Accelerated Wound Healing with Stapled Enteric Suture Lines

An Experimental Study Comparing Traditional Sewing Techniques and a Stapling Device

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The healing of 3-cm longitudinal colotomies closed with either Czerny-Lembert suture lines (CLSL) or TA-30 staple lines (SSL) were studied in 28 mongrel dogs using bursting strength (BS) measurements. Dogs from each group were sacrificed on postoperative days (POD) 1 through 7. Mean BS for the SSL in all 14 dogs was 165 mmHg ± 64 and for CLSL 80 mmHg ± 49 (DF = 13; t = 5.5672; $p < 0.00005$ for matched pairs). For POD 2 through 5, BS of the SSL was 154 mmHg ± 42, three times greater than the BS of the CSLS, which was 54 mmHg ± 33 (DF = 7; t = 5.6289; $p < 0.0004$ for matched pairs). BS of the SSL increased linearly from the first day of surgery: BS (mmHg) = 26 (POD) + 61 (n = 14; r = 0.838; $p < 0.01$). BS of the CLSL followed the traditional pattern of wound healing dropping to a nadir after 3 days and then increasing linearly: BS (mmHg) = 32 (POD) − 72 (n = 10; r = 0.834; $p < 0.01$). Microscopic examination revealed a greater inflammatory response to the CSLS than the SSL. Differences were most marked from 2 to 4 days following operation. Thus, the SSL healed more rapidly than the CLSL as measured by BS. The SSL healed with a negligible Lag Period of wound healing entering directly into the Period of Fibroplasia.

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THE MODERN AGE of intestinal suturing began in 1812 with the publication of Travers'[1] studies on the healing of intestinal anastomoses. He stressed the importance of serosal apposition in constructing enteric suture anastomoses. The commonly accepted doctrines of intestinal suturing date to 1827 when Lembert[2] described his inverting technique. During the remainder of the nineteenth century, several modifications of Lembert's technique were described.[3] These methods all shared several principles. It was deemed essential that the serosal sufaces be uniformly apposed around the full circumference of the anastomosis. The sutures that accomplished this must be anchored in the submucosa because of its holding strength.[4] In order for an anastomosis to reliably heal, it should be constructed in an environment free of hematoma, necrotic tissues, or infection.[5] These doctrines remain generally accepted today.[6]

Recently, stapling techniques have become widely used in constructing enteric suture lines and anastomoses. Clinical results have been remarkably good.[7] Little experimental information, however, has been published about the healing of stapled suture lines.[8] Available data suggest that these stapled suture lines provoke a minimal inflammatory response. Unlike other surgical techniques, direct comparisons of various stapling maneuvers have not been made with the traditional Czerny-Lembert suture line. Consequently, we have directly compared the healing of a stapled suture line with that of the most commonly used two-layered sewn suture line[9] in an experimental model using mongrel dogs. Histological examination and bursting strength measurements in these experiments exposed differences in the pattern of healing in the wounds closed by these two different techniques.

Methods

All experiments were performed on adult mongrel dogs. The dogs were fed standard dog chow until the night before surgery. They were allowed no food or water after midnight. The bowel was not prepared. No

TA-30 3.5 mm cartridges provided by the United States Surgical Corporation.

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TABLE 1. *Sex and Average Weight of 28 Mongrel Dogs Undergoing Enteric Anastomoses*

Technique	Female (number)	Male (number)	Total (number)
Stapled (lbs)	37.6 (7)	43.3 (7)	39.9 (14)
Sewn (lbs)	36.6 (5)	44.9 (9)	41.9 (14)

antibiotics were given. Nembutol® anesthesia was used. The dogs were intubated and ventilated with a Harvard Apparatus® respiration pump.

The dogs' abdominal walls were shaven, washed with soap, and painted with Betadine®. The abdomen was entered through a midline incision. A 3-cm longitudinal colotomy was made along the antimesenteric border 5 cm distal to the ileocecal valve. The colotomy was closed with an inverting Czerny-Lembert suture line (CLSL) in 14 dogs and an everting stapled suture line (SSL) in 14 dogs. The technique was determined randomly. The inner layer of the CLSL was constructed with a Connell suture of 000 chromic catgut. The outer layer was formed with approximately 13 interrupted Lembert sutures evenly spaced using 000 silk. A TS-30 stapling device (United States Surgical Corporation) with a 3.5 mm cartridge (blue) was used in placing the SSL. Both techniques were done open. The abdomen was not irrigated. The midline incision was closed in one layer using an absorbable suture as was the skin.

Following surgery the dogs were allowed food and water *ad libitum*. Two dogs from each group were sacrificed on POD 1 through 7. The day of surgery was counted as day 0. The terminal ileum and proximal colon containing the suture line were removed immediately after the dog's death. Bursting strength (BS) measurements were obtained on the fresh specimen. After BS were measured, the anastomoses were fixed in formaldehyde.

Bursting strength measurements were obtained by distending the fresh specimens with a constant stream of compressed air. The terminal ileum was clamped closed. A cannula was introduced through the distal colon and secured in place with a banding gun (Adjustable Tension Installing Tool, Thomas and Betts, Co.). The intraluminal pressure was transduced by strain gauge (Heiland Instruments, Honeywell), amplified by a carrier amplifier system (Heiland Instruments, Honeywell), and recorded on a Visicorder Model 1108 (Heiland Instruments, Honeywell). Calibration was checked with an absolute and differential mercury manometer (Manostat Corp.). Bursting strength was defined as the pressure recorded on the tracing at the time that the suture line ruptured. This was recognized as the peak where the

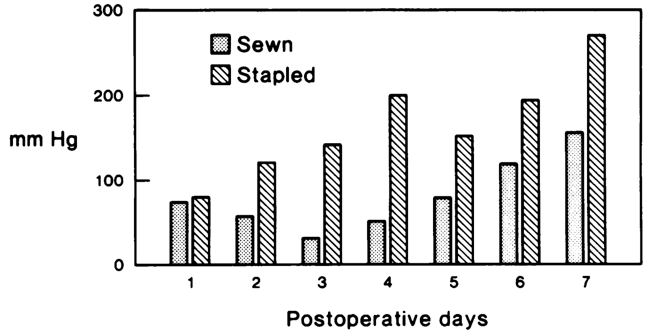

FIG. 1. Average bursting strength of 14 stapled and 14 sewn suture lines in mongrel dog colons on each day following surgery. Each bar represents two bursting strength measurements.

rising slope of the pressure tracing suddenly changed to a negative slope due to escaping air. Statistical analysis was done with a TI 58c programmable calculator (Texas Instruments) using the Applied Statistics Module (Texas Instruments).

Standard hematoxylin and eosin stains were used in preparing the histological sections of the anastomoses. Sections of stapled and sewn anastomoses from the same postoperative day were compared by a board certified pathologist in a blinded fashion.

Results

Fourteen dogs were studied in each group. The average weight by sex and for the entire group is listed in Table 1. There was no statistical difference between the two groups. There was a slight excess of male dogs in the sewn group.

The average BS for each group on each day following surgery is shown in Figure 1. Each value is the average of two BS measurements. The mean BS for the 14 SSL on POD 1 through 7 was 165.3 mmHg ± 64.4 (Fig. 1) as compared to 80.7 mmHg ± 48.6 for the 14 CSCL:

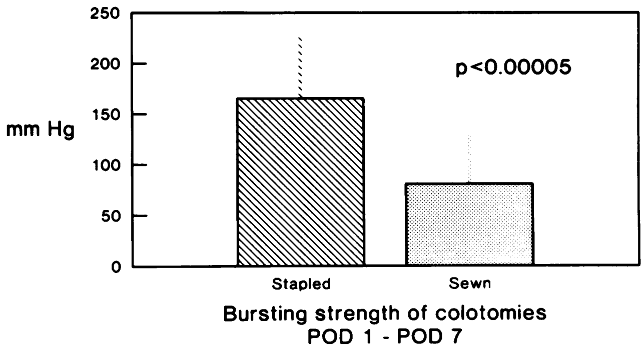

FIG. 2. The average bursting strength of 14 stapled suture lines, 165.3 mmHg ± 64.4, was twice that of 14 sewn suture lines, 80.7 mmHg ± 48.6, in mongrel dog colons on POD 1 through 7.

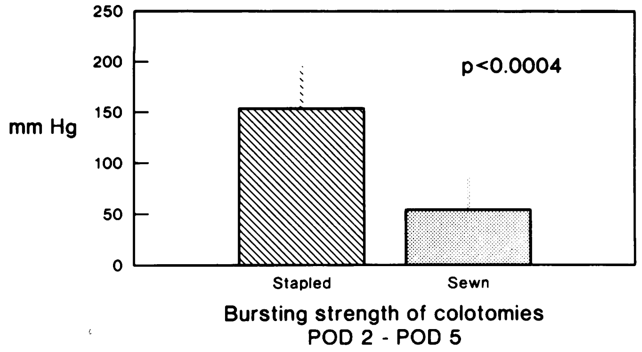

FIG. 3. The average bursting strength of eight stapled suture lines on POD 2 through 5, 153.5 mmHg ± 42.4, was three times greater than eight sewn suture lines, 54.1 mmHg ± 32.9.

this difference was statistically significant (t = 5.5672; $p < 0.00005$ for matched pairs). The mean bursting strength of the SSL (153.5 mmHg ± 42.4) was three times greater than that of the CLSL (54.1 mmHg ± 32.9) on POD 2 through 5 (Fig. 3): this difference was also statistically significant (t = 5.6289; $p < 0.0004$).

Linear regression analysis of the BS measurements demonstrated a pattern to the changing values (Fig. 4). The BS of SSL increased linearly from POD 1 through 7: BS (mmHg) = 26 (POD) + 61 (n = 14; r = 0.838; $p < 0.01$). BS of the CLSL dropped initially but then increased linearly from POD 3 through 7: BS (mmHg) = 32 (POD) − 72.1 (n = 10; r = 0.834; $p < 0.01$).

Comparison of histological sections from the SSL and the CLSL showed a dramatic difference. Each section was judged for number of polymorphonuclearleukocytes in the submucosa, congestion of the submucosal vessels, degree of neovascularization, degree of hyperplasia of the vessels' endothelium, and serosal edema. On each comparison, the pathologist picked the CLSL as showing the greater inflammatory response.

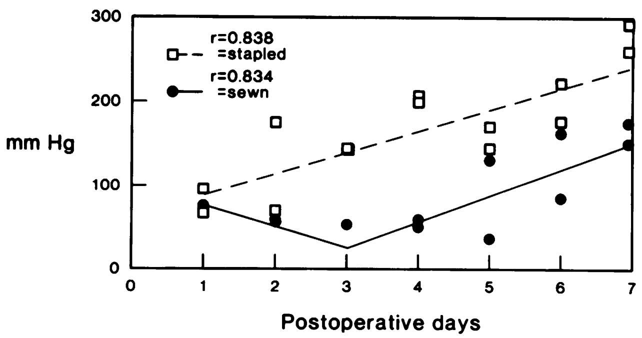

FIG. 4. The bursting strength of 14 sewn suture lines dropped to a nadir on POD 3 before increasing linearly through POD 7. The bursting strength of 14 staped suture lines increased linearly from POD 1 through 7.

Discussion

The average bursting strength of the stapled suture lines in this study was three times greater than that of the hand sewn ones from POD 3 through 5. Surprisingly, the SSL healed in a pattern different than is generally seen with other suturing techniques. The SSL either healed with an abbreviated Lag Period or without one, thus avoiding the dangerous weakening of the suture line in the early postoperative period generally observed during the Lag Period of wound healing.

The return of strength in the healing wound follows a pattern that can be divided into three periods. Whether measured by tensile strength[10] or bursting strength,[11] the integrity of the healing suture line drops to dangerously low levels during the Lag Period. This is the time period when inflammatory cells cleanse the wound of debris. After approximately 4 to 6 days, cellular elements proliferate (the Period of Fibroplasia) and wound strength begins to rapidly rise. By 2 weeks, the bursting strength of intestinal anastomoses exceeds that of the surrounding bowel. Tensile strength initially rises rapidly in the Period of Fibroplasia but asymptomatically approaches preoperative levels only during the prolonged Period of Maturation. Thus, it is during the Lag Period that surgical technique plays such a crucial role in the healing of the intestinal anastomosis. During this period, the suture line accounts for essentially all the measurable strength in the anastomosis.

Measurements of wound collagen content have illucidated the biochemical basis of these observations. Initially, the wound edges are stuck together only by fibrin. The holding strength of suture lines is dependent upon the collagen content of the submucosa. During the Lag Period, collagen content drops because of increased collagenase activity.[12] As the collagen content of the submucosa drops during the Lag Period, the strength of the anastomosis drops to a low.[11] During the Period of Fibroplasia new collagen fibrils are formed. Collagen bridges the anastomosis. Rising wound strength follows the rising wound collagen content.

Factors that incite inflammation further weaken the wound. Experimental studies have shown that all suture materials placed by hand produce inflammation. Dragging the suture through the wall of the bowel, in particular, damages it, precipitating a cellular inflammatory response.[13] Inflammation produced by sutures contributes to the drop in bursting strength and tensile strength of the anastomosis presumably by increasing collagenase activity.

Experimental studies with pulmonary resections in animals have indicated that stapled suture lines heal with less inflammation than hand sewn closures. Amosov and Berezovsky[14] in Russia found a minimal inflammatory response following closures of bronchi in dogs with an automatic stapling instrument. Smith et al.[15] compared bronchial stump closure in dogs using the Russian IKB-25 stapling device or several different sewing techniques. Disruption rates were similar in all groups. The stapled line showed less inflammation. Similar studies were performed with the TA-30 stapling device by Scott et al.[16] The inflammatory response to the sewn bronchial closure was much greater than that of the stapled closure. The BS of the stapled closure was 251.25 mmHg $\pm$ 82.9 while that of the sewn closures was 139.44 mmHg $\pm$ 78.9. The difference between the two techniques was statistically significant.

Several reports indicate that stapled enteric suture lines heal with less inflammation than sewn ones. Gritsman from the Research Institute of Experimental Surgical Apparatus and Instruments in the Soviet Union published studies using a stapling device that constructed an end-to-end enteric anastomosis with one row of staples.[17] He found little edema or induration in the anastomotic suture line. Experimental studies at Hopkins led by Ravitch[18] also indicated the presence of remarkably little cellular reaction at the stapled suture lines. These two groups of researchers concluded that stapled suture lines generally heal by primary intention in contrast to sewn suture lines which often heal by secondary intention with a marked inflammatory response.

The differences in wound healing between the stapled and sewn suture lines in this study related primarily to the duration of the Lag Period of wound healing. The CLSL followed the classical pattern of healing with a dropping bursting strength which reached a nadir on the third day. Subsequently, the BS increased linearly during the Period of Fibroplasia. Wound healing in the SSL did not follow this usual sequence. BS increased linearly from the first day after surgery. This linear increase was nearly parallel to that of the CLSL during the Period of Fibroplasia. No Lag Period of wound healing was demonstrable with BS measurements for the SSL.

The superiority of the SSL in this study was particularly striking because of the impact of LaPlace's Law. The surface tension on the wall of a tube is proportional to the cube of its diameter. Since the CLSL was a two-layered inverting suture line, its luminal diameter was smaller than that of the everted stapled line. Consequently, the surface tension on the CLSL at the same intraluminal pressure should have been greater than that of the SSL. The construction of longitudinal suture lines was designed to minimize the impact of this natural law but some difference undoubtedly persisted.

The histological sections of the suture lines demonstrated that the TA-30 stapling device incited a minimal inflammatory response as compared to that of a sewn suture line. From this observation, we might speculate that because of minimal inflammatory response little of the native collagen in the submucosa of the SSL was degraded by activated collagenase. Thus, wound strength was not weakened by erosion of the submucosal collagen content.

Conclusion

Few other experimental studies have compared stapled suture lines to sewn closures. Dunn et al.[19] from Minneapolis, found no difference in the bursting strengths of stapled end-to-end anastomoses using the TA-30 as compared to inverted single layer anastomoses of 000 silk in dogs. Unfortunately, both anastomoses were constructed in the same dog. Any inflammation from either wound would activate collagenase throughout the entire colon weakening both suture lines.[12] Polglase et al.[20] found no difference in the edema of anastomoses constructed with an end-to-end stapling device or a Gambee single layer inverting suture. They also found no statistically significant difference in the BS of the wounds closed with the two techniques. Half of their BS measurements, however, were well into the Period of Fibroplasia so that any early differences in BS may have been obscured. Experiments by Greenstein, Rogers, and Moss[21] comparing anastomoses with the end enteric anastomosis (EEA) stapling device and with a closure of continuous Dacron suture showed remarkably superior BS of the stapled wound. The average BS of the EEA staple line was two to six times stronger on POD 4 than that of the sewn suture line.

Our study supports the hypothesis that stapled suture lines heal by primary intention with a minimal inflammatory response resulting in superior wound strength during the critical first week following surgery. This allows healing by primary intention and a pattern of wound healing that is manifested by an abbreviated or absent Lag Period.

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