Blood Flow in Colonic Anastomoses

Effect of Stapling and Suturing

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Sutureline blood flow was measured with laser Doppler velocimetry in colonic anastomoses created with the stapler, manual suturing, or a combination. Blood flow was always reduced in the sutureline compared with normal mucosa. Of all the anastomoses studied, tight stapling reduced sutureline blood flow the most, whereas the two-layered manual anastomosis or stapling reinforced with sutures were somewhat less ischemic. Stapling adjusted to bowel wall thickness impaired flow only moderately. It was possible with practice to outperform the stapler by single-layered manual anastomosis using fine sutures. In humans, stapled ileocolostomy had a higher sutureline blood flow than the two-layered manual anastomosis. In view of the existing clinical experience of safe stapling without adjustment for bowel wall thickness, a low sutureline blood flow is probably tolerated to a considerable degree in humans. However, this study clearly shows that tight stapling can reduce sutureline blood flow unduly, whereas superior blood supply can be attained by attention to staple closure height relative to bowel wall thickness.

THE BLOOD SUPPLY to the sutureline, believed to be of fundamental importance in healing of anastomoses, is difficult to study because of logistical problems. The tension of suturing, a major variable that affects blood flow, is not easy to standardize. Also, the minute area of the sutureline does not lend itself readily to accurate flow measurements. In this study, stapling is used as a method of suturing at reproducible tension, with staple closure height adjusted according to tissue thickness. Sutureline blood flow is recorded with laser Doppler velocimetry, which provides a continuous recording in real time. By direct application of the fine laser Doppler probe to the narrow rim of tissue inside of the staple lines or on top of the manual sutureline, tissue blood flow of the area in question can be measured with confidence. The model was first tested for validity: the effect of tight stapling on sutureline blood flow was determined by this technique. The effect of manual suturing on anastomotic blood flow was then compared with that of stapling. The methodology was subsequently modified to study ileocolic anastomoses in patients.

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Methods

Laser Doppler Velocimetry

The instrument (Laserflo BPM 403, TSI Inc., St. Paul, MN) uses an infrared laser (wavelength 780 nm, output 2 mW) with a penetration depth of 1 mm. The flow probe, 2.2 mm in diameter, contains fine optical fibers that conduct the laser to the tissue and carry the reflected light back to photodetectors. The reflected light undergoes a shift in wavelength due to the Doppler effect, the magnitude of the shift being proportional to the velocity of the red blood cells. To minimize motion artifacts, a holder modified from a micropositioner was used to hold the probe against the tissue at a standardized pressure of 8 g/cm^2. Transmitted respiratory and cardiac motion was reduced by resting the gut on a platform; when movement proved difficult to eliminate, the probe was coupled to the tissue with a miniature suction cup so that the probe and tissue moved together. Motion artifacts were in general recognizable as erratic readings that appeared on tracing as sharp irregular spikes. Duplicate readings were obtained from steady tracings lasting at least several minutes.

The instrument readout was in hertz $\times$ 10^2, a frequency measurement. The instrument manufacturer recommends conversion into mL/100 g/min by multi-

TABLE 1. *Blood Flow in Colonic Anastomoses (Dog)**

Group	2 × Bowel Thickness	Staple Height	Control MBF	SBF	Percent Reduction	p
I	3.5 ± 0.5	3.4	28 ± 4 (36 ± 7)	16 ± 2 (23 ± 6)	43 (36)	<0.001† <0.05†
II	3.4 ± 0.5	1.7	31 ± 4	9 ± 1	71	<0.01‡
III	3.3 ± 0.5	3.3	28 ± 3	12 ± 2	57	<0.05‡
IV	3.2 ± 0.5	3.2 + suture	29 ± 4	13 ± 2	55	<0.05‡
V	3.5 ± 0.5	suture 1-layer	30 ± 4	22 ± 3	27	<0.01‡
VI	3.4 ± 0.4	suture 2-layer	29 ± 3	12 ± 2	59	<0.01‡

* N = 5, mean ± SE.
† MBF vs. SBF, paired t-tests.
‡ *vs.* Group I, unpaired t-tests.

MBF = mucosal blood flow, SBF = sutureline blood flow; flow units = mL/10 g/min; linear units = mm; figures in parentheses were obtained with the radiolabeled microsphere technique.[14]

plying with a conversion factor of 6, based on published experiments[1,2] and unpublished experiments. In our laboratory, 48 pairs of measurements of gastric and duodenal blood flow made simultaneously by the hydrogen gas clearance method and laser Doppler velocimetry were subjected to regression analysis. The correlation coefficient was 0.88 ($r^2 = 0.79$, $p < 0.0001$). In the range of 10–40 mL/100 g/min, the conversion factor was 5.11. This factor was used to convert the instrument readout into mL/100 g/min in the current study. The validity of this technique of measurement has also been extensively documented in the literature.[1-5]

The superior reproducibility of laser Doppler velocimetry over other techniques is in some measure due to averaging measurements over time. Although all other techniques yield "spot" readings and are subject to the spontaneous variation of the circulation, the readout of the laser Doppler flowmeter represents a large number of instantaneous measurements averaged by the computer. In this study a continuous recording of the readout over several minutes was further averaged.

Setting the Staple Closure Height

The thickness of the sigmoid colon was measured at the thickest portion (over the tinea) with a specially calibrated spring-loaded caliper delivering a pressure of 100 g/cm^2. In the dog this value was between 2.8 and 3.7 mm, representing the thickness of two layers of the bowel wall. The staple closure height was set according to this reading, using a stapler (ILS, Ethicon, Somerville, NJ) with provision for such adjustment in the form of a dial, specially calibrated to read up to 3.7 mm. The dialed gap was further checked with a micrometer before use; in all instances the reading was within 10% of the dialed measurement. At the tallest setting (3.7 mm) the closed staples assumed the "O" formation rather than the usual "B" formation.

The Anastomosis Model

Under pentobarbital anesthesia and controlled ventilation, a 2-cm colotomy was made in the sigmoid colon between stay sutures in large mongrel dogs. The mucosal blood flow was determined with the laser Doppler probe at the site selected for stapling or manual suturing, usually 4–5 cm away from the colotomy. The mesenteric arcade at the site of anastomosis was not disturbed. A 25-mm external diameter circular stapler was inserted *via* the colotomy, and after tying a ligature around the shaft, it was closed and fired at a staple closure height determined by bowel wall thickness. After removal of the stapler, the rim of the anastomosis was exposed and blood flow was measured by direct application of the laser Doppler probe to the narrow rim inside of the staple lines. In sutured anastomosis, the bowel was transected with intact mesenteric attachment and without using electrocautery. The blood flow 1 mm from the edge (edge flow) was then measured; the edge flow was found to be identical to the mucosal flow before transection. The least suture tension compatible with a mechanically sound anastomosis was used. After completion of the anastomosis, the flow probe was applied to the mucosal ridge in the space between the suture loops. To verify that the laser Doppler probe was in fact measuring the flow in the rim of the anastomsis, the radiolabeled microspheres technique was used simultaneously to measure sutureline blood flow in one group of dogs (Group I), excising blocks of tissue at the staple line 1 mm thick (measured from the lumen) for counting. The measurements were in accordance (see Table 1).

Experimental Protocol

In Group I, the staple closure height was set equal to the thickness of the bowel walls to be stapled, whereas in Group II, the setting was at half of this value. In Group III, the bowel was first transected without devascularization. Pursestring sutures were inserted at the open ends and stapling was accomplished by the usual technique, taking care to avoid gathering excess tissue by the pursestrings. Group IV was identical to Group I but an additional seromuscular layer of interrupted 5-0 silk was added. In Group V, a single-layered anastomosis was

accomplished with interrupted sutures of 5-0 silk, in such a manner as to impede flow the least, in the judgment of the operator. In Group VI, after bowel transection, a double-layered anastomosis was performed using 4-0 chromic catgut for an inner running layer followed by an outer layer of 5-0 interrupted silk sutures.

Human Studies

In patients who had right hemicolectomy, informed consent (approved by the Institution Review Board for the protection of study subjects) was obtained for randomization into stapling and suturing groups. To avoid an "insertion" colotomy, end-to-side ileocolic anastomosis was made, inserting the stapler *via* the transected transverse colon, and the sutureline blood flow (colonic side) was measured *via* the same open end of the colon before closure, using a sterilized probe. The staple closure height was set at 75% of the combined bowel wall thickness to avoid bleeding problems. The average setting was 2.4 mm. The manual anastomosis was done by a conventional two-layered end-to-end technique, with an inner running 4-0 chromic catgut suture and an interrupted outer layer of fine silk, modified so as to allow the sutureline flow to be measured after completion of three fourths of the anastomosis (both layers).

Results

Effect of Stapling on Blood Flow

A stapled anastomosis created with staple closure height equal to the thickness of the two bowel walls is theoretically the least ischemic possible. The blood flow of the narrow rim of mucosa obtained under this circumstance was only 56% of the normal mucosal flow, or a 43% reduction ($p < 0.005$) (Table 1). A 36% reduction was recorded by the radiolabeled microsphere technique used simultaneously. Allowing for the different principles of measurement, the agreement was remarkably close. In three of the five anastomoses, significant bleeding occurred requiring manual tamponade before blood flow could be measured. The staples appeared to be somewhat "loose" and not perfectly aligned as in the stitches of a sewing machine, but no macroscopic leakage was demonstrable. The staples were generally in the "B" configuration, although the legs were separated from the body of staple by a gap of about 1 mm.

Effect of Tight Stapling on Blood Flow

When staple closure height had been set to half of the combined thickness of the bowel walls, the sutureline blood flow was reduced by 69% of mucosal flow ($p < 0.001$, paired t-test). This reduction was greater than that in Group I ($p < 0.01$, unpaired t-test).

In Group III the staple closure height was the same as for Group I, but the bowel was first transected and pursestring sutures were applied to both open ends. The flow reduction at the staple line was 57%, greater than that in Group I ($p < 0.05$, unpaired t-test).

Effect of Manual Suturing on Blood Flow

Double-layered suturing (Group VI) resulted in 59% reduction in blood flow, even when surgical technique of the best tradition was followed. The anastomosis was significantly more ischemic than the stapling in Group I ($p < 0.01$). The least impairment of flow was attained after several attempts with a single-layered manual anastomosis, using fine sutures and meticulous attention to tying tension (Group V, 27% reduction; Group V < Group I, $p < 0.01$, unpaired t-test). Even though no leaks were demonstrable grossly, some of these anastomoses appear mechanically precarious to the surgeon accustomed to more secure suturing.

Addition of a layer of interrupted fine sutures to an appropriately stapled anastomosis (Group IV) exacted a toll on the blood flow, although the difference (Group I *vs.* Group IV, $p > 0.05$) was not significant. The net effect of this anastomosis appeared to be similar to a two-layered manual suturing (55% *vs.* 59% reduction).

Human Data: Stapled Versus *Two-layered Manual Ileocolic Anastomosis*

The mucosal rim (colon side) of stapled end-to-side ileocolostomy was compared with the end-to-end ileocolic manual anastomosis (colonic mucosa) in five patients who had elective right colectomy for carcinoma, with similar extent of resection of the mesentery. There was no dilatation involving the parts anastomosed, and preoperative preparations were the same. Even though the configurations were different, in both groups the mesenteric attachment of the bowel was left intact right up to the anastomotic line. The results in all five patients are listed in Table 2. The three stapled anastomoses had less reduction in blood flow, although the small sample size precluded meaningful statistical analysis. No sutureline bleeding occurred in either group.

Discussion

The two basic considerations in the surgical technique of intestinal anastomosis are mechanical integrity and tissue viability. If the suturing is too loose, the anastomosis is mechanically leaky, and if the suturing is too tight, tissue viability is jeopardized by ischemia. Sound surgical technique must score well on both counts.

The mechanical integrity of stapled anastomosis is well established.[6–8] Stapled anastomoses, as do well-constructed, double-layered, hand-sewn anastomoses,

TABLE 2. *Blood Flow in Ileocolic Anastomoses (Human)*

Patient	Technique	Control MBF	SBF	Percent Reduction
1	Stapled (2.4 mm)	41	17	58
2	Sutured	38	11	71
3	Stapled (2.6 mm)	33	17	48
4	Sutured	48	15	69
5	Stapled (2.3 mm)	34	16	53

MBF = mucosal blood flow; SBF = sutureline blood flow; flow unit = mL/100 g/min.

withstand vigorous challenges such as prostigmine and castor oil administration. Even total obstruction caused by error in stapling may not disrupt the staple line.[8] Bursting strength studies,[9,10] which reflect the degree of healing as well, showed stapling to be superior.

The vascularity of stapled anastomosis is less well studied. Microangiography showed that small vessels do cross the staple lines, through the holes of the B formation of the closed staples.[8,11] There have been no quantitative blood flow studies to date, to the best knowledge of this investigator.

The current study shows that all suturing decreases blood flow, an almost self-evident truism. "Tight" stapling, as contrasted with "loose" stapling, decreases sutureline blood flow. Even though there is no tension data on manual suturing, it is reasonable to infer that tight suturing must have the same effect, a commonly held surgical belief. The "tight" stapling in this experiment may not be too tight by clinical standards, since most staplers have a fixed closure gap at 2 mm, even allowing that the human colon is somewhat thinner than the dog colon. However, some circular staplers currently used allow a minimum gap setting of 1 mm or so, when even lower anastomotic blood flow can be expected. Unduly tight closure of the stapler is instinctively eschewed by the experienced surgeon, but this may still constitute a pitfall to the unwary.

In the most ideal circumstances, when the staple closure height equals the bowel wall thickness, stapling reduced blood flow by 43%, significantly superior to conventional suturing in two layers (59% reduction) or stapling "reinforced" with suturing (55% reduction). However, good vascularity in stapled anastomosis is accompanied by a definite risk of sutureline bleeding, since the stapler makes a circular incision inside of the concentric staplelines, unlike manual suturing. Furthermore, excessively loose staples may be at risk from displacement causing uneven spacing and even leakage. It is likely that in manual suturing, the continuous running layer contributes more to the ischemia. The stapled anastomosis "reinforced" with sutures is in fact a three-layered affair, the resulting decrease in blood flow is not surprising.

The reason for decreased staple line blood supply in the technique using pursestring sutures is not clear. The gathered tissue by the pursestrings added bulk only in the core of the stapler, and the staple lines included only two layers of bowel. Some stretching of the bowel wall at the circumference of the stapler may conceivably have occurred as the "donuts" were being pushed inside the stapler during closure of the machine, thereby interfering with blood flow.

In an attempt to outperform the stapler with manual suturing, this investigator succeeded in the laboratory only after several attempts (and some practice) by using a single layer of fine sutures with meticulous attention to the tying tension, conditions not necessarily always fulfilled in clinical practice. The data support, at least in theory, that single-layered manual anastomosis is the least ischemic, recognizing that in practice it need not be so.

The human data of this study indicate that a somewhat lower sutureline blood flow was accomplished without significant bleeding, by adjusting the staple closure height to 75% of bowel wall thickness. The vascularity of the staple line (about 53% reduction) appeared to be superior to the conventional manual two-layered suturing (about 70% reduction). Such a height also conferred good mechanical security. It is likely that the different anesthetics and suture tensions used by different operators in these cases might account for the greater variance: a large number of cases would be required to discern statistically significant differences.

Although in the acute state, greatly reduced blood flow follows multilayered suturing or tightly stapled anastomosis, it is not known what compensatory mechanisms are triggered and what happens to the decreased blood flow in the hours or days after the operation. Ongoing chronic study in our laboratory shows that severe ischemia may be tolerated in stapled anastomoses without complication in the dog, provided it is not extreme. Other reports have also indicated that the course of focal ischemia (such as ligation of the arcade vessels) in the intestine of the dog is often unpredictable: it may progress to frank gangrene or have no apparent effect.[12,13] Data of ischemia in the dog are thus less likely to be of value as a clinical guide, and more human data are needed to establish a safe lower limit for sutureline blood flow.

The closure height of most circular staplers are nominally fixed, usually at 2 mm. A decade of clinical experience with this type of stapler demonstrated the relative safety of the 2-mm staple closure height for most gastrointestinal stapling. Since the thickness of the gut varies

not only with individuals and anatomic regions but also with disease processes, the uniform closure height, although ideal sometimes, must also be relatively ischemic in others. This suggests that even in humans, tolerance of a certain degree of ischemia exists in anastomotic lines. It is important to know, however, in circumstances where blood flow may already be threatened, that attention to staple closure height with respect to bowel wall thickness may help preserve sutureline blood flow.

Inflexibility, a characteristic of all machines, is probably the most notable shortcoming of the stapler. Although staple closure height is adjustable in some instruments, the size and spacing of individual staples are not. A wider choice of diameters of the circular staplers, as well as size and spacing of staples, may enhance its use and reception by the surgical craftsman.

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Discussion

DR. GEORGE H. A. CLOWES, JR. (Boston, Massachusetts): Dr. Chung, I would like to ask you a question as to whether we have any correlation between your observations on blood flow and the actual healing of suture lines in the gut of some animals other than the rat. The rat, unfortunately, is a poor animal to choose for something like this. Since rats have great resistance to infection, all you have to do is be socially clean for the rat to heal.

Secondly, most of us were brought up to believe that the serosa and its inflammatory reaction are of greatest importance in localization of leaks and infection at colonic suture lines. Dr. Ravitch's experiments some years ago in which he placed a rubber dam around a suture line and got a large percentage of breakdown showed the importance of the adjacent tissue to walling off infection at the suture lines.

Do I quote you correctly on that? Dr. Ravitch is going to respond.

DR. MARK M. RAVITCH (Pittsburgh, Pennsylvania): I believe one of the problems with almost any study of intestinal anastomosis is that nature is so forgiving and the *vis medicatrix naturae* is so beneficent that unless you do a bad job the bowel will heal very well.

I only need to remind you that we all have learned to apply our sutures lightly and tie them just tightly enough so they do not produce any compression. Yet, Edgar Poth of Galveston has done just the opposite. He puts the sutures through all thicknesses of bowel and says you must tie them tightly until you feel them cut through the muscle. He gets perfect results, and he can show by naked eye observation that whereas in a few minutes the lightly placed suture produces a little area of ischemia when edema comes, in contrast, his tight sutures loosen and there is no ischemia. This seems almost an anti-intellectual, anti-perfection argument, but the fact is that you can go home happy with the technique you have always used even though it disagrees with every one else's technique, and you get good results because nature is so forgiving.

DR. RAPHAEL S. CHUNG (Closing discussion): I thank the discussants for their comments.

Dr. Clowes, the ongoing experiments in our lab in which we tried to produce strictures by tight stapling is still ongoing. All I can say is it is difficult to produce bad results by tight stapling, as Dr. Ravitch has just pointed out.

I would also like to point out the enormous amount of clinical data indicating that over 90% of the time you can get away with closing the staple at a fixed gap of 2 mm, up and down the GI tract.

The significance of these laboratory data is that when the patient is at risk of developing anastomotic dehiscence because of pre-existing adverse conditions such as ischemia, the anastomoses should be sewn or stapled loosely rather than tightly.