreased tissue handling.
2. The non-crushing "B" shape of the staples permits nutrition to pass through the staple line to the cut edge of the tissue promoting healing and reducing the possibility of necrosis.
3. The essentially non-reactive staples reduce the occurrence of tissue reaction or infection.
4. Anastomoses performed with staplers appear to function sooner than with other techniques.
5. Avoids the shifting and tearing that occur in hand-performed sutures.
6. Needle and suture holes are of the same fine caliber, since the staple is both the needle and suture.
7. No bowel trauma due to suture dragging through the tissue.
8. Leakage from the anastomosis is reduced due to uniform and firm compression of the tissues around the entire circumference.
9. Significantly decreased operative time.

10. Results depend less upon the operator's skill.
11. Stapling procedures are simple to perform and decrease fatigue to the operator.
12. Results are more uniform between surgeons.
13. Reduced spillage of bowel contents.

Most articles on intestinal anastomosis in the horse are clinical. In the only experimental study reported, Reinertson compared clinical recovery and observations of gross healing at necropsy of everted, end-on (Gambee), and inverted anastomoses in the horse.[118] His findings, though inconclusive, indicated that end-on apposition of bowel wall ends is ideal and everted anastomoses are clinically acceptable. Histologic evaluation of healing of intestinal anastomoses or comparative studies using automatic stapling in the horse have not been previously reported.

1.3 Purpose of This Investigation

The investigation undertaken was designed to evaluate healing in everted stapled and Gambee anastomoses. Both types of anastomosis were performed in each animal at the same operation. Healing of the stapled anastomosis was compared to healing of the Gambee anastomosis in the same animal under identical conditions. This method of obtaining paired samples utilizes the animal as its own control.

The animals were sacrificed and intestines harvested from 42 to 52 days after operation. Healing in the anastomotic region was evaluated by gross and histologic examination. Gross observations included evaluation of adhesions, serosal lesions, and mucosal lesions. Calculations of anastomotic constriction and dilatation proximal to the anastomosis were based on luminal measurements. The anastomotic region

was evaluated microscopically for inflammatory response and return to normal histological architecture. The latter included: estimation of collagen deposition by measuring bowel wall thickness, distance between the cut ends of intestinal muscle layers and serosal thickness; evaluation of alignment of intestinal muscle layers and evaluation of the architecture and continuity of the mucous membrane.

REVIEW OF LITERATURE

Intestinal anastomosis is a surgical establishment of a communication between two formerly distant portions of instestine.[44] Intestinal anastomosis is most often created where disease processes necessitate removal of a section of intestine. In the horse these processes are usually associated with obstruction or potential obstruction of the intestinal lumen.[153]

Intestinal anastomosis has been a hazardous operation in both humans and animals because of complications from obstruction and from the anastomotic procedure itself.[83] Better understanding of the pathophysiology of intestinal obstruction, advances in supportive care and development of antibiotics have considerably increased the safety of anastomotic procedures. Because complications still occur, surgeons continue to study new methods of anastomosis.

2.1 Methods of Anastomosis

There is no accepted format to completely describe differently made anastomoses. The words, "technique" and "method" are all used interchangeably to describe different aspects of the intestinal anastomosis. For ease of discussion, some definitions have been made here.

2.1.1 Open or Closed Anastomosis

A closed anastomosis is accomplished while both ends of the intestine are clamped closed. The suture pattern is performed with the clamps closed

and tied when the clamps are removed. This technique was designed to prevent spillage of intestinal contents during operation and thus provide an aseptic closure.[123]

An open anastomosis is performed with the lumen exposed. To prevent spillage of intestinal contents, the lumina of both segments of intestine are occluded a short distance from the site of anastomosis. The ends of the lumen may be suctioned or rinsed clean of chyme to further decrease risk of contamination of the abdominal cavity.[53,74]

2.1.2 Configuration of the Anastomosis

The configuration describes how the portions of bowel meet in the anastomosis. (Figure 1) The luminal pathway of the bowel is determined by the configuration. Discrepancy in size of bowel, character of lesions, location and exposure of the site may dictate the configuration to be used.[29] A number of suture patterns may be used to obtain each configuration.

End-to-End

After resection, the cut ends of bowel are brought together with their cut surfaces apposed and sutured to each other. The luminal pathway established is as before resection; it is straight with no change in direction. (Figure 1a)

Side-to-Side

The cut ends of the bowel are closed and both the distal and proximal portions of bowel are joined together around incisions made through the side of their walls. The lumen of the anastomosis may be made larger than the normal diameter of the bowel, allowing easy passage of ingesta. The luminal pathway is changed to a

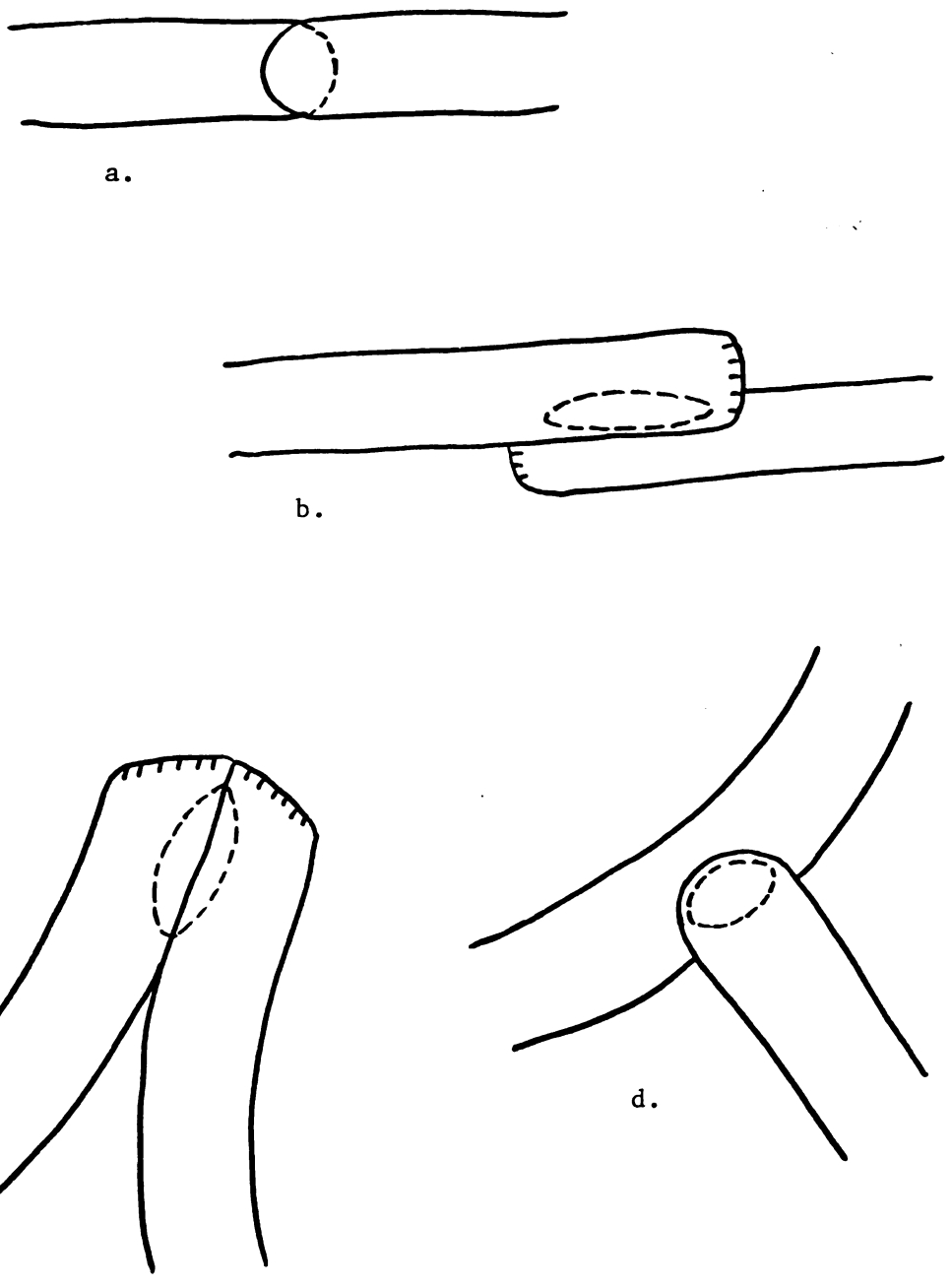

Figure 1. Various configurations for intestinal anastomosis: a. end-to-end; b. side-to-side, isoperistaltic; c. side-to-side, double-barrelled (functional end-to-end); d. end-to-side

zig-zag pattern (Figure 1b) if the anastomosis is iso-peristaltic and to a U-shape (Figure 1c) if it is a double-barrelled (functional end-to-end) anastomosis.[107]

Anastomoses are performed in this configuration to circumvent a lesion which is left in place, to create a gastric pouch or to compensate for a large discrepancy between the diameters of the bowel to be anastomosed.[29]

End-to-Side

The end-to-side anastomosis is usually made from the end of the proximal portion of bowel to the side of the distal bowel. This configuration is used most often to construct diversion limbs.[29] (Figure 1d)

2.1.3 Apposition of Bowel Wall Ends

The bowel wall to be rejoined may be apposed in several arrangements:

1. The cut ends may abut one another (Figure 2a), described as end-on.[28]
2. The cut ends may be inverted in the lumen of the intestine.[28] (Figure 2b)
3. They may be everted.[60] (Figure 2c)

Modifications of these methods include end-on with mucosal inversion (Figure 2d), very mild inversion and double to triple inversion.[53,60] Double and triple inversion is created by adding second and third rows of inverting-type suture patterns. The suture pattern will also determine to some extent the degree of eversion.

2.1.4 Suture Patterns

The suture pattern will help determine the manner of apposition of bowel wall. A simple interrupted pattern has been used for end-on,

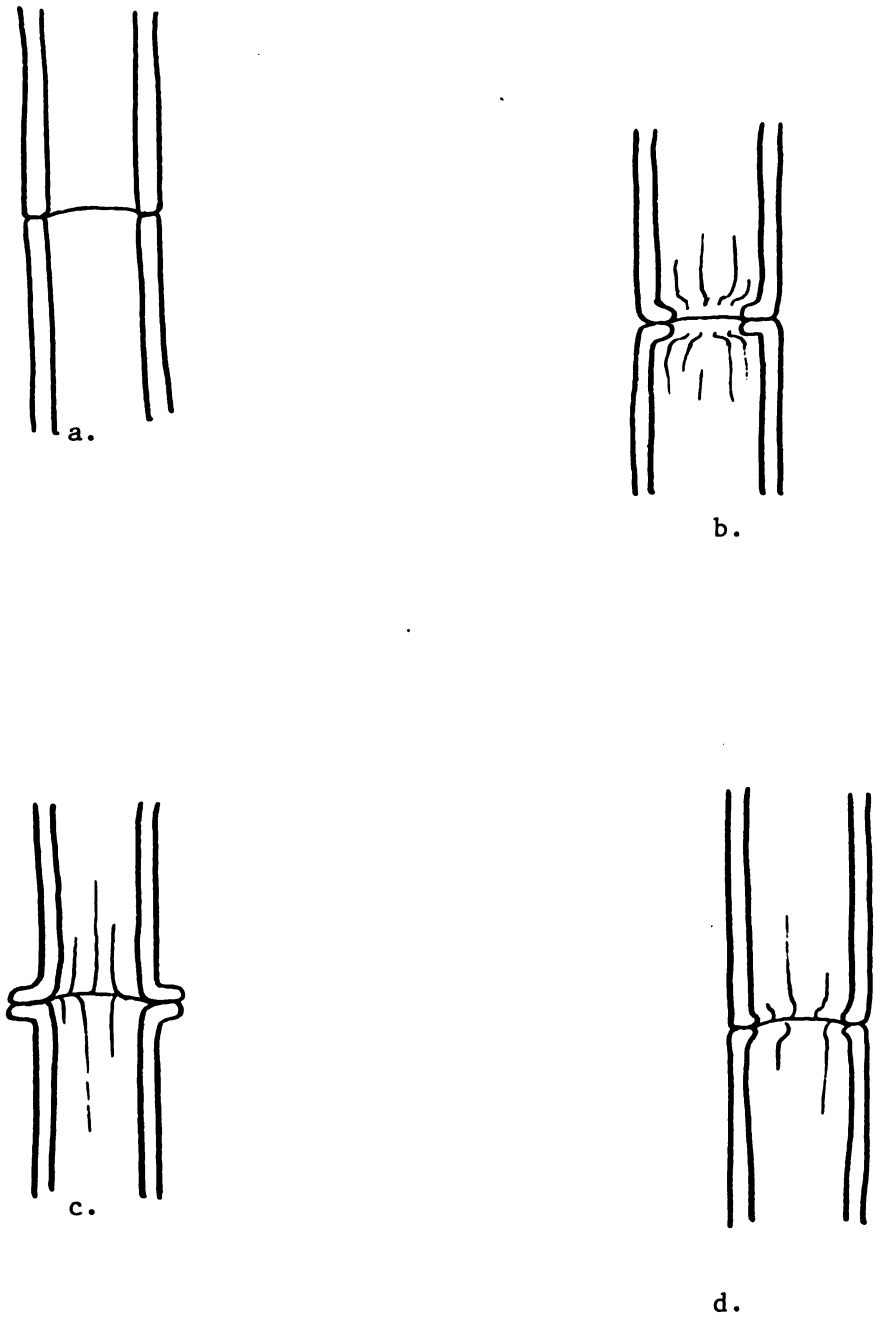

Figure 2. Apposition of bowel wall ends for anastomosis: a. end-on; b. inverted; c. everted; d. mucosal inversion

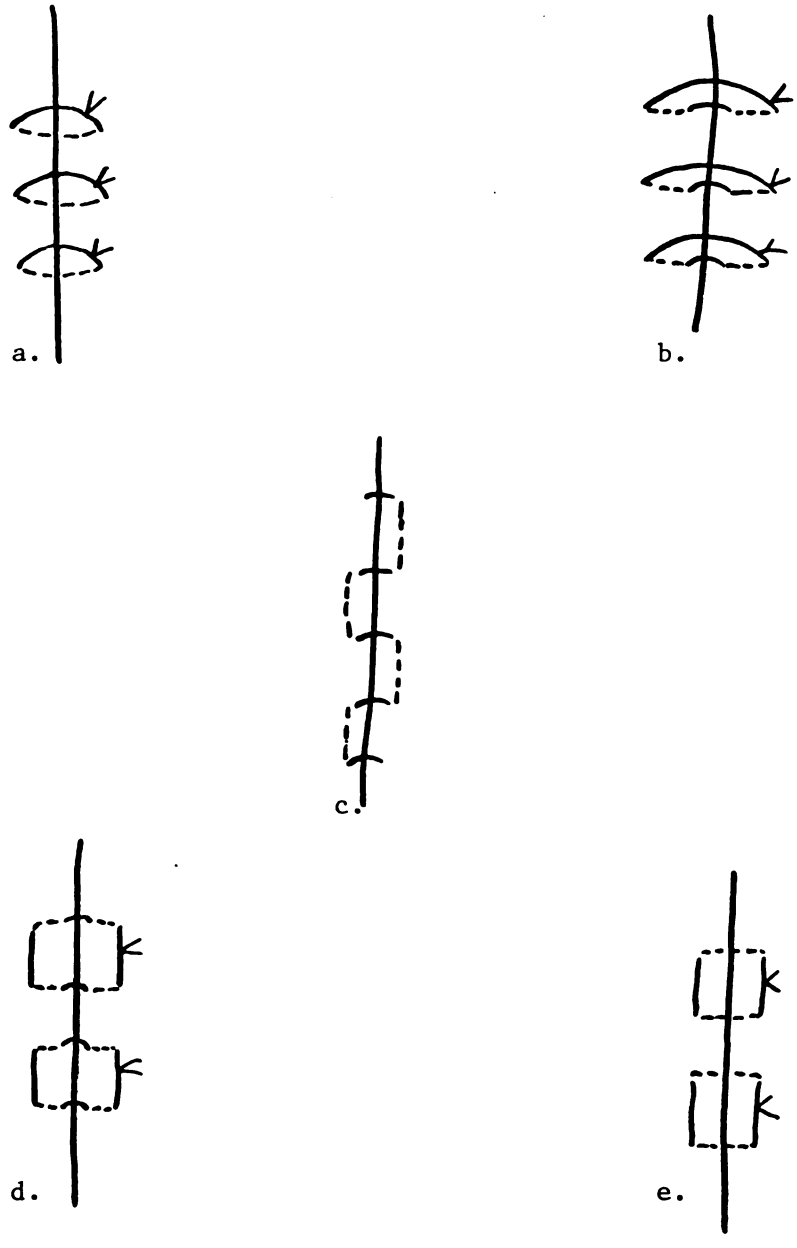

Figure 3. Suture patterns used for anastomosis: a. simple interrupted; b. Lembert; c. Cushing or Connell; d. Halsted; e. interrupted horizontal mattress

mild inversion and mild eversion (Figure 3a).[53,59,90] The Lembert (Figure 3b), Cushing and Connell (Figure 3c) suture patterns result in inversion of the bowel.[85] The Cushing and Connell are alike except the Connell enters the lumen and the Cushing does not. Halsted's "plain quilt" stitch, an interrupted mattress pattern, creates a one-layer mildly inverting apposition (Figure 3d).[73] A continuous or interrupted horizontal mattress may be used for an everted apposition (Figure 3e).[60] Gambee initiated the use of a simple interrupted suture tied within the lumen. This pattern was used on one half of the bowel to maintain mild inversion. The "Gambee" stitch, applied from the serosal side, was used to mildly invert the mucosa of the other half of the anastomosis (Figures 18 & 19).[53] Staples may be used to produce inverted side-to-side anastomoses or everted end-to-end anastomoses (Figure 10).[109]

2.2 History of Intestinal Anastomosis

In 1812, Travers wrote concerning intestinal anastomosis: if secure closure and close contact were achieved, the particular method of closure was not important.[144] Since that seemingly reasonable statement was made, discussions regarding intestinal anastomosis, nevertheless, have concentrated on which method is best.

In the early 17th century, it was believed that adhesions were necessary for healing of intestinal wounds. Bichat found more adhesions associated with inverted anastomoses and recommended that type of apposition for superior healing. In 1820 Jobert performed the first interrupted through-and-through inverting anastomoses. Lembert popularized serosa-to-serosa apposition in 1826. The serosa was thought to have the best

tensile strength and to be leak-proof. Lembert emphasized the importance of closing the muscular layer separately from the mucosa. Inverted closures and multiple layers became customary.[60,62,116]

The next landmark for intestinal surgery was Halsted's paper of 1887 in which he described his experiments using dogs for circular suture of the intestine. He noted that healing could take place without adhesions. He was the first to criticize multiple inversion for decreasing blood supply to the cut ends of bowel and so preferred one-layer closures. Halsted used glass clamps to control the fecal stream and insisted that, to further limit bacterial contamination, the suture material should not enter the lumen of the gut. He considered the Lembert suture pattern to be constricting and recommended the "plain quilt" stitch, an interrupted mattress pattern. Halsted's most notable contribution was his recognition of the submucosa as the strongest layer of the intestine. He emphasized the importance of including this layer in each bite of suture.[73]

Despite Halsted's findings and because anastomotic procedures continued to result in peritonitis, the two and three layer inverting anastomosis became the standard operation in the late 1800s. It was presumed to produce a leakproof closure.[60]

The closed method of anastomosis was introduced by Kerr in 1923 to provide for an aseptic anastomosis. The open anastomosis was not again used until the mid 1940s, when anastomotic operations were made safer with antibiotic treatment.[60] Since that time, there has been a gradual increase in the clinical application of the open anastomosis.

Saint and Mann, like Halsted, recognized that the interrupted suture was more sparing of the blood supply than continuous patterns; they used a

simple interrupted pattern for esophageal anastomosis.[122] In 1951, Gambee recommended a one-layer, simple-interrupted pattern that produced a mild inversion.[53] In this pattern the suture passed through the lumen and through all layers of the bowel wall, or "through-and-through." A single layer, simple interrupted pattern used for end-on anastomosis was preferred by others in the 1960s and has come into general use in the 1970s.[153] Many surgeons have doubted the safety of the one-layer techniques and debate since the 1950s has centered on this subject.[54]

In the 1960s a new controversy began. An everting procedure, the Navy technique, was used experimentally in dogs and clinically in humans by Getzen, et al., and was found to be a stronger closure than any inverted type.[60] A number of studies have been done comparing inverted and everted techniques, with mixed results.

2.3 Wound Healing

2.3.1 Phases of Wound Healing

Substrate Phase: 1-4 days

This phase is also called the inflammatory phase or lag phase. The components of the substrate phase are vascular, hemostatic and cellular in sequence.

Immediately after wounding vasoconstriction occurs, followed by vasodilation and exudation of plasma proteins. Blood vessels then retract, succeeded by platelet aggregation, fibrin formation and clotting.[105]

In 12 to 16 hours after wounding the cellular response begins. Neutrophilic granulocytes migrate into the area. Granules from

degenerated neutrophils play a role in resolution of fibrin, tissue debris and bacteria. Fibrinolytic activity is directly related to breakdown of granulocytes. Lymphocytes, macrophages and monocytes appear late in the substrate phase.[81]

There is an optimal inflammatory response for rapid fibroplasia. Excessive trauma with marked inflammation delays repair and may proceed to more massive fibroplasia and wound contraction.[105] The smaller the amount of new collagen, the more rapidly it can be structurally strengthened.[48] Bacteria initiate physiologic reactions including cell-mediated responses that result in increased tissue injury.[81]

Proliferative Phase: 5-20 days

Epithelial and fibroblastic cells proliferate rapidly during this phase in most tissues. The epithelium covers defects both by mitosis and migration.[75,88] Rapid collagen synthesis accounts for increase in wound strength during this phase. Most tissues gain only 25 to 30 percent of original tensile strength until remodeling takes place.[81,105]

Remodeling Phase: 20 days-2 years

Remodeling, reorganization and differentiation of collagen begin in the third week and last for many months in most tissues. Collagen fibers realign in response to stress and strain in the wound. During remodeling, gains in tissue strength are made slowly and continue for years. Most tissues regain only 60 percent of original strength by 50 days and never regain original strength.[75,81,105]

2.3.2 Intestinal Wound Healing

Healing of the gastrointestinal tract differs from fascial or skin healing in three ways:

1. The proliferative phase is marked by a rapid decrease in collagen.[46,105]
2. The remodeling phase is almost nonexistent.[46]
3. The wound reaches full strength in 14 days and is measurably stronger than the surrounding normal tissue.[28,46]

The loss of existing collagen in the proliferative phase is due to increased concentrations of collagenase in the mucosa.[46] Postoperative collagenase activity in the gut is about ten times normal.[78] Collagenase activity in the gut is higher than in other tissues and the effects are greater. In fascia and skin the collagen is much more dense and less subject to rapid dissolution so that increases in collagenase activity are not so devastating to the strength of the wound.[46]

Lytic activity predominates for three or four days. Decreases in tensile and bursting strength at the anastomosis and in adjacent bowel become critical at this time.[91] In addition, infection and trauma increase collagenase activity at the anastomosis.[78] Exposure to peritoneal defenses are important to control numbers of bacteria.[105] Poor blood supply, protein depletion of the patient and hypoxemia retard collagen synthesis.[46,105]

There is almost no remodeling of collagen in intestinal wounds because the bowel wall is composed of fairly loose connective tissue. For that reason the wound reaches normal strength when collagen content is normal. In two to three weeks when the collagen content at the anastomosis is increased above that of the normal surrounding bowel,

first the bursting strength, then the tensile strength of the anastomosis exceeds that of the normal bowel wall.[75,98]

Connective tissue replaces both muscular layers in the intestinal wall at the anastomosis.[60] There is often an increase in wall thickness due to connective tissue. This decreases the expansibility of the anastomosis in comparison with the normal intestinal wall. The normal intestine is pliable because muscle is easily expanded and submucosa is composed of disorganized collagen.[52] Normal extension in the submucosa is due to straightening of the collagen fiber network. Collagen in the wound is more dense, more organized and, therefore, less able to expand than unwounded tissues. The basic quality of a wound cannot be measured only by tensile or bursting strength. Pliability of the intestinal wound is important to a functional anastomosis.[49]

Phases of healing vary with different methods of anastomosis. Sealing of the fresh anastomosis, migration of blood vessels across the anastomosis, the amount of granulation tissue formed at the anastomosis, and spanning of the wound by epithelium are influenced by the method of anastomosis.[60,112,123]

2.3.3 Effect of Suture Pattern on Healing

Suture patterns may depress healing by decreasing blood supply to the anastomosis.[86] Patterns that are placed transverse to the long axis of the bowel tend to compress blood vessels supplying the cut ends of bowel. Mattress patterns like the Halsted (Figure 3d) are especially constricting of blood supply.[28,53]

Continuous patterns also decrease blood supply to the ends of the bowel wall, although they produce a water-tight seal.[28,90] Continuous

suture patterns have also been cited for limiting expansibility of the bowel.[73] Ulcers may result from the use of continuous, non-absorble sutures because the suture is not easily extruded if infected.

Simple interrupted sutures run in the long axis of the bowel and so allow blood to reach the anastomosis despite tension on the suture.[28,90,123] They are recommended in areas of poor blood supply, such as the esophagus.[105,122]

Capillaries can pass through the B-shape of stainless steel staples.[113] The staggered arrangement of staples is said to allow expansion of the bowel.

2.3.4 Effect of Suture Material on Healing

General

All suture is foreign material and should be used sparingly.[37,53,63] Healing of an anastomosis is affected by tissue reaction to the suture materials.[37,75,86] Intense inflammatory reaction to suture can produce edema at the anastomosis that may result in stenosis of the lumen.[60] Inflammatory changes may lead to leakage at the anastomosis. Prolonged inflammation can stimulate excessive production of fibrous tissue, fibrous contraction and adhesions.[86,105,119]

Since sutures are foreign materials, it is best if they would disappear in time.[105] Absorbable suture material may not be used where long-term approximation of tissues is necessary; because tensile strength is gained quickly in an anastomosis, absorbable suture may be used.[52,105] The support of sutures is of greatest importance during the lag phase of healing.[75]

Non-absorbable suture has long been thought appropriate for outer layers of closure only. Traditional materials have been multifilamented. Capillarity is increased over monofilament strands because the surface area of the suture strand is increased.[31,40] This is true even for materials as impervious as stainless steel although capillarity is greatest in more wettable fibers. Braiding or twisting of non-absorbable suture improves handling characteristics, but increases tissue drag and thus trauma, and adds nothing to knot security.[40,47] Regardless of composition, multifilament materials leave interstices for harboring bacteria.[31,40]

Suture Materials Used for Anastomosis

Non-Absorbable Materials

Natural Materials: Silk and Cotton

Silk has been the traditional suture for gastrointestinal operations. Silk handles very well and is easily knotted. In strength and knot security silk is superior to catgut, collagen and cotton, but inferior to many other materials.[47] Silk is known to induce intense inflammatory reaction, sometimes resulting in abcesses and fistulas.[19,40,123] Cotton handles and reacts similarly. Both types of material lose 30 percent of their strength in two weeks.[45]

Synthetic Materials

Non-absorbable synthetics stimulate very little inflammation, usually of a non-specific nature. They are quite strong in comparison with natural non-absorbable materials and maintain strength longer in situ. They have not been used extensively

for small intestinal anastomosis. Synthetic monofilaments handle poorly.[47]

Polypropylene, a polyolefin, is very good in contaminated wounds because it is a monofilament and inert.[37,47] It has high tensile strength in small calibre, but good knot security requires three or four throws.[40,47,65]

Polyesters, such as Dacron have the advantages of synthetics but the disadvantages of multifilaments. Dacron is even stronger than polypropylene but requires many throws to maintain adequate knot stability.[76]

Wire

Monofilament stainless steel has very little capillarity and very low tissue reactivity.[86] It is the strongest of sutures both in tensile strength and knot security.[76] Monofilament steel causes minimal tissue drag and trauma.[31] Very fine wire is used in intestinal anastomosis. Fragmentation, poor handling and a tendency to cut through tissue are the chief disadvantages.[31,47,86]

Absorbable Suture

Natural: Gut and Tendon Collagen

Gut has been the standard material for closure of the inner (mucosal) layer of intestinal anastomoses.[52] Made from the submucosa of sheep intestine, surgical (chromic) gut stimulates intense inflammatory reaction and edema.[47,76,132] Adhesion formation and increased fibrosis at the anastomosis

is more common with surgical gut than with synthetic absorbables.

Tensile strength of dry catgut is very low in comparison with most other suture materials. Catgut experiences a loss of strength and of knot security when it becomes wet, as it does when implanted in tissues.[25,47] Catgut then maintains strength for ten days, after which time it loses strength rapidly.[25] Strength is completely gone at 21 to 25 days and absorption is usually complete by 50 days.[47,92]

Extruded tendon collagen suture reacts much like surgical (chromic) gut, although it holds a knot better, lasts slightly longer and causes somewhat less tissue reaction.[13,76,132]

Synthetics: Polyglycolic Acid (PGA)

Polyglycolic acid suture has been used for both mucosal and through-and-through closure of intestine. PGA suture has high tensile strength, when compared to nonabsorbable synthetics.[76] It has excellent knot security, loses no strength due to wetness and causes minor tissue reaction of a nonspecific nature.[37,47,92] PGA has a linear loss of strength that does not complement gain of strength in wounds, although it is suitable for intestine because of rapid gain in intestinal wound strength. Negligible suture strength is left at 21 days.[76] Absorption is slower than catgut with traces of the material found at 50 to 90 days.[92]

2.3.5 Complications of Intestinal Healing

Early Complications

Early postoperative complications are obstruction due to luminal stenosis at the anastomosis, abscesses, functional obstruction and peritonitis resulting from dihiscence, leakage or soiling of the abdominal cavity at the time of surgery.[28,79] Pathological ileus may result from any of these causes. Anastomotic disruption is related to tension at the anastomotic site and a compromised vascular supply.[60]

Late Complications

Late complications include adhesions which constrict or compromise the luminal pathway, fistula formation, obstruction from stenosis due to fibrous contraction at the anastomotic site and so-called functional obstruction.[59,73,90,118]

Normal serosa does not form adhesions due to local fibrinolytic activity of a high degree.[119] Formation of adhesions begins with injury to the serosa and accompanying inflammation.[49,98,119] Exudation next occurs with coagulation of the exudate with fibrin formation, adherence of adjacent structures and finally fibroblastic proliferation with organization by collagen deposition.[28,49] All phases of normal wound healing occur in this process.[98]

All anastomoses inflict injury to the serosa, but not all stimulate formation of adhesions. Necrosis or loss of blood supply at the anastomosis is the starting point for adhesions.[49] Leakage of intestinal contents at the anastomisis will stimulate adhesion formation.[28,95,111] In both cases the mesentery, omentum or an organ endowed with good blood supply comes in contact with

the intestine to provide it with a vascular graft and fibroblasts.[49,71,95] With either necrosis or frank leakage of bowel contents, there is escape of bacteria into the peritoneal cavity. Antibiotics have been found to inhibit adhesions.[111] In a leaking anastomosis, adhesions are necessary for healing.[95,98]

Fibroblastic activity at the periphery of the wound which results in sequential production and resorption of collagen is related to wound contraction that causes anastomotic constriction.[46] Necrosis, lack of blood supply and continued inflammation stimulate prolonged fibroblastic activity, resulting in a thicker scar that causes luminal stenosis.[65]

2.4 Presently Accepted Techniques of Intestinal Anastomosis

2.4.1 Open Anastomosis

The open method of anastomosis is preferred by most surgeons. Chemotherapy and antibiotics make it possible to keep the risk of infection at a minimum whether the open or closed method is used.[53] The open method is a safer procedure because it permits a more careful and meticulous technique and is less time-consuming.[29,74]

2.4.2 End-to-End Anastomosis

The end-to-end configuration should always be made if feasible; the flow of chyme and restoration of smooth muscle continuity make it most physiological. Diseases resulting from blind loops and side-tracked bowel are avoided.[20,29] Side-to-side or end-to-side anastomoses are associated with the highest incidence of malfunction of anastomoses for atresia of small bowel.[140]

2.5 Contended Techniques of Intestinal Anastomosis

2.5.1 One-Layer Versus Multiple-Layer Inversion (Standard)

One-Layer Superior

One-layer techniques are more often found superior to multiple-layer techniques. Advantages found for the one-layer apposition are decreased adhesions, ease of technique, very mild luminal obstruction, protection from leakage and excellent vascularity.[1,73 74,91,123] In the first five days of healing, more granulation tissue and reticulum fibers were found in the one-layer closure than the Standard (using special histochemical techniques).[74] Sako and Wangensteen demonstrated earlier cross-circulation in the one-layer apposition versus the Standard by using India ink infusion.[123] With histologic evaluation Hamilton found increased edema in the Standard apposition compared to the one-layer closure.[74] Letwin and Williams found bursting pressures to be significantly greater on one-layer than in Standard appositions.[90] Goligher found fewer dehiscences of colon anastomoses in humans with the one-layer technique.[63] The Standard operation was more time-consuming and more difficult.[74,91]

Inversion of the bowel wall involves folding tissue into the lumen of the bowel. For each layer of inverting suture added, more tissue is folded into the lumen. Because the tissue is inverted 90 degrees to the long axis of the bowel, blood supply to the flange of tissue is decreased.[53,90] Lymphatic and venous drainage is also diminished and the flange becomes edematous and devitalized.[73,74] Continuous sutures and increased amount of suture

further decrease blood supply and limit drainage. This devitalized tissue is a good medium for bacterial growth.[53] It was felt by many workers that this devitalization contributed to leakage and peritonitis.[54,90] Trauma from excessive manipulation of the bowel, local sepsis from leakage and lack of blood supply are the main causes of pathological adhesions.[28,49]

It has been increasingly recognized that the larger the flange of tissue inverted, the more likely it is to be obstructive.[53,90] However, Hamilton found the one-layer Halstead closure to be nearly as obstructive as a two-layer closure.[74] Obstructions from inversion occur in the early phases of healing. The inverted tissue later sloughs into the lumen.

Multiple-Layer Superior

Some investigators found the Standard apposition to be superior to the one-layer. By excluding the anastomosis from the peritoneum, Cohen and Harrison estimated leakage to be greater in the one-layer apposition.[28] Loeb also found the Standard to be stronger.[91] Abramowitz and McAlister, through microangiographic techniques, showed that the double inverted bowel does maintain good vascularity and found cross-circulation at one week of healing.[1] Because the Standard anastomosis has been in use for so long with good results, many surgeons have felt it was a safer technique and have attributed complications to poor surgical technique.

2.5.2 Inverted Versus Everted Apposition

Although everted procedures were probably among the first attempts at anastomosis, eversion of gut mucosa has been considered dangerous

since Lembert popularized the technique of serosa-to-serosa apposition. The principal hazards of inversion, i.e., lumen narrowing, suture line ischemia and anastomotic breakdown, have been attributed to poor surgical technique. Everted apposition has recently been examined to alleviate the morbidity caused by these factors.

Investigators that compared a mildly inverting suture pattern, (Gambee) with an everting pattern (Navy) most often found the Gambee to be superior.[63] The results of healing may be altered by variations in the application of each suture pattern. For example, a simple interrupted pattern was used most often to produce the everted anastomosis. Some authors found this anastomosis to revert to an end-on apposition or that the apposition would vary from inverted to everted around the circumference of the anastomosis.[111] Ravitch, et al., used a mattress pattern to assure mucosa-to-mucosa apposition.[111]

If small bites of tissue are taken when performing the Gambee pattern, negligible cuffing of tissue results. Large bites taken could result in a considerable cuff of tissue inverted.

Inversion Superior

Healing of everted anastomoses showed no early seal of the wound. By contrast, the inverted anastomosis gave evidence of a vascularized coagulum (microangiographic techniques) at the serosal surface of the anastomosis at 48-72 hours postoperatively.[1] Regeneration of blood vessels began early in the inverted anastomosis and circulation was established across the anastomosis by seven to nine days.[123] Regeneration of blood vessels in everted anastomoses began by seven days but cross-circulation was not visible until 14 days (India ink infusion) and in a different experiment, until

six weeks (microangiography).[1,123]

Mucosal degeneration must occur before healing can take place in the everted anastomosis.[60] This extends the lag period, when the anastomosis is weakest.

By the ninth day, the inverted closures were consistently lined by a continuous layer of mucosa and there was good continuity of the muscular layers. The everted anastomosis did not obtain this degree of reorganization before the twenty-eighth day. A plug of omentum, mesentery and leukocytes sealed this closure during this period.[123,146]

At six weeks an avascular line continued to separate mucosal surfaces in the everted anastomosis by microangiographic techniques: the mucosa was histologically discontinuous.[1,111] A slow return to normal mucosal architecture was the usual finding.[106]

Some authors found edema and inflammation to be greater in the everted anastomosis.[74,111,134] This produces an undesirable delay in healing.[111] Microabcesses and mucoceles were found in the suture line of everted closures that threatened to weaken the anastomosis.[91,106,111]

The inverted cuff in a properly constructed one-layer anastomosis was negligible. Stenosis was four percent for the inverted and three percent for everted anastomosis in the early postoperative period.[74]

Though different methods of study were used, the inverted anastomosis was usually found to be significantly stronger during the entire period of healing until 28 days postoperatively.[74,91,146] Some investigators found excessive leakage in the everted anastomosis

during the early phases of healing.[1,2,98] Some anastomoses in dogs did not heal and others had dehiscence.[24] In clinical trials in humans, Goligher found the incidence of dehiscence in everted anastomoses to be five times greater than in inverted anastomoses.[63]

Leakage results in adhesions in an attempt to stop the leakage.[28,111] Desquamating exposed mucosa in everted apposition and increased inflammation due to capillary leakage between mucosal surfaces were cited as causes for adhesions; serosa-to-serosa apposition prevents leakage.[1,98] Everted apposition significantly increases chances for severe adhesions and subsequent complications and late death.[1,2,74,91,98,146]

The lumen of everted anastomoses tended to be compromised by adhesions.[1,118] In growing pigs, the anastomosis shrank in size and caused deaths from obstruction.[2] Goligher found progressive stenosis in everted colonic anastomoses in humans.[64] This type of anastomotic constriction may be due to fibrous contraction caused by chronic inflammation or tissue hypoxia.[65,111]

Eversion Superior

The events of healing in everted and inverted anastomoses were described differently by several investigators.[59,60] Healing began with a fibrin seal that filled the anastomotic site in both types of apposition. Exposed mucosa in everted apposition underwent progressive regression or "disuse atrophy" between the first and seventh day.[60] From the seventh to the twenty-first day this regression and concommitant healing resulted in a smooth mucosal conjunction. Ravitch found that mucosal degeneration was not necessary for healing to occur: fibrous tissue migrated through

the mucosa, bridging the anastomotic defect.[111]

Inflammation was significantly greater in inverted anastomoses from early healing to three months postoperatively. No significant mucosal or submucosal inflammation occured in everted anastomoses at three months.[60]

The muscular and submucosal layers of the bowel wall tended to align normally in the everted anastomosis. There was very little fibrous tissue interposed at the anastomotic junction. At three months the inverted anastomosis had a constant fibrous separation at the anastomotic junction. The bowel wall layers seldom aligned properly.[60,111,113]

The everting procedure provided the least constriction in the immediate postoperative period.[60,74,118] Getzen, et al., reported that all inverted specimens were stenosed and created a proximal dilation at phases of healing from 12 hours to 21 days.[59,60]

Mellish found the everted anastomosis to be as strong as the inverted anastomosis.[98] Getzen, et al., had determined adhesions to be alike for both inverted and everted anastomoses.[60]

2.6 History of Mechanical Stapling

Mechanical suturing methods were first conceived to avoid soiling of the abdomen with gastrointestinal contents, considered the major reason for mortality in gastrointestinal resection.[38] Resection of the stomach was of the most concern, due to the wide resection opening and difficult mobilization of this organ.

The Hultl-Fischer stitching forceps, a Hungarian product devised in 1908, placed two rows of staples in a chessboard-like pattern across the resected end. This ponderous and complicated instrument weighed

3.5 kg and took two hours to assemble; hence, it never gained much popularity among surgeons.[38] Adam, of Hungary, created a similar device in 1908.[135]

In 1923, Aladar dePetz, also of Hungary, invented an instrument that places two parallel rows of stapled one-fourth inch apart, separated by a crushed furrow. With a crushing surface five and one-half inches long, the stapler is in size and shape similar to the stomach crushing clamp of Payr. The instrument is first clamped across the stomach at the point of desired resection. The removable handle is attached and rotated three times driving 46 U-shaped silver staples one pair at a time through both walls of the stomach and against the anvil, giving the closed staple a B-shape. The stapler was of hard-forged, non-rusting steel and did attain some popularity. DePetz noted that the staples were dispelled into the stomach on healing.[38] DePetz claimed good success due to asepsis in four years of performing stomach resections with his machine. In addition, the apparatus was used to close other organ segments in preparation for anastomosis.

Steichen and Ravitch related that the dePetz clamp was known to produce a leak-proof, hemostatic crushing closure of the stomach duodenum and colon, but "the gross staples of new or German silver, in spite of the correct B formation, were never relied on for definite closure of the bowel."[136]

Friedrich, in 1934, devised a stapler much like modern devices, of C-clamp design and with exchangeable cartridges. Compression of tissues is achieved by squeezing the handle of the instrument once; a second compression drives home all 32 staples at once, arranged in two parallel, paired rows. Despite improvements on dePetz's stapler, Friedrich's

device never gained wide acceptance, a fate it shared with similar devices proposed by von Bruecke (1934) and von Seemen (1935). Sandor, in 1936, and Tomoda, in 1937, and Nakayama, in 1964, also improved on dePetz's initial idea with models of their own.[70,136]

Interest extended to mechanical suture for other purposes. Busto and Bucherl (1954) used staples experimentally in the closure of bronchial stumps.[23] Samuels experimented with blood vessel staple anastomosis in 1955 and has since developed a hemostatic clip.[124]

Vogelfanger and Beattie, in Canada, and Nakayama and associates (1964), in Japan, have devised instruments for vascular anastomoses.[70,101]

2.7 The Soviet Instruments

As a part of the program for the improvement of medical technology and services in the Soviet Union, the Council of Ministers of the USSR established in 1951 the Scientific Research Institute of Experimental Surgical Apparatus and Instruments (NIIEKHiI). The institute's structure provides for a complete cycle of scientific investigations and practical work for the development of new surgical apparatuses, from the drawing board to the production of experimental models, which are tested in the institute's experimental clinical department and proved in the best hospitals of the USSR.[69]

High priority was given to the development of automatic suturing devices and, to that end, stipulations were formulated to govern the medical design and operational features of the instruments. They are abbreviated as follows:

1. must take less time than manual suturing
2. the biological and physiological characteristics must be superior to manual results

3. the quality of the outcome must depend as little as possible on the capabilities of the surgeon
4. the apparatus must reduce trauma to the tissues and adjacent organs compared with manual methods.[69]

Since 1951, over 300 instruments have been designed by teams of engineers, technicians and doctors, more than 30 of which were put into mass production and some of which have been used extensively in clinical practic.[70] Among the most original products of the institute (NIIEKHiI) is an apparatus for the mechanical ligation of vessels with tantalum ligatures.

The first models for circular angiorrhaphy were built by a team headed by Gudov and have since been radically redesigned so that the appliances have become handier and cheaper. The interchangeable inserts permit vessels of any caliber to be sutured without damaging the intima or leading to constriction due to eversion of the vessel ends and stapling around the periphery.[4] Tantalum causes no inflammation and, because the staples do not enter the vascular lumen, thrombosis is prevented.[4]

Indications for use include:

1. traumatic vascular lesions
2. aneurysms
3. organ grafts
4. plastic operations on vessels
5. reconstructive surgery
6. embolectomy
7. suturing bile ducts
8. suturing the ureter.[128]

By 1956, Androsov had reported 29 successes of 29 attempts at angiorrhaphy for vessel injury and 42 good results of angiorrhapy for aneurysm.[4]

The device for mechanical suturing of the bronchial stump in pneumonectomy or lobectomy was suggested and tested by Babuler in 1952, but needed improvement. The second apparatus, the BSS, corrected the problems of leakage. Made of eight parts, able to be stripped and assembled without tools, this was the forerunner of the C-clamp staplers. It later evolved into the UKB (Figure 4). Tissue is compressed between the jaws by turning the end nut, and staples are extruded in one row perpendicular to the line of resection. The tantalum sutures are hand loaded into the magazine, a very tedious procedure.[55]

The LAVA vessel ligating apparatus, built in 1955 at the institute, was designed for use on lung hilar vessels to complement the BSS. Both were used for lobectomy and pneumonectomy, predominantly for tuberculosis and cancerous processes. A few splenectomies were performed with the BSS acting to mass ligate splenic vasculature.[56]

The Soviet apparatus UKZh-8 for suturing the gastric stump was developed by Bobrov with assistance of Bablev and associates (Figure 5). It is distinguished from existing models by the fact that it can insert a double row of buried suture. The 0.9 kg device passes the first row of tantalum sutures through all layers of both gastric walls, compressed beforehand, along the line of sutures with a force sufficient to insure hemostatsis. This row of sutures invaginates into the gastric lumen as the second row passes through the serous and muscular layers of the anterior and posterior walls. The apparatus can be used in resection of both the antral and cardiac portions of the stomach with a transverse

or oblique incision. Two to five minutes are required to staple the gastric stump.[7,17]

The Soviets developed an instrument for double ligating the mesenteric vessels and one that forms an end-to-end or end-to-side intestinal anastomosis. The anastomosing apparatus consists of two hinged, detachable clamps that do not crush but only hold the intestinal walls and close the lumen so that intestinal contents do not flow out. Each clamp has a matrix on one blade and a magazine containing U-shaped staples on the other. The clamps are inserted on the intestine so that the intestinal segments are approximated. When the plunger is pressed, the staples transfix the intestinal walls and are bent into a B-shape by the matrix. It remains for the surgeon to apply sero-muscular sutures.[11]

The UKL device was developed for suturing of mucous membrane for gastro-esophageal resection. In 1957 Bobrov reported on the SMSH, developed for seromuscular anastomosis.[17] In 1958, Vittenberger described an apparatus for simulataneous gastric resection and gastrointestinal anastomosis by a closed method.[150]

Some 100 types of instruments were evolved and used in Soviet intestinal surgery by 1957.[10,82] In 1970 Androsov described the following instruments for use in abdominal surgery:[5]

1. UKZh-8, for inverted closure of gastric stump (Figure 5)
2. PKS-25, for performing oesophago-enterostomy
3. KTs-28, for creating an anastomosis with the rectum
4. NZhKA-60, for performing lateral gastro-enterostomy (Figure 4)
5. UTL-70, for suturing pulmonary tissue

The PKS-25 is a cylindrical instrument mounted in a gun-like fashion on a squeezable handle. It is inserted into the lumen of the intestine

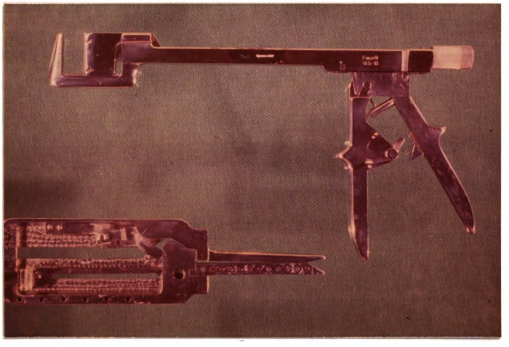

Figure 4. The Soviet instruments, UKB, (above) for bronchial stapling, and NZhKA-60 for lateral gastroenterostomy.

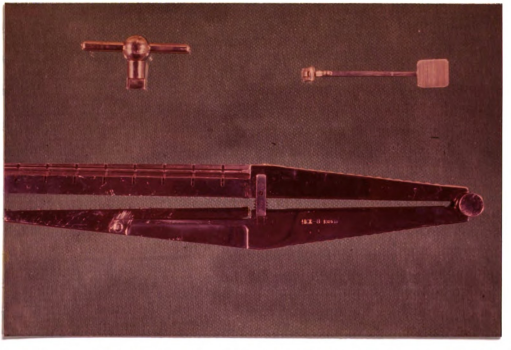

Figure 5. The Soviet instrument UKZh-8 for inverted closure of gastric stump.

through an enterotomy incision and directed proximally. A purse-string suture holds the mushroom-shaped cap end with its anvil in the esophagus. The cap end is inserted into the apparatus and, with a single pressure to the handles, the staples are projected, forming a circular, single-row inverting anastomosis, while simultaneously an opening is made between the esophagus and intestine. Androsov reported clinical success on 33 of 35 patients with this procedure.[5]

A similar instrument, the KTs-28, anastomoses the rectum with the small colon or small intestine by insertion through the anus.[5] Androsov recommended a second row of hand sutures for both of these methods.

The NZhKA-60 is a double-forked instrument that performs side-to-side anastomosis or lateral gastroenterostomy (Figure 4). Each fork of the instrument inserts into one organ. One fork holds the magazine containing the staples and the other the matrix that forms them into the B-shape. The staples are discharged by a sliding mechanism that also pushes a knife between the two rows of staples, forming the opening for the anastomosis.[70,82]

The UTL-70, designed primarily for pulmonary parenchymal stapling in wedge resections, has found wide use in abdominal surgery, especially for closure of gastric and duodenal stumps in resection of the stomach, for closure of the ends of the small intestine and colon after resection, and in creation of an artificial esophagus from small intestine or colon. Prominent in the C-clamp family, the UTL-70 places sutures along its entire length in three different patterns supplied by interchangeable magazines.[5]

Nasarov described one-stage ileocoloplasty by application of the SPTU apparatus for circular anastomosis.[102] The device, apparently very much like the PKs and KTs instruments, was inserted through the

rectum for the lower anastomosis and through a previous colostomy. After successful results in 20 dogs, Nasarov performed ileocolo- and ileocolorectoplasty in 16 persons. Normalization of function ensued in four to six months after ileocoloplasty and in one to one and one-half years after ileocolorectoplasty.

The Soviet instruments are ingenious and beautifully engineered. The tiny staples must be hand-loaded, a very tedious procedure. Each apparatus must be dismantled and cleaned, or blood and tissue interferes with the moving parts. These disadvantages later encouraged American surgeons to develop disposable cartridges containing magazines of staples.

2.8 Use of Staplers in the United States

2.8.1 Introduction and Development of Staplers

It appears that Ravitch was the first to introduce the Soviet instruments into the United States. The subject of his group's first American publication in 1959 was the Soviet bronchus stapler, UKB.[115] They performed experimental pneumonectomies on 20 dogs using the C-clamp type stapler with excellent healing results. No leaks, excessive granulation or exudate were reported. Microscopic studies revealed a vigorous polymorphonuclear reaction at four weeks which, by eight weeks, was minimal; by twelve weeks only mononuclear cells persisted. In addition, this group completed two pneumonectomies and seven lobectomies on clinical patients with tuberculosis and one with peripheral carcinoma. Ravitch, et al., again reported on the use of the bronchial stapler in 1964. By this time they had performed 139 pulmonary resections using the UKB-25 with a good rate of success.[114]

Ravitch, et al., intimated that Soviet surgeons had used a C-clamp stapler (UKL series) to apply a double-staggered row of staples in closing intestinal and gastric ends since 1958.[113] The Soviets had also developed an ingenious but cumbersome instrument, the UKZh, that closes intestine in two layers, the second layer being inverted.[17,68] Seeking less complexity, Ravitch, et al., implemented experiments closing viscera employing simple eversion with C-clamp instruments, some of Soviet design and others prototypes of the American* modifications (Figure 6). They created 58 duodenal stumps, 58 gastric stumps, 24 small bowel stumps, 30 large bowel stumps, and 4 Heidenhain pouches with no leakage or complications due to the technique. However, the closures usually had omentum or loops of bowel adherent to the stumps.

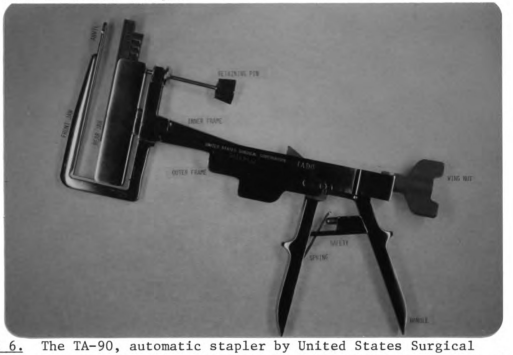

Figure 6. The TA-90, automatic stapler by United States Surgical Corporation, is the American modification of the Soviet C-clamp stapler.

*U. S. Surgical Corporation, New York.

Histologically, few inflammatory cells were noticed. Epithelium survived in the approximated flattened tissue in the form of microcysts and crypts which did not regress or enlarge after six minths. This was evidence that mucosa-to-mucosa healing was not dependent on complete necrosis of the mucosa and secondary fibrotic healing, as Getzen proposed.[59] This technique was put into regular use for a variety of procedures creating stumps at Johns Hopkins and Baltimore City Hospitals. A second row of inverting (Lembert) sutures was always applied. No leakages or operative difficulty were encountered.[113]

Ravitch's group simultaneously began testing the first American model of the Soviet NZKA stapler.[112,113] Consisting of two interlocking halves with projecting links containing the staple and anvil bushing, this instrument drives in two double rows of staggered staples while creating an anastomotic opening between them. Small stab wounds are made in adjacent organs through which the limbs of the instrument are inserted. When the staples are fired, a serosa-to-serosa, side-to-side anastomosis is produced. With repeated use of the NZKA it becomes extremely difficult to activate the staple driver due to accumulated blood and fibrin. After cleaning and reassembly by a machinist, the instrument will operate properly, but only for awhile. A major modification in the American stapler, GIA,* is the disposable preloaded cartridge and knife blade. The TA series also utilizes preloaded disposable cartridges, thereby allowing a single instrument to accept cartridges with different staple arrangements and eliminating hand-loading.

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*U. S. Surgical Corporation, New York.

Ravitch, et al., did gastroenterostomies in combination with gastrectomies on 24 dogs, employing both the TA and GIA models.[113] They experienced no leakage or other suture line problems and no bleeding. Healing was reported to proceed more swiftly and with less reaction than conventional methods although no histologic evaluation was done.

Canalis and Ravitch compared five different procedures of intestinal anastomosis in the dog.[24] One of the everted anastomoses was performed with the Russian vascular stapler that applies one row of very fine staples around the anastomosis. In two of these anastomoses, healing did not occur between the mucosal surfaces and only staples and adhesions held the intestine together.

Canalis and Ravitch compared this makeshift use of one-row vascular stapling with the good results of everted closure with the C-clamp instruments and surmised that compression and double-rowed, heavier staples account for the difference in success. They summarized by observing that everting end-to-end anastomosis can be expected to heal uniformly with silk sutures and implied better results with appropriate stapling equipment. These studies were made at 15 post-operative days and no histological observations were made. Although all the everting anastomoses were functionally successful, they did have a higher incidence of adhesions, which were considered the chief disadvantage in everted anastomoses.[24]

In later histological studies, prolonged inflammation was found in everted, stapled anastomoses at six weeks postoperatively. This inflammation, while perhaps not clinically significant, produces an undesirable delay in healing.[111]

Cooper, et al., developed an automatic cartridge stapler* that delivers one staple at a time.[30] They performed experimental studies on dogs utilizing this instrument to anastomose veins, arteries, large and small intestine, and to close the bronchial stump. The instrument resembles a pair of hemostats and can apply two sizes of staples. Nineteen end-to-end enterostomies and four colocolostomies were performed utilizing a technique comprised of inversion of the posterior wall (by stapling within the lumen) and eversion of the remaining one-half of bowel. It appears that one row of staples was used. The anastomoses were evaluated at one, three, and six weeks and were found to heal well with occasional omental adhesion, and one bowel-to-bowel adhesion; no constrictions or failures were reported. Cooper, et al., made no extensive histologic evaluation of the everted sites. One photograph of a microsection is printed in the paper with the comment that "mucosa is no longer evident on the serosal surface." The section appears to have a deep mucosal cleft, separated from the exterior of the bowel by thin segments of serosal healing. The appearance of this section agrees with that described by Ravitch, et al., in his late evaluations of everted enteroanastomoses.[111]

F. M. Steichen developed the "functional end-to-end" anastomosis involving the GIA and the TA instruments.[136] In appearance this double-barrelled, side-to-side configuration (Figure 1c, p.11) resembles Poth's blind double-ended anastomosis and is modeled after Mikulicz's technique for closing a double-barreled colostomy.[107] The GIA stapler is used for the division and serosa-to-serosa anastomosis of the spur formed by the

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*Manufactured by Codman and Shurtleff Company, Randolph, Massachusetts.

apposition of the intestinal walls. One of the TA series instruments closes the double-barrel stump, apposing mucosa to mucosa. Eleven anastomoses of this type were created and evaluated at varying intervals. No adhesions to structures other than the bowel's own supporting mesentery were found. The proximal bowel was normal in caliber. Histologic examination at one- to four-month intervals showed complete healing of the serosa-to-serosa portion with minimal inflammation and persistent inflammatory response through all layers of the wall of the mucosa-to-mucosa closure.

Primary side-to-side colorectal anastomosis (Duhamel operation for Hirschsprung's disease) was modified by Steichen, et al., to utilize the GIA apparatus.[134] The retention clamp left in the rectum was replaced by division and ligation of the spur by the GIA.

In operations on six dogs, primary healing of the colorectal anastomosis occurred in all cases with no evidence of obstruction. The anastomoses were evaluated at five to twelve weeks. A clinical trial on one infant prompted changes in technique due to complications incurred by a small remaining spur. The modified technique was subsequently performed successfully on three more infants. In 1971 Steichen claimed success with nine patients utilizing this technique.[135]

Charles McGinty developed the triangulation method of stapled, everted end-to-end anastomosis using the TA instrument.[94] He credited Carl Heifitz of St. Louis with the principle of triangulation, created to reconcile the disparity of lumina of unequal size. McGinty offers no experimental data but reports resection and anastomosis in 31 patients: 12 ileocolostomies, 18 left colon anastomoses, and 7 small bowel anastomoses with only one complication.

Waugh found that the GIA permitted easier and more rapid exploration of the stomach without the usual problems of hemostasis associated with gastrotomy incisions.[151] The GIA is used to create the incision while applying its double row of staggered staples on both sides. The incision is closed in the usual manner.

By 1971, Steichen had amassed data on 139 operations done with the GIA and TA series.[135] Operations included: gastric, intestinal, esophageal, pulmonary vascular and gynecologic procedures. Eleven deaths occurred, all unrelated to the technique. Seven, or 26.9 percent, of the 26 complications were related to the use of autosuture. These included hemorrhage, anastomotic leaks, fistula, and short-lived air leaks in pneumonectomy. Steichen's summary pointed to moderate to significant time-saving, evidence of lessened trauma due to diminished tissue handling and improved healing.

An instrument that ligates vessels by staples and divides between them is described by Ravitch, et al.[110] The LDS* applies two U-shaped staples of stainless steel one-fourth inch apart and divides between them, leaving a one-eighth inch margin of tissue. The machine utilizes disposable cartridges containing both knife blade and staples. The vessel must be admitted to an oval slot 4.5 x 10 mm, thus limiting vessel size to a cross section of 45 mm^2. The legs of the staples when completely closed are folded up into the curve of the staple, forming a doubled U-form. They resist opening up to 500 pounds psi. The LDS was used for the sole means of ligation in gastrectomies, colectomies, esophagogastrectomies, abdomino-perineal resection and hysterectomy.

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*U. S. Surgical Corporation, New York.

In addition, the authors reported use of the TA-30 with pads of Gelfoam^{R} for ligation of vessels during splenectomy.

In 1972 Ravitch and Steichen presented a thorough enumeration and analysis of "Technics of Staple Suturing in the Gastrointestinal Tract."[109] The LDS, GIA and TA instruments, their principles of use and possible errors of use are described in detail. Procedures described for the TA series were: triangulation method of end-to-end anastomosis, closing linear incisions such as gastrotomy and gastrectomy, closing stab incisions made in conjunction with use of the GIA (as in the Bilroth II and functional end-to-end anastomosis techniques), pharyngeal diverticulectomy, Bilroth I with triangulation, closed excision of gastric ulcer, Heineke-Mikulicz pyloroplasty, Finney pyloroplasty (with GIA), and in conjunction with GIA for esophageal substitution. The method of triangulation given was a modification of McGinty's complete eversion accomplished by inverting the first closure and everting the remaining two.[94]

In addition to those procedures described with the TA models, the GIA was used for lateral anastomoses including posterior gastroenterostomy, Duhamel procedures, esophageal substitutions (gastrocolostomy) and functional end-to-end anastomoses in any bowel. The GIA was also used ingeniously for reverse gastric tubes and by others in gastric substitutions. Ravitch and Steichen used the GIA for any transection of the bowel including enterotomy, gastrotomy and appendectomy.[109]

Steichen and Ravitch followed in 1973 with a paper of similar purport, focusing on the many uses and general success of all three appliances by United States Surgical Corporation. Included in this report is a brief history review and summary of clinical results of 477 procedures

in 222 operations on 218 patients. They experienced a 5.8 percent complication rate related to the use of autosutures. These involved suture leaks of gastrointestinal closures, air leaks and bronchopleural fistula in pulmonary resections and postoperative bleeding in both classes of surgery.[136]

Another general paper by Ravitch lists additional abdominal procedures routinely performed, including Jaboulay pyloroplasty, transverse closure of longitudinal duodenotomy for exposure of the ampulla of Vater, Janeway or Beck-Jianu gastrostomy, and resection of Meckel's diverticulum.[108]

Johnson and Fuerst utilized the GIA and TA models in constructing ileal conduits in 24 patients to provide ureteroiliocutaneous urinary diversion.[80] The ileum was subsequently anastomosed by Steichen's functional end-to-end technique. One enteroanastomotic leak occurred that healed well. No postoperative deaths or intestinal obstructions resulted.

In 1973 Moss reported a technique for standardized experimental bowel healing involving the TA and GIA instruments. A 40-cm blind loop of ileum is produced and attached to the abdominal wall, which was used in mechanical, metabolic and structural examinations.[100]

Ravitch, et al., described modified versions of Steichen's functional end-to-end anastomosis.[117] The methods tested in dogs involved closing both barrels of bowel (four wall thicknesses) with the one-clamping of the TA model of stapler. Results were good with no deaths due to the technique, and no instances of wound infection, anastomotic leak or intestinal obstruction were encountered in either method. In essentially every case the omentum was attached to the region of the anastomosis.

The simultaneous stapling together of the proximal and distal loops before division of the intestine renders this a fundamentally closed procedure, with the exception of stab wounds made for entrance of the GIA. Closing four layers of bowel wall with one application of the TA thus proved efficacious in dog colon and jejunum, and was applied in two cases of human anastomosis. The second procedure reduces cartridge use, which are expensive.

Griffin, et al., obtained good results in eight of ten patients with the palliative use of the reverse gastric tube for carcinoma of the esophagus.[67]

Doherty and Fleming reported on creation of the Hunt-Lawrence pouch from jejunum in complete gastrectomies.[39] The GIA and TA-55 were used effectively in concert to create substitute reservoirs which gave evidence of good healing and promise of effective function.

2.8.2 Veterinary Use of Staplers

Reports of staple use in veterinary literature are sparse. Boles reported on the year-long use of the TA-55, TA-90 and LDS for abdominal surgery in the horse.[18] Procedures performed were closure of enterostomies, end-to-end anastomosis in the small intestine or small colon, and end-to-side anastomosis of the small intestine to the cecum. Method of anastomosis used was triangulation of bowel with one side inverted. No results were given. It was noted that the instruments resulted in a significant decrease of time required for mesenteric or omental vessel ligation and for intestinal anastomosis.

Gideon gave a preliminary report of this study in 1976.[61] A description of the everted triangulation technique performed on the horse was

given as a film presentation and included postmortem specimens from case number one. He reported evidence of a well-healed anastomosis with no stricture formation.

Bloomberg, et al., described the use of the TA series, GIA, LDS and fascia stapler in the canine species.[16] The TA models were employed successfully in the closure of gastrotomies, pyloroplasties, intestinal resection, end-to-end anastomoses, and partial pulmonary lobectomies. The GIA was useful in performing rapid intestinal resection and side-to-side anastomosis. The LDS found use in ligation for splenectomy, removal of highly vascular tumors and feline ovariohysterectomy.

2.8.3 Complications Associated With Gastrointestinal Stapling

Ravitch, et al., enumerated precautions to insure proper function of each type of instrument, as improper use can result in complications.[109] By 1966, Ravitch and Rivorala had experienced no problem with bleeding in the experimental animal or in their few clinical patients and stated that bleeding was not mentioned in Soviet experience.[112] Steichen had experienced two cases of hemorrhage after normal clinical use of the GIA instrument.[135] He recommended taking great care in inspection of all suture lines and cautery of any bleeders. Steichen and Ravitch later found postoperative bleeding in five patients with the use of both the TA models and GIA.[136] When instruments are functioning properly, compression of the tissues reportedly stops bleeding from vessels of larger caliber. Due to the non-crushing B-shape of staples, blood flow to the cut ends of bowel through small capillaries is a cited advantage in tissue healing.[109]

Defective closure of staples was cited as the cause of excessive bleeding in GIA anastomotic closures in three patients.[51] The instrument was found to close defectively at the ends of the forks so that the last six staples did not form their proper B-shape. The stapler had been used extensively for two years. The author recommended periodic in vitro testing (on plastic models).

Elliott, et al., reported two cases of stenosis out of 29 patients from use of the GIA machine.[48] The viable edges of the anastomotic opening had healed together. Nearly 100 percent of the original opening had closed in a gastroenterostomy and 40 percent of a colonic anastomosis had closed. This finding was not reported elsewhere.

2.8.4 Expanded Use of Staplers

Staplers have been adapted to surgical procedures in disciplines other than gastroenterology. Most well-known is use of the TA series in bronchial stump closures and lung resections.[33,36,77,126]

Takaro was instrumental in development of the American vascular stapler.[93,138] In 1964, Nakayama, et al., described 21 cases of free autografts of bowel for esophageal replacement using a venous anastomosis apparatus.[101] Samuels used metal clips* for vascular anastomosis.[124] In cardiovascular surgery the TA series was used to close atriotomy incisions and Pott's anastomosis.[8,87]

Automatic sutures have been used in vaginal hysterectomy and colpoplasty and in abdominal hysterectomies.[3]

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*Sklar Manufacturing Company, Long Island City, New York.

The instrument for skin closure, SFM,* has been used successfully by Thompson and Ashley, and Lennihan and Mackereth.[89,141] A skin clip** of another design was developed and used by Samuels and Roedling.[125]

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*U. S. Surgical Corporation, New York, New York.

**Ethicon, Inc., New Jersey.

MATERIALS AND METHODS

3.1 Experimental Subjects

Twelve horses and ponies of various breeds and ages were used in this experiment. Half were males and half females. (Table 1)

Table 1. Anamnesis of Horses Used

	Breed	Age (yrs)	Sex[+]	Weight (kg)
1.	Standardbred	4	G	430
2.	POA[*]	5	G	185
3.	Half-Arabian	1	G	273
4.	Half-Arabian	6	M	320
5.	Quarter Horse	2	M	345
6.	Albino	3	M	320
7.	Thoroughbred	4	M	435
8.	Pony	4	M	115
9.	Thoroughbred	5	G	415
10.	Pony	3	S	115
11.	Standardbred	3	M	455
12.	Pony	1	G	127

[*]Pony of America [+]M = mare, G = gelding, and S = stallion

3.2 Preoperative Care

All animals were auscultated, examined grossly and determined to have clinically normal gastrointestinal tracts. The horses were housed in box stalls bedded in straw in the large animal clinical wards at Michigan State University's Veterinary Clinical Center. The diet consisted of oats, mixed grain and mixed hay. The presurgical care of each animal included deworming with thiabendazole (.09 gm/kg) 24 to 48 hours before operation, removing hay from the diet 24 hours before operation and withholding grain on the day of operation. Immediate presurgical treatment consisted of 1 to 2 gm of phenylbutazone[a] intravenously (for postoperative analgesia), 1 ml of tetanus toxoid,[b] and 25,000 units of procaine penicillin-G[c] and 12.5 mg of streptomycin sulfate[d] per kg of body weight intramuscularly. Antibiotics were used to decrease postoperative peritonitis.

3.3 Surgical Preparation and Anesthesia

Anesthesia was induced with 2 gm thiamylal sodium[e] in 500 ml of five percent glycerol guaicolate and maintained with halothane[f] anesthesia. Eight of the twelve horses were assisted or controlled with a positive pressure ventilator. The ventral abdomen was prepared by clipping, shaving the midline and scrubbing with surgical scrub[g] and solution.[g] The horse was draped for a ventral midline incision with cotton drapes and a plastic adhesive drape[h] over the site for incision.

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a Pitman-Moore, Washington Crossing, N. J.
b Jen-Sal, Kansas City, Mo.
c Pfizer Inc., N. Y., N. Y.
d Veticare, John D. Copanos, Inc., Baltimore, Md.
e Surital, Parke-Davis, Detroit, Mi.
f Fluothane, Ayerst Laboratories, Inc., N. Y., N. Y.
g Betadine, The Purdue Frederick Co., Yonkers, N. Y.
h Steridrape, 3-M Company, Medical Products Division

3.4 Surgical Procedures

3.4.1 Approach

A skin incision was made on the ventral midline from the umbilicus extending approximately 15 to 20 cm cranially. The abdominal wall was sectioned, the subperitoneal fat bluntly separated, and the peritoneum sharply incised. The apex of the cecum was exteriorized and ileocecal ligament palpated to locate the distal ileum, which was also exteriorized. A suitable mesenteric vascular pedicle was located in the distal jejunum approximately 2.5 m from the termination of the ileocecal ligament. Wet towels were applied at the periphery of the incision.

3.4.2 Transection

The bowel was manually emptied of its contents in either direction and half-inch umbilical tape applied around its circumference and secured with a clamp, thus occluding the lumen 6 to 10 cm from the anticipated point of sectioning. The main vascular supply to the section was triple-ligated with 0 silk, as were the arcuate vessels adjacent to the small bowel. The mesentery was then sectioned and a wet towel placed under the exteriorized loop of intestine. Atraumatic intestinal clamps were placed across the bowel at about 60 degrees just past the last visible serosal vessel, so that in the apposed intestine, the mesenteric border was longer than the antimesenteric border. Allis tissue forceps were placed 2 cm from the intestinal clamps and 1 cm from the anti-mesenteric border on the bowel that was to remain. The bowel was then sharply transected along the border of the clamp that was closest to the Allis forceps; thus, the intestinal clamps were removed with the resected portion of bowel. Two anastomotic procedures (Gambee and stapled)

were performed from 2 to 3 m apart on each individual. One-half of the total Gambee resections were placed distal to the staple resections and one-half were reversed in position.

3.4.3 Stapled Anastomosis

Three everting simple interrupted stay sutures of 2-0 Polyglycolic acid (PGA) suture[i] were placed 5 mm from the serosal edge of both open bowel ends, holding them in apposition. One suture was placed at the mesenteric border and the others placed at equal intervals in order to effect triangulation of the bowel (Figures 7 and 11). Two adjacent stay sutures were held with moderate tension by the assistant as the operator positioned the TA-90[j] automatic stapler (Figure 6) below the sutures and serosal edge. The retaining pin was screwed into the front jaw of the instrument and tightened firmly. The instrument jaws were closed until the tissue was firmly compressed as the operator checked to insure that the serosal edge extended beyond the edge of the jaws (Figure 12). The instrument was fired and the margin of tissue protruding from the jaws was removed by excision along the jaw border (Figure 8). The stay sutures were left intact in order to manipulate the bowel. The jaws were then opened, allowing the tissues to drop out and the retaining pin was screwed out. The bowel was rotated by the stay sutures to present the second side of the triangle for closure and the process of stapling was repeated (Figure 9). The stay suture at the staple-line crossover was removed with the tissue protruding from the jaws (Figure 13). The bowel was again rotated and the remaining side

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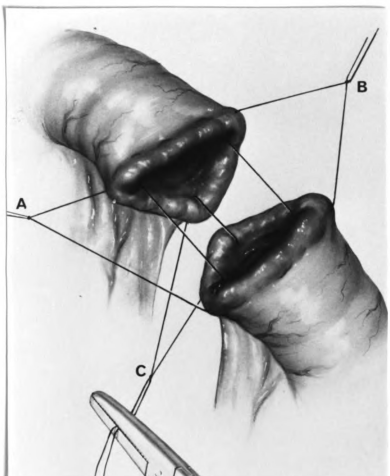
i Dexon, Davis and Geck, Pearl River, N. Y.
j U. S. Surgical Corporation, N. Y., N. Y.



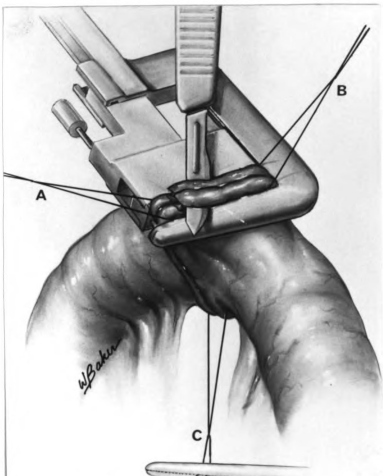


Figure 7. Everted triangulation of the bowel for staple closure of an anastomosis.

Figure 8. After compression and stapling of the bowel, the excess tissue protruding from the jaws is excised, leaving the stay sutures.

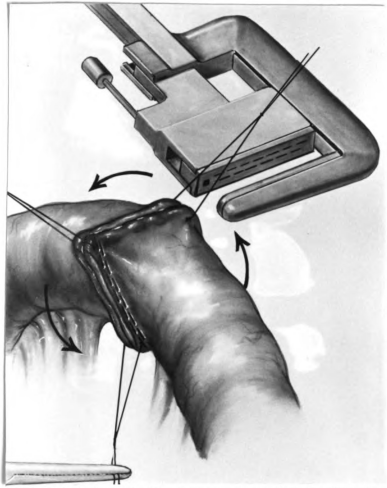


Figure 9. Rotation of the bowel to staple the second side of the anastomosis.

Figure 10. The completed stapled anastomosis.

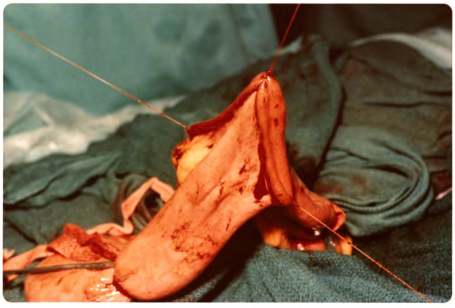


Figure 11. The mucosa protrudes when the bowel is everted for staple closure.

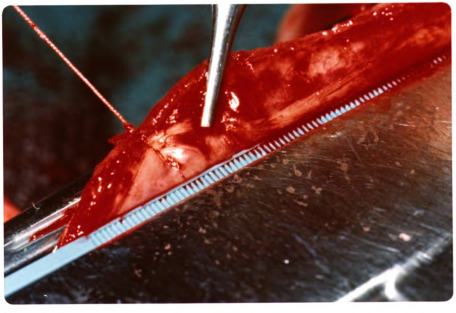


Figure 12. The serosal edge of the bowel must extend beyond the edge of the TA-90 jaws.

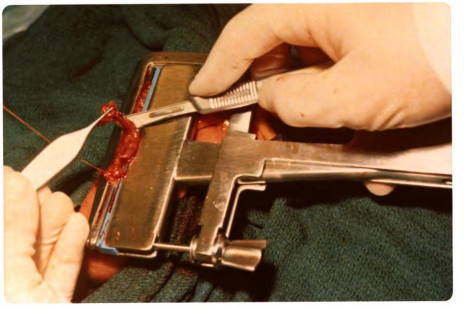


Figure 13. Excess tissue is removed along with the stay suture that is no longer needed after the second application of the TA-90.

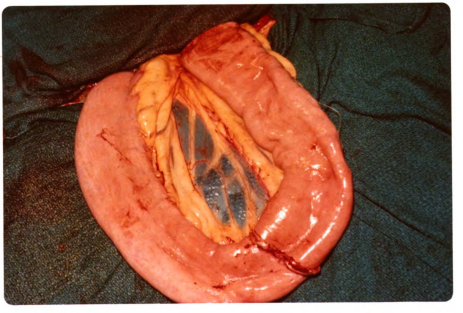


Figure 14. The completed stapled intestinal anastomosis.

closed, this time removing the last two stay sutures. The everted edges of the completed anastomosis (Figures 10 and 14) were examined for hemostasis, closure of staples and complete crossover of adjacent staple lines (Figure 15). Cautery was used to control excess bleeding. The mesentery was closed with 2-0 PGA suture in a simple continuous pattern, the anastomotic site was flushed freely with saline, the wet towels removed, and the bowel was returned to the abdominal cavity.

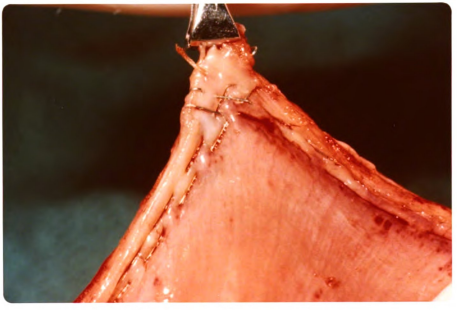


Figure 15. Crossover of staple lines at the stapled anastomosis.

3.4.4 Gambee Anastomosis

The Gambee technique is an interrupted suture pattern through the serosa and intestinal wall, into the lumen, back through the mucosa, and exits between the mucosa and submucosa on the cut surface (Figures 16 and 17). The pattern is reversed for the opposing bowel and tied firmly, causing the suture to crush through the mucosa (Figures 18 and 19). Three equidistant stay sutures were placed in this pattern with 2-0 PGA

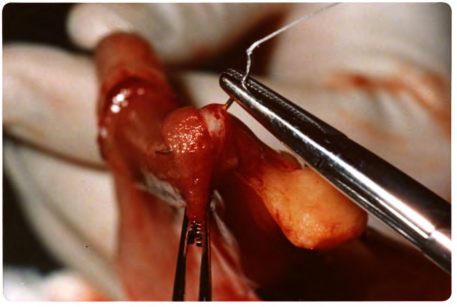


Figure 16. The Gambee pattern is begun by passing the needle into the lumen of the gut.

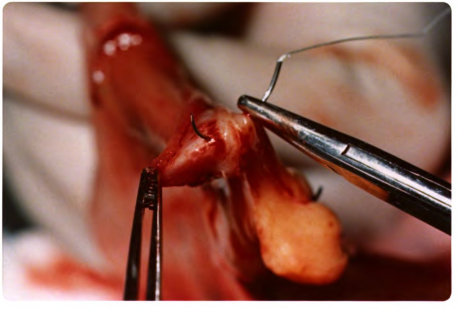


Figure 17. The needle exits between the mucosa and submucosa of the bowel end.

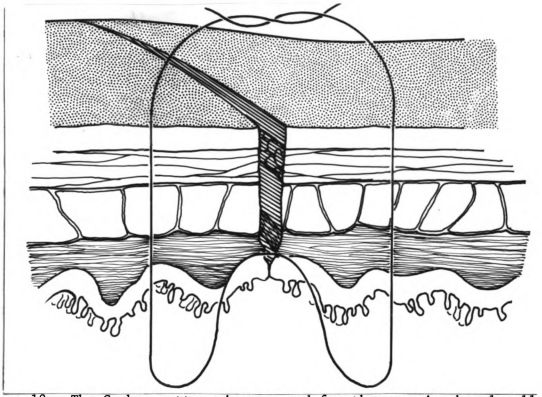


Figure 18. The Gambee pattern is reversed for the opposing bowel wall.

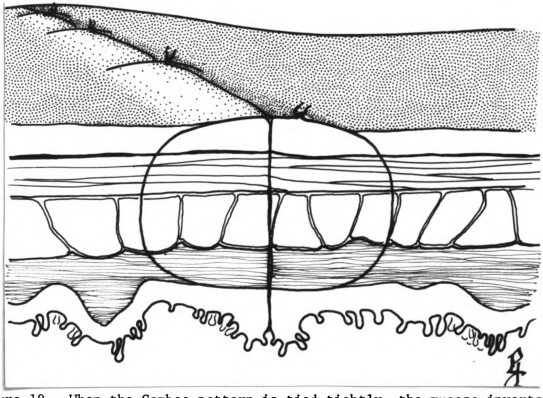


Figure 19. When the Gambee pattern is tied tightly, the mucosa inverts and the suture material cuts through the mucosa to enclose the submucosa tightly.

suture. The bowel was triangulated in order to avoid incorporation of the opposite wall in the suture line (Figure 20). This pattern was continued on each segment of the triangulated bowel, placing sutures approximately every 3 mm (Figure 21). Care was taken to invert and crush the mucosa encompassed in the suture. The mesentery was closed as described for the stapling technique. The bowel was flushed with saline, the wet towels were removed, and the intestine was returned to the abdominal cavity.

3.4.5 Closure

The peritoneum was closed with 2-0 PGA suture in a simple continuous pattern. The abdominal wall was closed with #2 double-stranded monofilament nylon suture[k] in a cruciate pattern and tied with five throws. The cruciate pattern is an interrupted mattress-like pattern that traverses the incision at right angles superficially and deeply forms a cross. The subcutaneous tissue was closed with #1 PGA suture with a swaged-on atraumatic reverse cutting needle in a continuous horizontal mattress pattern. The skin was closed with 2-0 Polyamid.[l] The abdomen was bandaged and the horse allowed to recover from anesthesia.

3.5 Postoperative Care

A nasogastric tube was passed and sutured in place. All medication and nutrition were given in liquid form through this tube for three days postoperatively. Postoperative medication consisted of: 5.5 mg of Tetracycline hydrochloride[m] and 2.5 mg of phenylbutazone[n] per kg BID.

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k Dermalon, Davis + Geck, Pearl River, N. Y.
l Supralon, J. Pfrimmer & Co., Erlangen Pharmazeutishche Werke
m Polyotic, Professional Veterinary Pharmaceuticals (American Cynamid Co.), Princeton, N. J.
n Pitman-Moore, Washington Crossing, N. J.

Figure 20. The bowel is triangulated with Gambee stay sutures.

Figure 21. The finished Gambee intestinal anastomosis.

Phenylbutazone and tetracycline were given, respectively, to decrease postoperative pain and peritonitis.[19] Nutrition was provided with 0.6 gm of nutrient powder[o] and 50 mg of potassium chloride per kg BID and 20-30 ml of a vitamin supplement[p] once daily. All nutrients and medication were given in water. Water was given at 50-100 ml per kg per day and divided TID.

Heart rate, respiratory rate, mucous membrane color, capillary refill, abdominal sounds, skin hydration, urination and defecation were monitored three times daily. Hematocrit, plasma total solids and blood gases were analyzed if indicated by physical signs. On the fourth day, solid food was reintroduced into the diet beginning with a small amount of mixed grain. Horses were allowed to drink water and antibiotics were discontinued. Physical parameters were monitored as hay was introduced on the fifth postoperative day. On the sixth day after operation, full feed was resumed.

The horses were kept in box stalls on mixed grain and hay and allowed occasional exercise in paddocks. They were subsequently euthanatized from 42 to 52 days postoperatively, with the exception of cases #2, #3, and #6, that were euthanatized at 28, 64, and 59 days, respectively.

3.6 Methods of Gross Evaluation

3.6.1 Extraluminal Changes

Gross observations at necropsy included evaluation of serosal changes and adhesions at and around both (Gambee and Stapled)

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o Amino Mix, Vita Vet Labs, Marion, Indiana
p Vinatura, Jen-Sal Kansas City, Mo.

anastomotic sites in each horse.

Serosal Changes

Serosal changes were graded 1, 2, and 3 for increasing area of involvement and 0 for absence of lesions.

Adhesions

Adhesions were graded into four degrees of severity on the basis of whether they were fibrous or friable, whether or not they included loops of other bowel and whether or not the luminal pathway was altered by the presence of adhesions. Grades were:

0 - no adhesions

1 - minimal: friable; lacking other pathologic characteristics

2 - mild: fibrous or involved a small change in luminal pathway

3 - moderate: fibrous and involved a moderate change in luminal pathway or adhered bowel to bowel

4 - marked: fibrous and involved a marked change in the luminal pathway and adhered bowel to bowel

3.6.2 Luminal Changes

Both healed anastomoses (Gambee and Stapled) were removed from each horse. The sections of bowel removed were approximately 1 m long with the anastomosis at the midpoint. The bowel was opened on its antimesenteric border and four kinds of changes looked for on the mucosal surface. These included:

1. constriction at the anastomosis
2. dilatation proximal to the anastomosis

3. changes in rugae

4. other changes

Anastomotic Constriction

Luminal measurements made of the circumference of the bowel at the anastomotic junction were compared to those made 10 cm distal to each anastomosis. (Normal bowel circumference was uniformly reestablished at 10 cm distal to the anastomosis.) Percent constriction was calculated using the formula:

$$\frac{C_d - C_a}{C_d} \quad (q)$$

Proximal Dilatation

Luminal measurements made of the circumference of the bowel 10 cm proximal to each anastomosis were compared with those made 10 cm distal to each anastomosis. (Dilatation was uniformly well-established at 10 cm proximal to the anastomosis.) Percent dilatation was calculated using the formula:

$$\frac{C_d - C_p}{C_d} \quad (q)$$

Changes in Rugae

Rugae are folds of mucosa and submucosa into the lumen, i.e., an increase in submucosal depth with a normal layer of mucosa.

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[q] C_d = distal circumference

C_p = proximal circumference

C_a = anastomotic circumference

These may follow various patterns but are consistent within a section of bowel. Changes in rugae formation at or about the site of anastomosis were graded from 0 to 4 as follows:

0 - no changes: No changes in gross mucosal architecture evident. The anastomotic site is indiscernible from the rest of the bowel lumen. (Figure 26)

1 - mild change: Normal rugae in the immediate region of anastomosis; the anastomosis is barely noticeable.

2 - moderate change: Rugae present in the anastomotic region are inconsistent with rugae formation in the rest of the bowel segment.

3 - marked change: Rugae present in the anastomotic region are few and abnormal.

4 - rugae absent: Rugae absent in the anastomotic region.

3.7 Methods of Histological Evaluation

3.7.1 Preparation of Tissue Sections

The segments of bowel (anastomosis and 1 m of surrounding bowel) were fixed in ten percent buffered formalin. Blocks of tissue were cut out of the anastomotic sites in the longitudinal axis of the bowel; they included 1 to 2 cm of tissue on both sides of the anastomoses. Blocks of tissue were also cut in the longitudinal axis of normal bowel. All tissues were processed by an automatic tissue processing machine.[r]

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r Autotechnicon, Technicon Co., Terrytown, N. Y.

The process consisted of:

1. fixation with ten percent buffered formalin
2. dehydration with a series of alcohols
3. clearing with xylene
4. infiltration with paraffin
5. sectioning: sections were cut at six microns with a rotary microtome.

One or two tissue sections from each anastomotic site were stained with hematoxylin and eosin and Gomori's (one-step) Trichrome method, which distinguishes muscle from connective tissue.

3.7.2 Gomori's Trichrome Sections

Sections stained with Gomori's Trichrome were used to evaluate the alignment of intestinal muscle layers and to measure areas of connective tissue deposition. (In all healed anastomoses, connective tissue separates the severed ends of the intestinal muscle layers, contributes to bowel wall thickness and is deposited in the serosa in response to inflammation.) An ocular micrometer was used to measure the following at 100x magnification:

1. distance between severed ends of intestinal muscle layers
    a. longitudinal
    b. circular
    c. muscularis mucosa
2. bowel wall thickness
3. serosal thickness

Distance Between Longitudinal Muscle Layer Ends

Distances were measured between the ends of longitudinal muscle where the muscle layer became continuous and normal on each respective side. The shortest straight-line measurement possible was taken. Occasional islands of muscle in the intervening space were ignored to insure consistent measurement. If an anastomosis was represented by more than one histological section, the longest distance was used.

Distance Between Circular Muscle Layer Ends

The distance between cut ends of circular muscle layer was measured for each anastomosis using the guidelines explained above.

Distance Between Severed Ends of Muscularis Mucosa

The distance between the severed ends of muscularis mucosa was measured adjacent to the mucosa in its undulating path and not taken as a straight line measurement.

Bowel Wall Thickness

Bowel wall thickness was measured from the basement membrane of the mucosa to the outer edge of the serosa, at the widest point within the anastomotic region. The latter is defined to include the area where distinct muscle layers become discontinuous and connective tissue predominates.

Serosal Thickness

The depth of serosa was measured from the external margin of the longitudinal muscle to the outer margin of the serosa.

Alignment of Layers of Intestinal Wall

Alignment of layers of the intestinal wall were graded: excellent = 1, good = 2, fair = 3, and poor = 4 on the basis of degree of separation of matching layers, their angle of incidence to each other and how closely they lined up.

3.7.3 Hematoxylin and Eosin Sections

Sections stained with hematoxylin and eosin were used to evaluate the architecture of mucous membrane and the inflammatory response in the anastomotic region of both types (Gambee and Stapled) of healed anastomoses using 100x and 430x magnification.

Architecture of Mucous Membrane at the Anastomotic Site

The mucous membrane was examined for architecture and continuity and graded from 1 to 4 as follows:

1 - excellent: Mucous membrane has a very consistent height, villi of regular length and size, glands of Lieberkuhn of regular size and distribution, epithelial cell populations in relatively normal ratios and rugae present. The site of mucosal anastomosis is indiscernible from the rest of the mucous membrane.

2 - good: Mucous membrane has a fairly constant height, fairly regular villi and glands of Lieberkuhn, and epithelial cells represented in normal ratios. Rugae may be absent and the anastomosis is discernible from the rest of the mucosa.

3 - fair: One or more of the above characteristics is lacking. The height of the mucous membrane may be irregular,

villi and glands of Lieberkuhn may be irregular or absent.

4 - poor: A segment of mucous membrane of any size must be completely absent. Connective tissue replaces the mucous membrane in space. Sections of the anastomosis stained with Gomori's Trichrome may aid in identifying the connective tissue replacement.

Inflammatory Response

Inflammatory response of each anastomosis was compared to that of normal bowel from each horse. Inflammatory response was graded on the basis of numbers and types of inflammatory cells in the anastomotic region.

0 - normal: Similar to the section from the normal gut from that horse.

1 - minimal: Eosinophils and/or lymphocytes present in small numbers.

2 - mild: Eosinophils and/or lymphocytes in slightly greater numbers than (1) above and/or macrophages in small numbers.

3 - moderate: Eosinophils, lymphocytes and/or macrophages present in moderate numbers.

4 - marked: Neutrophils and/or giant cells present, or lymphocytes and macrophages present in large numbers.

Aberrant Mucosal Elements

An isolated portion of mucous membrane epithelium was considered to be a mucocele if: it did not appear to communicate with the lumen;

it was completely surrounded by connective tissue rather than normal submucosa; and its architecture was abnormal. These structures contain a store of mucus-appearing material.

3.8 Methods of Statistical Analysis

Means were compared by paired t-test for every observation measured.[131]

RESULTS

4.1 Mortality and Morbidity

Three animals submitted to surgery died and were excluded from this study. One died from sudden shock the first postoperative night; the anastomoses were in good condition. Another was euthanatized immediately after operation because of paralysis of the hindlimbs. The third horse was euthanatized two weeks postoperatively after second operation revealed necrotic, obstructed bowel secondary to massive adhesions involving both anastomoses.

Of the 12 horses used in the study, only Cases No. 9 and No. 11 had signs of postoperative colic. Case No. 9 had severe signs of colic requiring sedation and intravenous fluids for the first two days after operation. Case No. 11 had intermittant intestinal obstruction requiring occasional sedation and removal of fluids from the stomach.

4.2 Gross Evaluation

4.2.1 Extraluminal Changes

All anastomoses were covered with serosa or adhesions. In general, the stapled anastomoses appeared to have a larger more fibrous scar than the Gambee anastomoses (Figure 22 and 23). None of the horses had active peritonitis at the time of necropsy.

Serosal Thickening

The only serosal change of any import noted was thickening of the serosa in a patchy pattern (Figure 23). Thickening of the serosal layer emanated from the closure sites and radiated both proximally and distally on the bowel surface.

Serosal thickening occurred to some extent in 9 of the 12 Gambee closures and 10 of the 12 stapled closures (Figures 22 and 23). Negligible difference in degree of serosal thickening existed between the stapled and conventional anastomoses ($p>.05$).

Severity of the lesions was much the same for each case at both anastomoses. Eight horses had the same grade of serosal change for both types of bowel closure; three differed by one grade and one by two grades.

Adhesions

Cases No. 1, 4, 7, and 11 had no adhesions. Cases No. 8 and 9 had adhesions at the stapled anastomosis but not at the Gambee anastomosis. Only Cases No. 10 and 12 had marked adhesions; in both cases, the stapled and Gambee anastomoses were adhered together by a long, fibrous band (Figure 24). In Case No. 5 the stapled anastomosis (grade 3 adhesion) was adhered to bowel 30 cm distally; the Gambee anastomosis had grade 1 adhesions. In all cases except No. 5, 8, and 9 both sites tended to react similarly. Although the stapled anastomosis had a higher incidence and greater severity of adhesions, the difference was not significant ($p>.05$).

4.2.2 Luminal Changes

Observations of luminal changes are summarized in Table 2. For the most part, the Gambee anastomoses had a more normal mucosal appearance than the stapled anastomoses. This is reflected in every category of evaluation. In only four cases did the mucous membrane appear healed in an uninterrupted manner for the entire internal circumference in the stapled anastomoses.

Anastomotic Constriction

The percents of constriction of the Gambee and stapled anastomoses are presented in Table 2. The stapled anastomoses had a higher incidence and greater degree of constriction than the Gambee anastomoses ($p<.01$), (Figure 25).

Proximal Dilatation

The percents of proximal dilatation of the Gambee and stapled anastomoses are given in Table 2. The stapled anastomoses had a higher incidence and greater degree of proximal dilatation than the Gambee anastomoses ($p<.05$), (Figures 22 and 29).

Changes in Rugae

The data on changes in rugae are presented in Table 2. Five Gambee anastomoses had normal-appearing lumina, i.e., the anastomoses could not be detected (Figure 26). The stapled anastomoses typically had disturbances or absence of rugae (Figures 25, 27, 28, 29, and 30). The stapled anastomoses had a significantly greater presence and severity of rugal defects than the Gambee anastomoses ($p<.01$).

In some cases, rugal patterns proximal and distal to the anastomosis differed from one another. Cases No. 3, 7, 9, and 10 of the stapled and Cases No. 1 and 11 of the Gambee anastomosis had circular rugal patterns proximal and mixed or longitudinal patterns distal to the anastomosis.

Triangulation Defects

A consistent abnormality was noticed in 5 of the 12 stapled anastomoses. Three cystic or pocket-like structures approximately 0.5 cm in diameter resided in each suture line at equal intervals. Some contained necrotic tissue (Figure 28); others were just outpocketings. These were characterized as triangulation defects, because they appeared at the point of staple-line crossover as shown in Figure 15.

Sphincter Defect

Another defect peculiar to the stapled anastomosis was termed a sphincter defect, since it resembled a muscular sphincter in appearance. This defect resulted from the depression of the staple line toward the serosa with bulging of the adjacent tissues toward the lumen creating a narrowing in the lumen (Figures 25 and 29). Nine of the 12 anastomoses had developed this defect to some degree. Three horses had neither the sphincter nor the triangulation defect in the stapled anastomosis.

Suture Line Cysts

In Cases No. 10 and 11, minute cysts were apparent in the suture line of the stapled anastomosis (Figure 30).

Table 2. Summary of Gross Luminal Evaluation of Healed Stapled and Gambee Anastomoses (12 cases each)

	Percent Constriction		Percent Proximal Dilatation		Change in Rugae[a]	
Horse No.	Gambee	Stapled	Gambee	Stapled	Gambee	Stapled
1	22.2	3.5	16.6	8.7	3	4
2	0.0	25.0	0.0	0.0	0	2
3	0.0	23.1	8.3	53.9	1	1
4	0.0	33.3	0.0	6.7	0	2
5	7.1	15.3	0.0	7.7	0	1
6	0.0	19.3	0.0	4.8	1	2
7	14.3	20.0	0.0	16.0	1	3
8	5.8	14.2	5.9	14.3	0	2
9	9.5	16.6	0.0	44.4	1	3
10	0.0	36.8	0.0	0.0	0	2
11	3.8	28.0	7.7	8.0	1	3
12	25.0	59.1	12.5	9.1	3	3
Means	7.3[b]	24.5[c]	4.3	14.5[d]	.9	2.3[c]
	± 2.6	± 4.1	± 1.7	± 4.9	± .3	± .3

[a] 0 = normal, 1 = mild change, 2 = moderate change, 3 = marked change, 4 = rugae absent.

[b] $\bar{X} \pm$ S.E.M.

[c] Significantly greater than mean for Gambee technique ($p < .01$)

[d] Significantly greater than mean for Gambee technique ($p < .05$)

NOTE: For Percent Constriction and Proximal Dilatation, standard error and paired t-test were computed using arcsine percentage but are represented here by mean percentages.

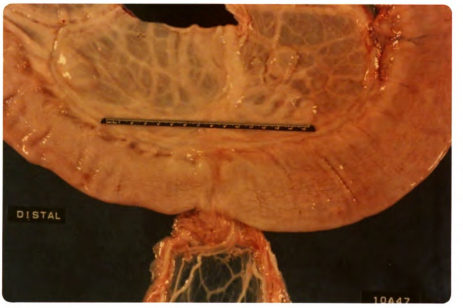

Figure 22. Case 9, stapled anastomosis. Note large fibrous scar, serosal thickening, proximal dilatation and omental adhesion.

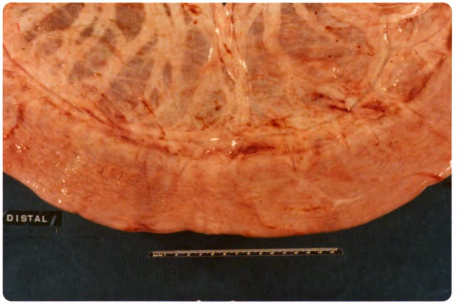

Figure 23. Case 7, Gambee anastomosis. Note negligable scar, uniform diameter and serosal thickening.

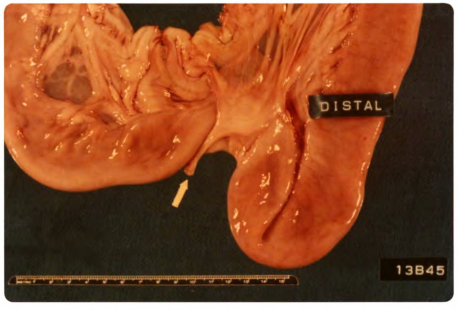

Figure 24. Case 12, Gambee anastomosis. The yellow arrow marks the fibrous adhesion that had linked both anastomoses. Note the change in luminal pathway due to adhesion of the anastomosis to its own mesentery.

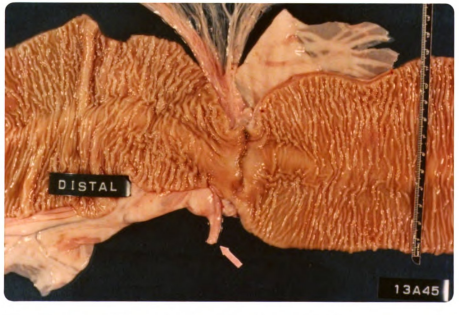

Figure 25. Case 12, stapled anastomosis. Note anastomotic constriction, changes in rugae and dilatation both proximally and distally.

Figure 26. Case 8, Gambee anastomosis. No evidence of anastomosis is seen; the rugal pattern is unchanged.

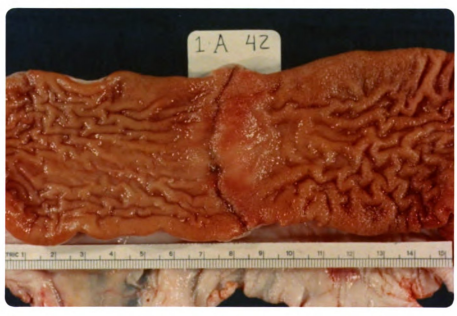

Figure 27. Case 1, stapled anastomosis: the best example in the study. There is no constriction or proximal dilatation. Excessive fibrous scar and change in rugae is evident.

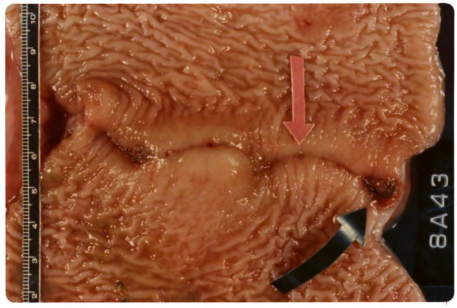

Figure 28. Case 7, stapled anastomosis. Note the triangulation defect (black arrow) and absence of rugae over the mound of fibrous tissue at the anastomosis. The pink arrow marks an extruding staple.

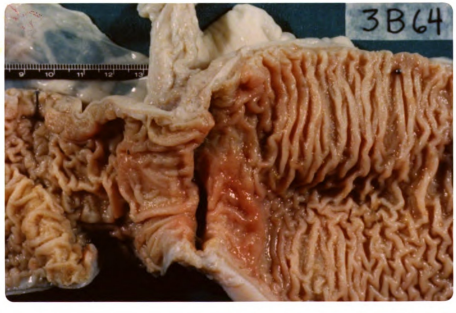

Figure 29. Case 3, stapled anastomosis. The most severe sphincter defect; note the proximal dilatation, change of rugae over the anastomosis and difference in rugal patterns proximal and distal to the anastomosis.

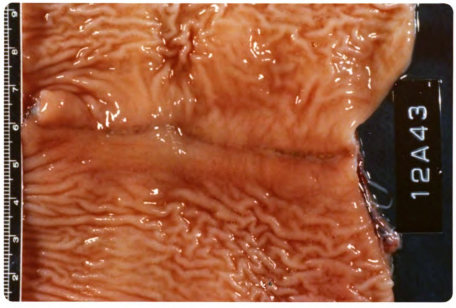

Figure 30. Case 11, stapled anastomosis. Suture line cysts are seen opening into the bowel lumen.

Figure 31. Gambee anastomosis, hemotoxylin and eosin stain (approximately 5.6x). Note close proximity of muscle layer ends, nearly normal thickness of bowel wall and normal architecture of mucous membrane.

4.3 Histological Evaluation

4.3.1 Gomori's Trichrome Sections

Distance Between Severed Ends of Muscle Layers

The data on the distances between the severed ends of the intestinal muscle layers, in healed Gambee and stapled anastomoses, are summarized in Table 3.

Longitudinal Muscle Layer

The mean distance between the severed longitudinal muscle layer ends was 8.69 ± 0.97 mm for the stapled anastomosis and was significantly greater ($p<.01$) than the mean for the Gambee closure, 4.29 ± 0.81.

Circular Muscle Layer

The mean distance between severed circular muscle layer ends for the stapled closure was 7.28 ± 0.74 mm, and 4.99 ± 0.72 mm for the Gambee closure. The difference was not significant ($p>.05$).

Muscularis Mucosa

In some instances the muscularis mucosa was found to be continuous but thin (two Gambee and two stapled anastomoses). The mean distance between the ends of the muscularis mucosa was 3.85 ± 0.95 mm for the stapled anastomosis and significantly greater ($p<.01$) than 1.26 ± 0.26 mm for the Gambee anastomosis.

Table 3. Distances between proximal and distal severed ends of each intestinal muscle layer in healed Gambee and stapled anastomoses (12 cases each)

Muscle Layer	Technique	
	Gambee	Stapled
	(mm)	
Longitudinal	4.29 ± 0.81[a]	8.69 ± 0.97[b]
Circular	4.99 ± 0.72	7.28 ± 0.74
Muscularis mucosa	1.26 ± 0.26	3.85 ± 0.95[b]

[a] $\bar{X} \pm$ S.E.M. (distance represents the separation between the severed muscle layer ends filled with connective tissue)

[b] Significantly greater than mean for Gambee technique ($p<.01$).

Bowel Wall Thickness

The data on bowel wall thickness are presented in Table 4. Mean bowel wall thickness was 7.03 ± 0.71 mm for stapled sites and significantly greater ($p<.05$) than the mean for Gambee sites, 5.18 ± 0.80 mm.

Table 4. Histological evaluation of bowel wall thickness at Gambee and stapled anastomotic sites (12 cases each)

Technique	Bowel Wall Thickness
	-------(mm)---------
Gambee	5.18 ± 0.80[a]
Staple	7.03 ± 0.71[b]

[a] $\bar{X} \pm$ S.E.M. (distance is measured as the longest distance from the muscularis mucosa to the outer serosal border within healed anastomotic zones).

[b] Significantly greater than mean for Gambee technique ($p<.05$).

Serosal Thickness

The mean serosal depths of stapled and Gambee closures were 2.63 ± 0.45 and 1.56 ± 0.21 mm, respectively. The difference was not statistically significant.

Alignment of Layers of Intestinal Wall

The distribution of anastomoses within scores is given in Table 5. The alignment score for the Gambee closure, $2.50 \pm .29$, was significantly better ($p<.01$) than the score of $3.58 \pm .23$ for stapled closure (Table 8).

Table 5. Histological evaluation of alignment of layers of the intestinal wall in healed Gambee and stapled anastomoses (12 cases each)

Grade:		1 = Excellent	2 = Good	3 = Fair	4 = Poor
Technique:	Stapled	0[a]	2	1	9
	Gambee	2	4	4	2

[a]number of cases within each score category

4.3.2 Hemotoxylin and Eosin Sections

Architecture of the Mucous Membrane

The distribution of anastomoses within scores is given in Table 6. The architecture of the mucous membrane of the Gambee anastomosis was superior to that of the stapled anastomosis. Five of the stapled cases lacked mucous membrane at the anastomosis. The stapled closure scored $3.08 \pm .31$, significantly higher ($p<.05$) than $2.00 \pm .21$ for the Gambee closure (Table 8).

Table 6. Histological evaluation of mucous membrane architecture of the intestine in healed Gambee and stapled anastomoses (12 cases each)

Grade:		1 = Excellent	2 = Good	3 = Fair	4 = Poor
Technique:	Stapled	2[a]	0	5	5
	Gambee	3	6	3	0

[a]number of cases with each score category

Inflammatory Response

The distribution of anastomoses within evaluation categories is given in Table 7. The mean scores for inflammatory response are given in Table 8. The stapled closure had a significantly greater degree of inflammatory response ($p < .01$) than the Gambee closure.

Inflammation was absent to moderate for most Gambee anastomoses. The most inflammation was found around suture material in these anastomoses (Figure 34). Inflammation was consistently worse for the stapled anastomoses and macrophages were usually present. In four cases neutrophils were found in the stapled anastomoses (Figure 35).

Findings Peculiar to the Stapled Anastomoses

Elements of mucosa were found throughout the bowel wall in the anastomotic junction of the stapled cases. These islands of mucosa occurred in a variety of fashions: mucoceles ranging in diameter up to 3 mm (Figures 36 and 37); crypts which, though appearing as mucoceles, had communication with the lumen (Figure 38); and microcysts of epithelial elements in groups of only a few cells. Eight of the 12 stapled anastomoses had apparent mucoceles in one or more

sections. All of the stapled anastomoses that did not have mucoceles had deep mucosal clefts (Figures 33 and 39). The deepest portion of most of these clefts approached the serosal surface, some extending to about 1 mm from the border. It appeared that only serosa healed over everted mucosa kept the anastomosis intact at this point.

Table 7. Histological evaluation of the character and degree of inflammatory response in healed Gambee and stapled anastomoses (12 cases each)

A. Degree of inflammatory response

Grade:	4=Marked	3=Moderate	2=Mild	1=Minimal	0=Normal
Technique:					
Stapled	4[a]	5	6	0	0
Gambee	0	3	9	1	2

B. Character of inflammatory response: types of cells present

Inflammatory Cell:	Macrophages	Neutrophils	Lymphocytes	Eosinophils
Technique:				
Stapled	11[a]	4	6	5
Gambee	7	0	5	3

[a]number of cases within each evaluation category

Table 8. Comparison of histologic features of healed staple and Gambee intestinal anastomoses (12 cases each)

Healing Characteristic	Gambee	Staple
Alignment of layers of intestinal wall score[1]	$2.5 \pm .3$[a]	$3.6 \pm .2$[b]
Mucous membrane architecture score[2]	$2.0 \pm .2$	$3.1 \pm .3$[c]
Inflammatory response score[2]	$1.8 \pm .3$	$3.1 \pm .2$[c]

[1] 1 = excellent, 2 = good, 3 = fair, 4 = poor

[2] 0 = normal, 1 = minimal, 2 = mild, 3 = moderate, 4 = severe

[a] $\bar{X} \pm$ S.E.M.

[b] Significantly greater than mean for Gambee technique ($p < .01$).

[c] Significantly greater than mean for Gambee technique ($p < .05$).

Figure 32. Gambee anastomosis, Gomori's trichrome stain (approximately 6.2x). An example of misalignment but close proximity of muscle layer ends. Note good mucosal architecture.

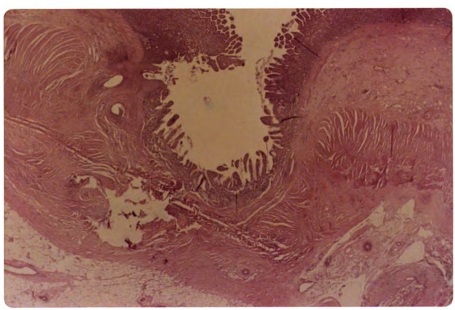

Figure 33. Stapled anastomosis, hemotoxylin and eosin stain (approximately 8.4x). An example of poor architecture of mucous membrane. Note the staple holes and excessive fibrous tissue resulting in a thickened bowel wall.

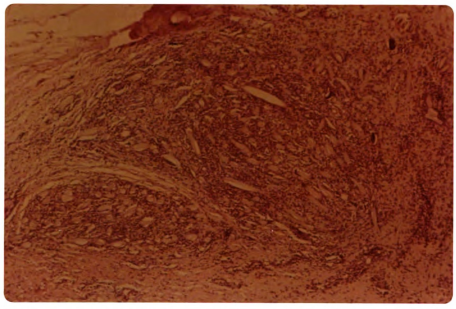

Figure 34. Gambee anastomosis, hemotoxylin and eosin stain (100x). Inflammatory response to suture material.

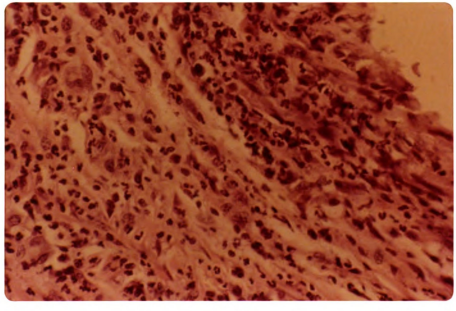

Figure 35. Stapled anastomosis, hemotoxylin and eosin stain (430x). Macrophages and neutrophils predominate. (Severe inflammation.)

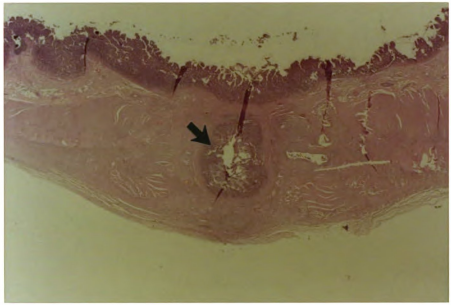

Figure 36. Stapled anastomosis, hemotoxylin and eosin stain (approximately 6.9x). Mucocele marked by arrow.

Figure 37. Stapled anastomosis, Gomori's trichrome stain (approximately 4.9x). Mucocele (large arrow) present and mucous epithelium absent (small arrow). Note distance between severed muscle ends and islands of muscle tissue.

Figure 38. Stapled anastomosis, Gomori's trichrome stain (approximately 6.9x). Mucocele connects with lumen and extends nearly to serosal border of intestine.

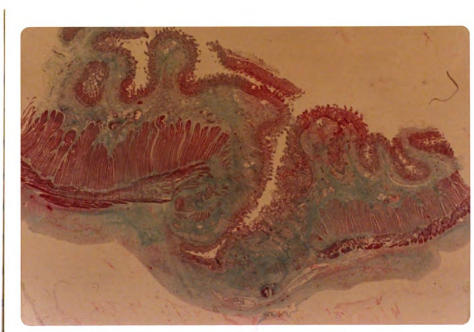

Figure 39. Stapled anastomosis, Gomori's trichrome stain (approximately 5.6x). Deep mucosal cleft.

DISCUSSION

5.1 Morbidity and Mortality

The conclusions made from this study were not influenced by morbidity and mortality of the subjects. Each horse had both types of anastomosis so that there was no way to ascribe signs of dysfunction to one anastomosis or the other. Only completely healed anastomoses were examined and compared. Animals that did not survive the required length of time were excluded from the study. Clinical signs of obstruction or colic were discounted.

5.2 Gross Evaluation

5.2.1 Extraluminal Changes

Serosal Thickening

An increase in connective tissue in the serosal layer occurred secondary to inflammation, probably as a result of bowel manipulation and perhaps drying during operation. One of the major advantages of automatic suturing is decreased handling of tissue.[113] This was the case in this study and expectations were that serosal inflammatory changes would be less in the stapled anastomosis; however, this did not happen. The tendency was for bowel from the same animal to react in the same fashion. Severity of lesions tended to be the same for both sites within the individual animal.

Care had been taken to prevent excessive drying of the bowel. It seemed that one individual horse reacted to tissue handling of any quality and duration in much the same manner.

Adhesions

The phenomenon of similar response of the individual to trauma at different sites, may be considered a consistent reaction of the individual or due to the common environment provided by the peritoneal cavity. Thus, each injured area (anastomosis) is influenced by the other through the medium of peritoneal fluid. There are no grounds for assuming that one type of closure proved deleterious to the other except for the following:

1. Horses No. 8 and 9 had no adhesions on the Gambee sites although the corresponding stapled closures did.
2. Three of the four stapled anastomoses without adhesions demonstrated considerable constriction, perhaps due to contraction of exuberant scar tissue formed as a result of leakage or excessive inflammation. (Lingering inflammation was found in the histologic studies of these stapled sites.)
3. In all three cases of severe adhesion of the Gambee anastomosis, the adhesions were attached to the stapled closure. These adhesions may have originated at the stapled anastomosis and involved other areas of serosal inflammation, including the Gambee anastomosis.

Most authors found that everted anastomoses in the dog are accompanied by more adhesions than other types of anastomosis.[1,2,98,146]

Reinertson found more adhesions associated with the everted anastomosis in the horse than with other methods.[118] Loeb and Getzen, et al., disagreed.[60,91] Ravitch, who has done the most work with automatic stapling devices, observed that the chief disadvantage with the everting anastomosis is the invariable increase in adhesions.[111] Adhesions are considered by many authors to be necessary to seal everted closures.[2,62,95]

Adhesion formation is often attributed to leakage at the anastomotic site.[2,62] Intraluminal pressure studies of healing anastomoses suggest that leakage almost uniformly occurs from points of entrance or exit of suture material.[123] Therefore, it appears more likely that a hand-sutured everted anastomosis would have more of a tendency to leak in comparison to a stapled closure. The stapled anastomosis employs firm compression of the suture line with minute staples that overlap their closure and removal of exposed mucosa 3 mm from the suture line.

Perhaps leakage of bowel contents does not occur but capillary leakage from the cut ends of gut or the desquamating mucosa itself causes inflammation that stimulates adhesion formation as suggested by Mellish.[98] This seems a more likely explanation for increased adhesion formation in stapled anastomoses. Histologic studies suggested that the everted stapled anastomosis depends on serosa healing over the everted mucosa. Healing is delayed and encourages excessive fibrosis that may result in adhesions. Persistent inflammation at the anastomosis may stimulate formation of adhesions.

Observations on the formation of adhesions for a particular technique should be made on a single bowel closure per animal.

Employing paired samples per animal is a valid method for studying healing qualities using the animal as its own control and finding differences between the paired samples. Where one sample may influence the other, as in the peritoneal cavity, observations have limited validity. One cannot make a sound comparison of adhesion formation for the two methods of anastomosis used in this study.

5.2.2 Luminal Changes

Anastomotic Constriction and Proximal Dilatation

The differences in degree of constriction and proximal dilatation between the stapled and Gambee anastomoses would be even greater if Cases 1 and 12 are excluded. Of the Gambee anastomoses, two specimens had constriction and dilatation greater than any of the rest of the group. Horse No. 1 had 22.2 percent constriction and 16.6 percent dilatation compared to means of 4.1 percent and 2.2 percent for the other specimens. Due to inexperience with the Gambee technique, too much tissue had been inverted in this first operation. Inversion of a 1.5 cm cuff created an internal circumference less than that of a normal lumen resulting in a mechanical obstruction with proximal dilatation. Horse No. 12 had a constriction of 25.0 percent associated with a proximal dilatation of 12.5 percent caused by adhesions that linked the conventional anastomosis to the stapled site. Since everted anastomoses are associated with more adhesions, it is possible that adhesions emanating from the stapled anastomosis attached themselves to the sutured anastomotic site and produced these changes in luminal circumference. Peritoneal influences may have extended beyond extraluminal changes.

The TA-90 delivers a double row of staples only 2 mm apart and produces an everted anastomosis. Either the double staggered row of

staples inhibits intestinal expansion and encourages stricture or the eversion of mucosa results in stricture, or both.

Several authors found sutured everted anastomoses to be more constricted in the late phases of healing than mildly-inverted or end-on anastomoses. They attributed the constriction to adhesions.[1,2,98,118] Constriction may be associated with persistent inflammation in the anastomotic junction. In this study more inflammation was found in the stapled anastomoses (Tables 7 and 8).

The presence of macrophages in a wound attracts fibroblasts.[105] Chronic inflammation encourages excessive fibroplasia resulting in a thicker scar that reduces luminal circumference.[65,83] This fibrous tissue is dense and inflexible. Inflammation also increases fibrous contraction of the scar, further compromising the intestinal lumen.[105]

Getzen, et al., found constriction in healed (21 days) Gambee anastomoses and no constriction in healed everted anastomoses.[60] Since Getzen, et al., used a simple interrupted suture pattern for the everted anastomoses, it is likely that these anastomoses reverted to an end-on approximation of bowel ends resulting in less mucosal entrapment and inflammation. Several authors used a mattress suture to ensure eversion and found inflammation and stenosis associated with these closures.[62,111,146] It appears from luminal casts made, that in performing the Gambee anastomosis, Getzen, et al., took larger bites of tissue with the needle than advisable.[60] This results in inordinate inversion as seen in horse No. 1 of this study.

Constriction was not associated with inverted stapled anastomoses. Ravitch, et al,, found no evidence of obstruction with the use of the GIA anastomosing instrument on dogs, and Fain, et al., found no evidence of stricture with the use of the KC-28 in dogs and human patients for

colorectal anastomosis.[50,117] Both of these instruments perform an inverted anastomosis. The GIA places two staggered rows of staples around the anastomosis much the same as the TA model. However, stenosis was reported in 2 of 29 clinical anastomotic procedures using the GIA instrument.[48] The cause of stenosis was attributed to the manner in which the instrument forms the anastomosis. The GIA extrudes and closes four rows of staggered staples and automatically cuts between the center two rows, creating an anastomosis. Stenosis was due to healing of the cut ends of bowel to one another, reestablishing continuity of the original organs. In this case, constriction of the anastomotic scar was not the cause of stenosis as it was for the aforementioned everted anastomoses.

The staggered arrangement of staples may limit expansion of the intestine, but does not result in constriction. However, limited expansibility during healing may affect the circumference and expansibility of the healed anastomosis. The suture material, stainless steel, is known to be inert to tissues.[86] Constriction at the anastomosis seems to be related to the everted configuration of the bowel and not the method of suturing.

The cause of intestinal dilatation proximal to the anastomosis is not clear. Dilatation of the intestine proximal to the anastomosis seems to be related to constriction at the anastomosis, but they are not directly proportional. Those cases with a lot of dilatation were usually associated with substantial constriction, but it did not follow that appreciable of constriction resulted in substantial dilatation (Table 2). Specifically, in Cases 2 and 10, the stapled anastomoses were 25 percent and 37 percent constricted and had no proximal

dilatation, and Case 12 was 59 percent constricted with only 9 percent dilatation. Conversely, for the amount of constriction present, Cases 3 and 9 had inordinate dilatation: 54 percent and 44 percent respectively.

An intestinal constriction will cause retention of chyme which, depending on the amount of constriction, will cause a distension of the lumen proximal to the anastomosis. Chronic distension results in dilatation of the bowel.

Other factors may influence the dilatation of intestine so that constriction and proximal dilatation are not directly proportional:

1. Variation in the expansibility of the anastomosis may occur.
2. The constriction may occur at different times postoperatively in response to aforementioned factors such as adhesions and inflammation. (The stage of development of dilatation may be variable at post-mortem.)
3. Because of interruption of nervous conduction or smooth muscle layers there may be physiologic influences on peristalsis that result in proximal dilatation.[22,79,130] Disruption of intrinsic sympathetic inhibitory fibers may result in obstruction and proximal dilatation.[79]
4. Dilatation distal to the anastomosis occurred to some extent in a number of cases, but markedly so in two stapled cases which were very stenosed, Cases 10 and 12. Because the computation of constriction used the circumference distal to the anastomosis, the amount of constriction was high. The proximal dilatation was reduced because it was computed by

comparing the dilated intestine distal to the anastomosis with the proximal intestine. Dilatation distal to the anastomosis may be a post-stenotic dilatation due to the increased rate of flow of chyme through the narrowed anastomosis.

Only Getzen, et al., measured proximal dilatation.[59] They found it occurred with the Gambee anastomoses and not with the everted anastomoses. If Getzen, et al., performed both types of anastomosis in the manner proposed above, (e.g., inverting excessive tissue in the Gambee and using a simple interrupted pattern for the everted anastomosis) proximal dilatation would be likely to accompany the constricted Gambee anastomoses.

Changes in Rugae

Intestinal rugae are ridges of mucosa and underlying submucosa that increase the absorptive surface area of the intestine. In the horse, these ridges may be oriented longitudinally or transverse to the long axis of the small bowel (circular rugae), or the pattern may be mixed.[58,142] Rugae are somewhat plastic in nature and respond to tensions applied to the bowel wall. In distended bowel they may flatten completely.[22,142] Rugal patterns are noteworthy because they reflect the function of the intestine.

The form rugae acquired in the anastomotic junction is influenced in several ways. A mound of connective tissue at the anastomosis tends to flatten rugae. A decrease in the luminal circumference will force rugae into a longitudinal pattern (Figure 29). Dilatation encourages circular orientation of rugae. Rugae that cross the

anastomosis without an interruption or change in pattern reflect optimal healing in the mucosa and in the layers beneath the mucosa.

The defects most frequently seen in the stapled anastomosis reflected excessive connective tissue at the anastomosis and decrease in the luminal circumference. Circular orientation of rugae proximal to the anastomosis, and longitudinal or mixed patterns distal to the anastomosis occurred in all cases of proximal dilatation greater than 15 percent. This orientation was more common in stapled anastomoses. Circular patterns of rugae both proximal and distal to the anastomosis were seen in intestine that was dilatated both proximally and distally to a markedly constricted anastomosis.

Other Luminal Changes

Triangulation defects in the stapled anastomosis were probably due to decreased blood supply caused by the overlapping of staple closure lines. In these areas the mucosa did not heal together; serosal healing provided the only closure. Not all stapled anastomoses had this defect. The compression of tissue by the C-clamp or staples may have varied from operation to operation. To prevent this defect, the operator should take care to compress the tissue minimally. The optimal amount of compression to use with the TA-90 is not known, and there is presently no method to measure this compression. If special attention is given to the matter, subjective estimates by the operator may be adequate.

A cross section of the outpocket found in triangulation reveals the bowel wall to be very thin at this point. Histologically it is represented by a wide mucosal cleft that lacks muscular layers completely (Figure 37). In some cases, mucous membrane was absent

at these sites. This defect provides a point of weakness in the anastomosis, which may not be of clinical significance. Because fibrous tissue traverses the anastomosis at this point, it will probably withstand a higher pressure than the normal bowel before rupturing.[98] The anastomosis will not expand much with pressure and thus will be subjected to less pressure than the normal expansible bowel.[91] However, these evaginations may continue to form necrotic masses or collect debris with a potential for inflammation or intramural abcess formation. No reports on stapled anastomoses of the small intestine mentioned this problem.

Sphincter defects are due to excessive production of fibrous tissue adjacent to the staple line and the inability of the mucosa to heal to itself, resulting in serosal healing only. Thus, the intestinal wall is thicker in the anastomotic junction but abnormally thin at the staple line. This excessive fibrosis is undoubtedly due to continued attempts at healing and prolonged inflammation. This defect was not mentioned by other authors. Prolonged inflammation and failure of the site to heal through the mucosa was reported by others.[62,111]

Suture line cysts that connect with the lumen of the intestine are also due to failure of healing to take place through the mucosa. On histological exam, complete encysting of mucosa was also found. Ravitch, et al., described entrapment of mucous elements in everted, stapled anastomoses.[111]

5.3 Histological Evaluation

5.3.1 Basis of Evaluation: Findings Common to Different Techniques

In order to objectively evaluate histological sections of anastomotic sites, the following question must be answered: What changes are present in any anastomosis when compared with normal bowel? Histologic changes common to both types of anastomosis studied are as follows: First, there is discontinuity of all muscle layers. The interstice formed is filled with connective tissue. The severed ends of muscle layers do not necessarily line up correctly; some muscle ends approach their counterparts on a different stratum or angle or are separated by large distances. The bowel wall at this point is thicker than normal bowel due to this connective tissue replacer. Some of the increase in thickness is due to connective tissue proliferation in the serosa as well.

In addition to the major muscular layers, the muscularis mucosa is usually disrupted, as is the mucous membrane itself. Changes in the mucous membrane vary and include changes in shape, size and frequency of microvilli and glands of Lieberkuhn; change in depth of the entire mucous membrane or complete absence in spots; and changes in frequency of cell types.

Throughout the submucosa, lamina propria and deposited connective tissue, inflammatory cells often persist in the anastomotic junction. Although the lamina propria and submucosa of normal, unresected bowel of the horse have a small number of eosinophils and lymphocytes, macrophages and neutrophils are abnormal in noticable numbers.[142,143] For both types of anastomosis studied, all of these changes were present in some degree.

5.3.2 Gomori's Trichrome Sections

Distance Between Severed Ends of Muscle Layers and Bowel Wall Thickness

The distance between the severed ends of muscle layers and the bowel wall thickness in the anastomotic junction are indications of the amount of connective tissue deposited in the wound. No measurements of the width and depth of connective tissue in the anastomotic junction were found in the literature reviewed.

The stapled anastomosis had more connective tissue deposited in the anastomosis than the Gambee. Excessive connective tissue decreases the size of the lumen, limits the expansibility of the anastomosis and increases the distance between the smooth muscle, perhaps disrupting slow wave and nervous conduction and the smooth flow of chyme.[22,83]

Excessive connective tissue in the stapled anastomosis was probably due to continuing effort of the intestine to heal, compounded by persistent inflammation. Entrapped mucosa and its attending bacteria resulted in excessive inflammation which stimulates production of fibrous tissue.

Serosal Thickness

Stapled closures had a greater serosal depth than Gambee closures but the difference was not significant. This increase in serosal thickness is due to connective tissue deposition beneath the serosal epithelium. Deposition was somewhat greater in the stapled anastomoses probably because connective tissue had to cover the protruding mucosa.

Alignment of Layers of Intestinal Wall

Poor muscular realignment, often due simply to the great distance between muscle layer ends, was significantly greater in the stapled anastomosis. Getzen, et al., found everted hand-sewn anastomoses to have better muscle alignment than Gambee anastomoses.[60] It is possible that Getzen, et al., performed more of an end-on anastomosis than one of a strictly everted configeration as was mentioned previously (5.2.2). It is also possible that this group's Gambee anastomosis was excessively inverted. Gillet, et al., found better muscle alignment in inverted anastomoses compared to everted anastomoses.[62]

5.3.3 Hematoxylin and Eosin Sections

Architecture of Mucous Membrane

The poor architecture and lack of mucous membrane in the stapled anastomoses are probably due to the manner in which everted anastomoses heal. Apposed mucosa heals not to itself, but through itself from invasion of fibroblasts through the staple holes and through the injured adjacent tissue. In some areas this healing did not take place and when the staples were extruded from the bowel wall, only the healed serosa held the anastomosis together. The mucosa in the area had sloughed and migration and replication of mucosal cells were insufficient to cover the bare expanse. In other areas, healing through the mucosa took palce, but mucosal regeneration was still inadequate to replace degenerated mucosa. Some of the mucosal cells were lost into the bowel wall as

mucoceles. Perhaps inordinate compression of the tissues from the staples or the jaws of the stapling device was responsible for excessive sloughing of mucosa.

In contrast, none of the mucosa in the Gambee was lost, so there was none to replace. The mucosa was inverted into the lumen of the gut and on histological exam appeared even to be somewhat redundant (Figures 31 and 32).

The mucosa is the first line of defense between the pathogenic organisms in the intestinal tract and the peritoneal cavity. Spontaneous perforation of the intestinal tract begins with a defect in the mucosa.[54] When an anastomosis is performed, a defect in the mucosa is inevitable, but it should be quickly covered. It is essential that a healed anastomosis have a complete mucous epithelium.

Few studies included histological evaluation. Most that did found the architecture of mucous membrane to be superior in the Gambee anastomosis compared with other methods.[2,62,111] Abramowitz and Butcher found gaps in the mucous membrane filled with granulation tissue in the inverted anastomoses.[2] However, Getzen, et al., reported a "disuse atrophy" of everted mucosa which progressed to a smooth mucosal conjunction.[60] Once again, perhaps the anastomoses performed by this group reverted to an end-on apposition.

Inflammatory Response

The Gambee anastomoses had significantly less inflammatory response than the stapled anastomoses. The distribution of mucosal elements through deeper layers accounts for the severity and nature of inflammation present in the stapled closures.[62] Neutrophils

present in these specimens more than 50 days after operation is attributable to bacterial flora accompanying trapped mucosa and mucus. Proliferation of macrophages in response to retained epithelial elements is further stimulated by production of mucus by trapped goblet cells.[62]

Other authors found everted anastomosis to have persistent inflammation in the anastomotic zone.[62,111,134] Steichen performed a double-barrelled inverted (side-to-side) anastomosis with the GIA instrument.[134] The TA was used to close the double-barrelled open ends of intestine in everted apposition. Steichen observed complete healing in the serosa-to-serosa portion of the anastomosis but persistent inflammation in the mucosa-to-mucosa closure. In view of this observation, the stainless steel staples should not be held responsible for persistent inflammatory changes. Studies by many authors attest to the low tissue response to stainless steel sutures.[9,31,145]

Persistent inflammation in the anastomosis delays healing and stimulates excessive fibrosis.[62,83] It appears to be responsible for fibrous contraction, resulting in constriction at the anastomosis.

Findings Peculiar to the Stapled Anastomoses

Mucosal elements were stranded in a bed of connective tissue because of the manner in which everted anastomoses heal (Section 2.5.2, page 30).[111] Ravitch, et al., found islands of epithelium buried in the anastomotic zone in both hand-sutured and stapled everted anastomoses in dogs. They noted that these epithelial cysts were still present at six months after operation. Others found

epithelial cells, cysts and mucoceles in healed anastomoses.[2]

Histological sections of stapled anastomoses that had no epithelial components usually had a deep mucosal cleft. Other investigators found mucosal clefts in everted anastomoses in dogs at six weeks postoperatively.[2,111]

Evidently the mucosa did not heal through itself and the anastomosis thus healed only at the serosal border. These mucosal clefts constituted weak points in the anastomosis. Mucosal cysts and clefts indicate that healing of mucosa to mucosa is inferior to healing of serosa to serosa. The mucosal elements stimulated continued inflammation that resulted in excessive fibroplasia, fibrous contraction and constriction of the lumen.

The advantages of speed, simplicity, conformity of results and less tissue handling are attractive enough to warrant further trials of stapled anastomosis in the horse. It may be desirable to experiment with other methods of stapled closure that do not involve eversion of mucosa. Perhaps Steichen's largely inverted, functional end-to-end anastomosis (Section 2.8.1, page 44) would be a subject for study.[137] To assess clinical recovery and adhesions, each animal should have only one anastomosis.

CONCLUSION AND SUMMARY

This comparative study of the Gambee and staple techniques for equine bowel anastomosis indicates that the Gambee technique is superior to the staple technique in long-term healing qualities as measured by gross and microscopic structural evaluation. The main disadvantage of the staple technique is a strong tendency for anastomotic constriction due to chronic inflammation. This chronic inflammation is most likely due to the everted apposition of bowel ends employed in the staple technique. However, the staggered arrangement of staples may limit the expansibility of bowel during healing and thus result in a scar with a small circumference.

Whether or not clinical recovery is more favorable with Gambee or stapled anastomoses could not be proven by these methods. Postoperative complications could not be attributed to either surgical technique because of the method of paired sampling that was used. Using the animal as its own control is a respected and often utilized method, but observations on each particular technique cannot be made under these circumstances if they are referable to the entire animal.

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