Blood Flow in Colon Anastomotic Stricture Formation

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PURPOSE: The influence of both blood flow and anastomotic technique on the development of anastomotic stricture formation was studied using a dog model. METHODS: Fifty-three dogs underwent distal colocolonic anastomosis with either an EEA™ (U. S. Surgical Corp., Norwalk, CT) circular stapler or a Czerny-Lembert two-layered, handsewn anastomosis. Blood flow was measured by Laser Doppler Velocimetry using the Laserflo BPM^2 ™ (Vasamedics Inc., St. Paul, MN). The animals were separated into three blood flow groups: greater than or equal to 62.5 percent of normal blood flow, between 37.5 percent and 62.5 percent of normal blood flow, and less than or equal to 37.5 percent of normal blood flow. Each blood flow group had an anastomosis performed by either stapling or by hand sewing techniques. At six weeks, the anastomoses were opened longitudinally and fixed to determine the anastomotic index (AI). AI is defined as two times the anastomotic circumference over the proximal circumference plus the distal circumference. Blood flow groups and anastomotic technique groups were compared with an interaction variable for the outcome, AI using a two-way analysis of variance. RESULTS: The AI of the stapled anastomoses was found to be significantly higher than handsewn anastomoses ($P < 0.006$). There was no difference in AI between different blood flow groups and no correlation of observed histologic findings with AI. CONCLUSION: Clinically relevant ischemia does not directly influence stricture formation in either handsewn or stapled distal colonic anastomoses. [Key words: Colonic anastomosis; Anastomotic stricture; Anastomotic stenosis]

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Stapling in distal colonic anastomoses has become a routine technique. However, little is known about the late complication of anastomotic stricture associated with stapling. There have been reports of stricture rates in circular stapled colon anastomoses varying from 0 to 30 percent.[1–19] Several papers have reviewed the healing characteristics of stapled *vs.* handsewn anastomoses, finding stapling to be superior in many important ways.[14, 20–22] It has been proposed that the circular stapled anastomosis has a higher stricture rate than a handsewn anastomosis in the colon.[14, 20] It is, therefore, puzzling that a method of anastomosis with superior healing characteristics would be more prone to stricture formation.

Anastomotic healing can occur without complication if 1) the tissues involved are viable with an adequate blood supply,[23, 24] 2) there is no infection involving the anastomotic line or in proximity to it predisposing it to disruption,[20, 25–28] and 3) the material used to create the anastomosis does not induce an inflammatory response, allowing healing by primary intent.[20, 22, 29] It was our intention to define the role of blood flow in the development of stricture formation. Before this study there has been no comparison between circular stapled and handsewn anastomosis in the presence of minimally, moderately, and severely compromised blood supply.

MATERIALS AND METHODS

Two groups of Beagle dogs weighing 25 to 35 pounds underwent a low colon anastomosis. The first group consists of animals that received a Czerny-Lembert two-layer, handsewn anastomosis. The second group received Premium EEA™ (U. S. Surgical Corp., Norwalk, CT) circular stapled anastomoses. Within each group there were three subgroups: those with blood flow greater than or equal to 62.5 percent of normal mucosal blood flow, those with blood flow between 37.5 percent and 62.5 percent of normal mucosal blood flow, and those with blood flow less than or equal to 37.5 percent of normal mucosal blood flow. Before creation of the anastomosis, blood flow groups were determined by calculating the mean percentage of total blood flow remaining after devascularization. Animals were selected at random before

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surgery; however, the blood flow group and anastomotic technique group were not randomized. One surgeon performed all of the anastomoses and blood flow measurements.

Animals received a standard mechanical bowel preparation and oral antibiotics. Anesthesia was induced with pentobarbital and maintained with a mixture of 1 percent halothane, 49.5 percent nitrous oxide, and 49.5 percent oxygen during the operation. The percentage of halothane administered was varied to maintain the animals blood pressure within a narrow range. A femoral arterial catheter was placed using a cutdown technique, and continuous monitoring was accomplished using a Gould™ (Gould Corp., Rolling Meadows, IL) monitor setup. A preoperative and postoperative hematocrit was assessed to rule out confounding variables.

A vertical midline celiotomy incision was performed, and the distal colon was identified. While applying enough tension on the colon to straighten any redundancy, a point 10 cm from the pubic symphasis was identified as the site of the anastomosis by intra-abdominal measurement with a ruler and was marked with a single 3–0 silk suture placed in the antimesenteric border. By using a Laser Doppler Velocimeter (LDV), Laserflo BPM^2 ™, blood flow measurements were taken in the normal mucosa at the anastomotic site by introducing the LDV probe through an antimesenteric longitudinal colotomy. The LDV probe head (model P-450) was placed in a wax vehicle that was then introduced through the colotomy into the lumen of the distal rectum. The probe head monitors at a right angle to the optic cable, which allowed for mucosal measurements to be recorded with minimum difficulty.

To assure that the regional blood flow was accurate, four blood flow measurements were taken in the region concerned, along a 180 degree sweep of the antimesenteric wall of the colon. We were able to monitor blood flow in the anastomotic rim after stapling and directly over sutured anastomoses with our probe and vehicle.

The mesenteric fat and vessels were then serially divided at the level of the serosa until the desired blood flow was obtained; the devascularized distances were measured in millimeters with a ruler. Blood flow measurements were repeated after devascularization. Subjective observations of the bowel were also recorded at this time.

Either a handsewn, two-layer Czerny-Lembert (inner continuous 3–0 chromic and outer interrupted 4–0 silk layer) or a premium EEA™ circular stapled anastomosis was performed. The stapled anastomosis was accomplished through the previously established colotomy, which also allowed access for mucosal blood flow measurement within the anastomotic ring after the completion of the anastomosis. The colon was not divided before stapled anastomosis. The colon was divided between crushing clamps before establishment of the handsewn anastomosis, and, after posterior Lembert sutures were placed, the clamps were excised with a knife and bleeding controlled with the running Czerny suture. This technique resulted in nearly the same amount of tissue removed for both the stapled and the handsewn anastomoses. In handsewn anastomosis, blood flow measurements were similarly taken directly over the sutures through the established colotomy. The colotomy was closed transversely with a TA55™ (U. S. Surgical Corp., Norwalk, CT) stapler.

The animals were then followed for a period of six weeks, allowing edema to subside. The animals underwent receliotomy after a six-week interval. A proximal colotomy was performed to measure mucosal blood flow over the site of the anastomosis. After blood flow measurements were taken, animals were sacrificed and the anastomotic segment excised. The anastomotic ring was opened with a longitudinal incision. The specimen was fixed and sent to the Department of Pathology for measurement, sectioning, and histologic examination. All anastomotic circumferences were measured as well as the circumference of the bowel 2 cm proximal and 2 cm distal to the anastomosis. An anastomotic index (AI) was calculated for each specimen:

$$\text{anastomotic index} = \frac{2 \times \text{anastomotic circumference}}{\text{proximal circumference} + \text{distal circumference}}$$

RESULTS

There were a total of 53 dogs. Twenty-seven of these animals underwent an EEA™ circular stapled anastomosis, whereas 26 animals underwent a Czerny-Lembert two-layer, handsewn anastomosis. These groups were further subdivided by blood flow into three subgroups (Table 1). The subgroups were compared with each other to establish whether any significant difference existed between the mean anastomotic index calculated for each subgroup. It was determined, using a two-way analysis of variance, that

Table 1.
Anastomotic Indices in Stapled *vs.* Handsewn Anastomoses by Blood Flow

	≤37.5%	37.5–62.5%	≥62.5%
Stapled			
No. of animals	9	10	8
Mean AI ± SD	1.056 ± 0.18	1.060 ± 0.178	1.013 ± 0.083
Handsewn			
No. of animals	10	11	5
Mean AI ± SD	0.950 ± 0.11	0.909 ± 0.104	0.940 ± 0.089

no significant difference existed between the anastomotic indexes in the three blood flow groups. The distribution of AI was found to be normally distributed as tested by Shapiro-Wilks statistics. There was, however, a statistically significant higher anastomotic index in the stapled groups relative to the handsewn groups indicating a more patent anastomotic ring ($P < 0.006$). The difference in anastomotic indexes between the stapled and handsewn groups does not statistically differ over the three blood flow groups (Fig. 1).

None of the physiologic variables correlated with any of the outcomes including starting hematocrit, ending hematocrit, mean arterial pressure, or weight of the animal. The bowels of all animals with blood flows less than or equal to 37.5 percent were observed to have subjective evidence of ischemia including color changes, edema, or venous thrombosis, with 84 percent of these exhibiting combinations of these changes.

None of the animals exhibited any clinical evidence of leak, and at re-exploration there were no instances of abscess. Incidences of complications overall were minimal, with one case of seroma in the incision and one animal that developed intestino-intestinal intussusception with incarceration requiring partial enterectomy.

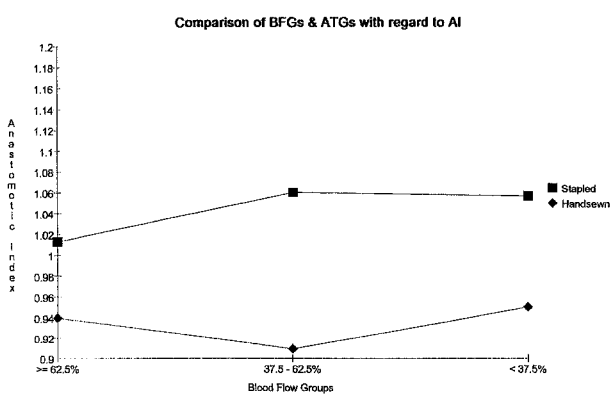

Figure 1. Comparison of blood flow groups and anastomotic technique groups with regard to AI.

The devascularized distance was inversely correlated to the mean devascularized blood flow ($P < 0.0001$). Mean devascularized blood flow correlated in a linear fashion to mean anastomotic blood flow at six weeks ($P < 0.003$).

The sample size of nine animals in each anastomotic subgroup was found adequate to allow detection of a difference of 2 mm or more in colonic radius at an alpha of 0.01 level of significance with 95 percent power simultaneously in the three blood flow groups. This assumed that the standard deviation of the difference in colonic radius between the anastomotic subgroups was 1.5 mm, which after completion of the study was found to be reasonable. AI is related to but not the same as the radius; however, we have no means of directly determining the power to detect differences in the AI. Clinically relevant differences in the radius would be much larger than 2 mm, and this study would have had the power to detect such a difference.

DISCUSSION

No previous study has evaluated the effects of blood flow on early stricture formation by studying different levels of blood flow in stapled and handsewn anastomosis formation. This study is, therefore, the first to demonstrate that blood flow does not significantly influence early stricture formation and that this lack of influence is independent of anastomotic technique. We observed subjective changes in the appearance of the bowel, which paralleled the measured blood flow. The decrease in blood flow was related to the devascularized distance in a predictable manner, and the inverse correlation was highly statistically significant. Other mechanisms felt to interfere with anastomotic healing were controlled for; we had no clinically evident anastomotic leaks and no evidence of intra-abdominal abscess, wound infection, or wound dehiscence. There were no significant complications related to surgical technique. All animals tolerated the surgical procedure well, with

oral feeding by postoperative day 1 and early return of bowel function.

Based on the results of our experiment we found ischemia played no significant role in the development of anastomotic strictures. Comparison of AIs between different blood flow groups demonstrates not only no significant difference but also no trend toward lower AIs with decreasing blood flow. The inability to generate anastomotic strictures, even with blood flows less than 37.5 percent of normal mucosal blood flow, strongly suggests that blood flow is not a major factor in the development of this complication.

It was previously demonstrated that blood flow to the anastomotic rim is compromised, regardless of the technique used to fashion the anastomosis; however, this study revealed that circular stapling reduces blood flow less than hand sewing.[21] A correlation between perianastomotic oxygen tension and breaking strength and breaking energy was reported.[24] In fact a minimum oxygen tension was defined, below which the leakage rate was 100 percent.[24] Devascularizing a length of bowel to decrease the blood flow below a critical value as measured by LDV and intramural pH resulted in an increase in stenosis and leakage.[23] These studies collectively demonstrate the intuitive principle that blood flow is critical to a viable anastomosis and that decreasing the blood flow below critical levels leads to increases in complications. It is clear from our study that critical levels of blood flow are extremely low and that variations in blood flow over an extraordinarily large range do not participate in the generation of complications. Differences in reduction of blood flow caused by the different anastomotic techniques most likely does not contribute in any substantiative way to outcome.

We found a highly significant difference in anastomotic index when comparing circular stapling to two-layered, handsewn anastomoses. The difference was reflected in the lower AI in the handsewn group relative to the circular stapled group. The finding of greater cross-sectional anastomotic area relative to adjacent bowel in circular stapled anastomoses is consistent with previously published studies.[30–32] Our study found that the advantage in early anastomotic patency enjoyed by circular stapling was preserved over the six-week period of study; this is in contrast to the results of a published study demonstrating a reversal of this advantage at 28 days.[33] We believe that the advantage in AI is most likely a function of excess inversion of mucosal tissue, which accompanies a Czerny-Lembert handsewn anastomosis, an explanation discussed in previously published reports.[32, 34]

The LDV was used to measure blood flow during our experiments because of its ease of application and ability to generate real time flow data. The LDV has been shown to be accurate and reproducible.[35–37] Specifically, the LDV used in our experiment, the Laserflo BPM^2 ™ uses an infrared laser diode and a microprocessor-based signal analyzer, which provides a highly reliable and reproducible means of monitoring blood flow in real time.[38]

Animals were sacrificed at six weeks in our experiment to allow up to 70 percent of healing to occur.[39] Measurement of AI was chosen as an index of stricture because it assigns a numeric value to a given anastomosis. The use of AI in discussing the propensity of an anastomosis to stricture has been described in several recent articles addressing this issue.[30, 31, 33] The equation, 2 times the anastomotic circumference over circumference 2 cm proximal plus circumference 2 cm distal, defines the AI used in our experiment. Understanding the relationship between the anastomosis and the adjacent bowel reveals that an AI less than 1 indicates a decreased cross-sectional area at the anastomotic site (i.e., stricture). An AI greater than or equal to 1 designates an anastomosis without stricture. An AI that equals 0.7 corresponds to a decrease in anastomotic cross-sectional area of 51 percent. Our findings demonstrate that blood flow, within the range encountered clinically, is not a determinate in late stricture formation.

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