REVIEW ARTICLE

Systematic Review of the Technique of Colorectal Anastomosis

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Many different techniques of colorectal anastomosis have been described in search of the technique with the lowest incidence of anastomotic leak. A systematic review of leak rates of techniques of hand-sewn colorectal anastomosis was conducted to provide a guideline for surgical residents and promote standardization of its technique. Clinical and experimental articles on colorectal anastomotic techniques and anastomotic healing published in the past 4 decades were searched. We included evidence on suture material, suture format, single- vs double-layer sutures, interrupted vs continuous sutures, hand-sewn vs stapled and compression colorectal anastomosis, and anastomotic configuration. In total, 3 meta-analyses, 26 randomized controlled trials, 11 nonrandomized comparative studies, 20 cohort studies, and 57 experimental studies were found. Results show that, for many aspects of the hand-sewn colorectal anastomosis technique, evidence is lacking. A single-layer continuous technique using inverting sutures with slowly absorbable monofilament material seems preferable. However, in contrast to stapled and compression colorectal anastomoses, the technique for hand-sewn colorectal anastomoses is nonstandardized with regard to intersuture distance, suture distance to the anastomotic edge, and tension on the suture. We believe detailed documentation of the anastomotic technique of all colorectal operations is needed to determine the role of the hand-sewn colorectal anastomosis.
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Construction of a colorectal anastomosis is a hallmark of surgical training. However, although surgical residents can refer to key publications with evidence-based conclusions for many topics, mere imitation of an experienced surgeon traditionally is considered the basic source for the technique of hand-sewn colorectal anastomosis. The large variety of anastomotic techniques is one of the main difficulties in the interpretation of the literature. Anastomotic leak (AL) following colorectal resection is a major problem of surgical care, with an incidence between 3% and 19%.[1-4] Although accurate prediction of risk is impossible, certain factors are known to contribute to AL, including surgeon-related factors (eg, increased incidence of AL in a colorectal anastomosis constructed after hours[5] and the positive role of specialization in reducing the complications of colorectal surgery[6]) and patient-related risk factors (eg, the inverse relationship between the height of the colorectal anastomosis from the anal verge and the leak rate[7-12]). Decades of research have resulted in many studies investigating different techniques for constructing colorectal anastomosis in search of the safest method. Appreciating the conclusions from this extensive research is essential for the quality of colorectal surgery and for the resident being trained in colorectal surgery. Our aims were to perform a systematic review of all aspects of the technique of hand-sewn colorectal anastomosis and compare hand-sewn with mechanical colorectal anastomosis to pro-

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vide a guideline for residents and promote standardization of the technique.

METHODS

SEARCH STRATEGY

A literature search was conducted using MEDLINE, EMBASE, and Cochrane databases for studies published between January 1, 1970, and February 1, 2011, using the key words presented in the eFigure (http://www.jamasurg.com). The search was restricted to articles published in English, Dutch, and French. References in the selected publications were searched for additional studies.

STUDY SELECTION

Clinical as well as experimental studies were selected to address several aspects of the technique of hand-sewn colorectal anastomosis. These included:

1. suture material,
2. suture format (size of suture bites, in-between distance of bites, suture tension, configuration of the bite, and inverting vs everting sutures),
3. single- vs double-layer colorectal anastomosis,
4. interrupted vs continuous sutures,
5. hand-sewn vs stapled colorectal anastomosis,
6. hand-sewn vs compression colorectal anastomosis, and
7. configuration of colorectal anastomosis (end-to-end [ETE], end-to-side, side-to-end, side-to-side, length of the side-limb, and length of the enterotomy).

INCLUSION CRITERIA FOR CLINICAL STUDIES

Only clinical studies comparing 2 or more colorectal anastomotic techniques with regard to clinical AL were considered relevant. When only 1 comparative study was available on a particular subject, clinical cohort studies were added to the selection. Results were analyzed only if the study groups and results were clearly described with proper statistical analysis.

INCLUSION CRITERIA FOR EXPERIMENTAL STUDIES

Experimental studies were selected when comparing 2 or more colorectal anastomotic techniques using objective measurements for anastomotic healing: AL, anastomotic bursting pressure (ABP), anastomotic breaking strength, histologic results, or collagen concentration.

When 2 studies were reported by the same institution, either the better quality study or the most recent publication was included. As with clinical studies, results were analyzed only if the study groups and results were clearly described with proper statistical analysis. However, the lack of statistical analysis of histologic findings in experimental studies was accepted.

EXCLUSION CRITERIA

Because the healing of small-bowel anastomoses is different and the incidence of AL is lower compared with large-bowel anastomoses, studies including both procedures without differentiating the results and statistical analysis were excluded. Ileocolic anastomoses after right hemicolectomy or ileocecal resection represent healing of the colon and were therefore included. Studies reporting radiologic AL without distinction of clinical AL were excluded, as were studies reporting only on emergency operations, children, and colo-anal anastomosis or pouches. Results of experimental studies measured directly after the construction of colorectal anastomosis were not taken into account because these do not reflect anastomotic healing.

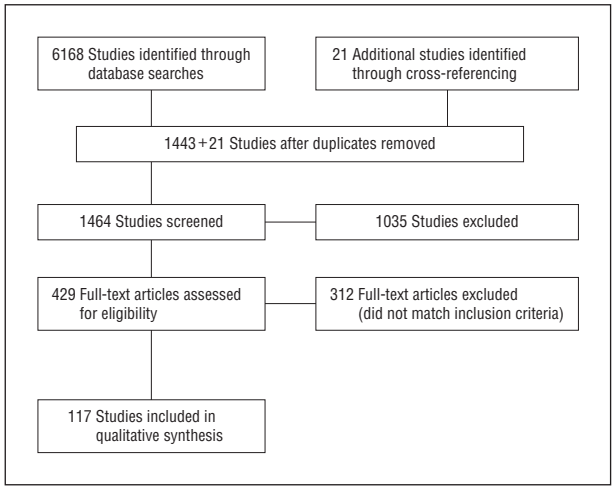

Figure. The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) flowchart: selection of relevant studies.

DATA EXTRACTION FOR CLINICAL STUDIES

Two physicians (J.C.S. and F.D.) entered data in a database following standard protocols. Seven factors were considered for clinical studies. These included:

first author and year of publication,
level of evidence (following the Centre of Evidence Based Medicine, University of Oxford),
study design,
number of patients,
location of anastomosis in the gastrointestinal tract,
definition of outcome by the authors (AL, clinical AL, and radiologic AL), and
results and statistical analysis.

DATA EXTRACTION FOR EXPERIMENTAL STUDIES

Six factors were considered for experimental studies. These included:

first author and year of publication,
study design,
number of animals per group,
species,
outcome factors for anastomotic healing (AL, ABP, breaking strength, histologic results, or collagen concentration), and
results.

RESULTS

The literature search identified 6168 articles; 1443 articles remained after duplicates were removed. The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) flowchart presented in the **Figure** shows the selection of studies: 117 were included in the systematic review. Included studies

Table 1. Included Studies on Suture Material

Source	Level[a]	No. of Cases	Outcome	Results
Clinical				
Gillatt et al,[24] 1987	1b (RCT)	57 Patients, colorectal	Clinical AL	AL: PDS, 0 (n = 30); silk, 3.7% (n = 27); not significant
Clark et al,[23] 1977	1b (RCT)	194 Patients, colon	Clinical and radiologic AL	AL: catgut, 24% (n = 99); polyglycolic acid, 8.4% (n = 95); significant
Experimental				
Andersen et al,[20] 1989	. . .	196 Rats	Histologic results	Polyglactin 910 vs PDS: equal histologic results at days 7 and 56
Foresman et al,[17] 1989	. . .	160 Rats	ABP	Polyglyconate vs PDS: difference in ABP at days 0, 7, 14, 21, 42 not significant
Lord et al,[18] 1978	. . .	30 Rats	Histologic results of the submucosa	Rough surface vs smooth surface: rough surface (catgut, braided silk, polyglycolic acid), most damage to submucosa; polyethylene terephthalate coated with polytetrafluoroethylene better, polypropylene suture best histologic results
Orringer et al,[15] 1977	. . .	84 Dogs	Histologic results	Silk vs polypropylene vs wire: silk, most inflammation; polypropylene, less inflammation; wire, least inflammation at days 4, 7, 10, 14
Munday and McGinn,[19] 1976	. . .	44 Rats	ABP, histologic results	Catgut vs polyglycolic acid: equal ABP and histologic results at day 7
Deveney and Way,[16] 1977	. . .	60 Dogs	Breaking strength, histologic results	Catgut vs chromic catgut vs polyglycolic acid vs polyglactin 910: equal strength and equal histologic results at days 4, 7, 14
Hastings et al,[13] 1975	. . .	127 Dogs	Breaking strength, histologic results, collagen	Absorbable vs nonabsorbable sutures: absorbable, less breaking strength at days 14 and 28, equal collagen at day 120, worse histologic results at day 120
Letwin,[14] 1975	. . .	28 Dogs	Histologic, results, ABP	Double-layer anastomoses "chromic catgut-silk" vs polyglycolic acid–polyglycolic acid: catgut-silk, significantly more suture reaction and significantly lower ABP at day 7
Pasternak et al,[22] 2008	. . .	85 Rats	Breaking strength	Doxycycline (MMP-i)–coated sutures vs control carrier-coated sutures: higher breaking strength in doxycycline sutures at days 0-3
Pascual et al,[21] 2008	. . .	40 Rats	AL, ABP	Polyglactin 910 with mesenchymal cells vs polyglactin 910: no difference in AL, no difference in ABP; fewer adhesions in polyglactin 910 with mesenchymal cells at days 4, 7, 14, 21

Abbreviations: ABP, anastomotic bursting pressure; AL, anastomotic leak; MMP-i, matrix metalloproteinase inhibitor; PDS, polydioxanone sutures; RCT, randomized controlled trial; ellipses indicate not applicable.
[a] Highest level of evidence, 1b.

and their characteristics are listed in **Tables 1**, **2**, **3**, **4**, **5**, **6**, and **7**, together with all results of outcome measures. The results per research question are summarized herein.

SUTURE MATERIAL

Decades ago, several materials, such as silk, linen, catgut, polyglactin 910, and nylon, were commonly used for colorectal anastomosis. Today most gastrointestinal anastomoses, including colorectal anastomosis, are constructed with polydioxanone sutures. Ten experimental studies[13-22] were included. Results show that absorbable sutures compared with nonabsorbable or slowly absorbable sutures cause more tissue reaction[13-15]; one of these studies[13] showed that absorbable sutures dissolve too rapidly, influencing anastomotic strength. Multifilament compared with monofilament sutures cause more tissue damage and easier adherence of material within the interstices of multifilament sutures,[16-19] providing a basis for infection.[121] Surprisingly, experimental studies on the healing of colorectal anastomosis constructed with polydioxanone sutures are scarce; only 2 studies[17,20] were included, finding equal ABP and histologic characteristics between polydioxanone and polyglycolic acid. Noncomparative experimental studies[121-124] that did not meet the inclusion criteria for the present systematic review have shown that polydioxanone sutures possess all aspects considered important: monofilament, little histologic reaction, slowly absorbable with long preservation of strength, and low adherence of bacteria to the material.

New possibilities for the use of sutures coated with mesenchymal stem cells and doxycycline were explored in 2 experimental studies with promising, but not yet convincing, results.[21,22] Two included randomized controlled trials (RCTs)[23,24] on suture material failed to achieve a unanimous conclusion because of the small number of patients included and the different suture materials tested that are rarely used today.

In conclusion, on the basis of experimental studies, nonabsorbable or slowly absorbable monofilament sutures seem to be the first choice for colorectal anastomosis. However, there is no level 1 evidence to confirm this hypothesis.

SUTURE FORMAT

Size of Suture Bites

Since Lembert[125] described the construction of intestinal anastomoses in dogs using suture bites with 5-mm distance to the cut edge nearly 2 centuries ago, this aspect seems to have become less clear in surgical literature. One experimental study[25] was found for this systematic review that investigated the difference in anastomotic strength in rats with sutures placed between 3 mm and 1.5 mm from the cut edges. Results showed lower breaking strength for small bites, measured at day 2. One RCT by Greenall et al[26] reporting on the distance of the suture to the wound edge matched the inclusion criteria. They randomly allocated patients to have bowel sutures placed either 5 or 10 mm from the cut edges, with no significant differences in AL. Because it is not possible to extrapolate the distances used in a rat model to the clinical situation, we can only conclude from one level 1b RCT that distances of 5 and 10 mm from the cut edge will probably give adequate results.

Table 2. Included Studies on Suture Format

Source	Level	No. of Cases	Outcome	Results
Size of suture bites[a]				
Clinical				
Greenall et al,[26] 1979	1b (RCT)	100 Patients, colon	Clinical AL	Suture bite: 5 mm, AL, 4% (n = 50); 10 mm, 6% (n = 50); not significant
Experimental				
Högström et al,[25] 1985	. . .	80 Rats	Breaking strength	1.5-mm vs 3.0-mm distance from wound edges; less breaking strength 1.5 mm at day 2
In-between distance of bites				
Experimental				
Waninger et al,[27] 1992	. . .	432 Rats	Histologic results	2.5-mm vs 1.5-mm suture distance: 1.5 mm, better histologic results
Suture tension				
Experimental				
Waninger et al,[27] 1992	. . .	432 Rats	ABP, histologic results	No tension vs moderate tension vs high tension on knot: moderate tension, better histologic results; moderate tension, higher ABP at day 4; no tension, higher ABP at day 7
Configuration of the bite[b]				
Clinical				
Leslie and Steele,[30] 2003	2b (cohort)	484 Patients; colon	Clinical AL	AL: interrupted serosubmucosal stitches, 0.2%
Pye and Steele,[31] 1996	2b (cohort)	214 Patients; colorectal	Clinical AL	AL: interrupted serosubmucosal stitches, 0.5%
Carty et al,[32] 1991	2b (cohort)	421 Patients; colorectal	Clinical AL	AL: interrupted extramucosal stitches, 2.1%
Lafreniere and Ketcham,[33] 1985	2b (cohort)	134 Patients; colorectal	Clinical AL	AL: interrupted full thickness (modified Gambee), 0
Motson et al,[34] 1984	2b (cohort)	92 Patients, colon	Clinical AL	AL: interrupted full thickness (mattress suture), 4.4%
Experimental				
Krasniqi et al,[29] 2009	. . .	73 Rats	Histologic results	Serosubmucosal (Halsted) vs full thickness (Gambee) vs posterior Gambee/anterior Halsted stitch: better macroscopic and microscopic histologic results with full thickness
Houdart et al,[28] 1983	. . .	210 Rats	Histologic results	Extramucosal vs full-thickness stitch: equal histologic results
Inverting vs everting[a]				
Clinical				
Goligher et al,[38] 1970	1b (RCT)	70 Patients, colon	Clinical AL	AL: inverting, 2.9% (n = 35); everting, 28.6% (n = 35); significant
Experimental				
Ortiz et al,[35] 1975	. . .	88 Rats	AL, histologic results	Inverting vs everting: no AL, slower healing, equal adhesions with everting
Irvin and Edwards,[36] 1973	. . .	93 Rabbits	AL, ABP, histologic results	Inverting 1-layer vs inverting 2-layer vs everting: more AL, lower ABP, delayed mucosal union with everting
Le Douarec and Jouanneau,[37] 1972	. . .	65 Rabbits	Histologic results	Direct (everting) vs intraluminal (inverting) sutures: direct, more severe inflammation; intraluminal, better histologic repair

Abbreviations: see Table 1.
[a] Highest level of evidence, 1b.
[b] Highest level of evidence, 2b.

In-between Distance of Bites

Lembert described in 1826[125] an in-between distance of approximately 1 cm between sutures. One experimental study conducted by Waninger et al[27] investigating the distance between sutures in rats was included in our review. It concluded that a small distance between sutures (1.5 mm) improves apposition compared with a larger distance (2.5 mm). Neither clinical comparative studies nor cohort studies were found. Again, distances in a rat model are difficult to extrapolate to the patient. Because clinical studies on this topic are lacking, no precise maxim can be distilled from the literature.

Suture Tension

In routine clinical practice, 2 undefined schools of thought seem to exist: the first believes that sutures should be tightened to prevent dehiscence of the anastomosis, and the second considers that sutures should be applied more loosely, allowing maximal perfusion of the cut edges. Only one rat study[27] investigated this, with moderate tension giving the best histologic and microangiographic results. Whether tension on knots could influence the incidence of AL in a clinical setting has not been investigated for interrupted or continuous suturing. On the basis of the literature evaluated in the present review, nothing can be concluded on the proper tension on the thread or the knot.

Configuration of the Bite

Historically, all opinion leaders proposed their own configuration of gastrointestinal sutures. Anatomic apposition of all layers promoting primary healing was thought to be important. These days, most surgeons use a simple through-all-layers technique. From ex vivo studies,[126,127] it is known that sutures through the mucosal layer do not contribute to anastomotic strength.

Table 3. Included Studies on Single- vs Double-Layer Colorectal Anastomosis[a]

Source	Level	No. of Cases	Outcome	Results
Everett,[51] 1975	1b (RCT)	92 Patients, colorectal	Clinical AL	AL: 1-layer, 5.0% (n = 40); 2-layer, 4.8% (n = 52); nonsignificant
Ceraldi et al,[52] 1993	2b (nonrandomized)	84 Patients, colon	Clinical AL	AL: 1-layer, 6.8% (n = 44); 2-layer, 9.5% (n = 21); nonsignificant
Fielding et al,[53] 1980	2b (nonrandomized)	1466 Patients, colon	Clinical AL	AL: 1-layer, 12.0% (n = 458); 2-layer, 13.5% (n = 968); nonsignificant
Reichel et al,[47] 1975	2b (nonrandomized)	408 Patients, colorectal	Clinical and radiological leak	AL: 1-layer, 10.3% (n = 320); 2-layer, 10.3% (n = 88); nonsignificant
Athar et al,[48] 1996	. . .	18 Dogs	Breaking strength	1-Layer, more strength; 2-layer, fewer adhesions, smaller-diameter anastomosis
Langer et al,[46] 1996	. . .	26 Rabbits	AL, ABP	Corticosteroid model, 1-layer vs 2-layer (vs stapled, NIR): equal AL; 2-layer, higher ABP
Templeton and McKelvey,[42] 1985	. . .	40 Dogs	AL, ABP, histologic results, collagen	1-Layer vs 2-layer (vs 2× stapled, NIR): AL, 0% vs 30%; histologic results, worse for 2-layer; equal ABP and collagen
Yesilkaya et al,[43] 1985	. . .	20 Dogs	Collagen	1-Layer vs 2-layer: lower collagen in 2-layer
Graffner et al,[41] 1984	. . .	18 Pigs	AL, breaking strength, histologic results, blood flow	1-Layer vs 2-layer (vs stapled, NIR): no AL; 2-layer, more inflammation; 2-layer, less blood flow; equal breaking strength
Wheeless and Smith,[50] 1983	. . .	81 Dogs	Blood flow	1-Layer (Gambee) vs 2-layer (vs stapler, NIR): 1-layer, higher blood flow
Schillaci et al,[44] 1979	. . .	30 Dogs	ABP, collagen	1-Layer vs 2-layer (vs sleeve, NIR): equal ABP and collagen
Chung,[45] 1987	. . .	30 Dogs	Blood flow	Different hand-sewn vs stapled anastomoses: 2-layer, more reduction of blood flow
Langer,[39] 1975	. . .	80 Dogs and rats	Histologic results, blood flow	1-Layer vs 2-layer: 2-layer, delayed recovery, more ulceration and stenosing, delayed revascularization
Reichel et al,[47] 1975	. . .	360 Dogs	AL, ABP, histologic results	1-Layer vs 2-layer: no AL, equal ABP, histologic results worse in 2-layer
Irvin and Edwards,[36] 1973	. . .	93 Rabbits	ABP, histologic results, collagen	1-Layer vs 2-layer (vs everting, NIR): equal ABP, collagen, and histologic results
Herzog,[49] 1973	. . .	200 Rats	Breaking strength, blood flow	1-Layer, better vascularization and higher bursting strength
McAdams et al,[40] 1970	. . .	116 Dogs	Histologic results	1-Layer (Gambee) vs 2-layer (Czerny-Lembert): 2-layer, more inflammation

Abbreviations: ABP, anastomotic bursting pressure; AL, anastomotic leak; NIR, not included in the present review (in case a supplemental subgroup was also studied, outside the topic of this review); RCT, randomized controlled trial; ellipses indicate not applicable.

[a] Highest level of evidence for all studies, 1b.

The present review included 2 experimental studies on rat colon, comparing histologic results of full-thickness sutures with those of serosubmucosal sutures. Houdart et al[28] found no significant histologic differences, but Krasniqi et al[29] found better histologic results for full-thickness sutures with equal anastomotic strength. No comparative clinical studies were found on the configuration of the bite. Because of this lack of evidence, we have included cohort studies,[30-34] reporting low rates of AL for both serosubmucosal and full-thickness suture formats (AL, 0%-4.4%).

We can only conclude, using scarce level 2b evidence from the cohort studies evaluated, that both serosubmucosal and full-thickness sutures seem to provide low rates of AL. It is clear that the configuration of the suture bite is considered of little interest in studies regarding AL.

Inverting vs Everting Sutures

Since the publication of Lembert,[125] surgeons generally have advocated an inverting technique of gastrointestinal anastomosis because it is believed that protruding mucosa will lead to AL. However, in the 1960s, 2 clinical studies[128,129] showed good healing of everting anastomoses with a low incidence of AL. Between 1960 and 1970, these 2 noncomparative studies were followed by many experimental publications comparing everting with inverting techniques. They failed to achieve a unanimous conclusion on anastomotic healing; however, they were consistent in showing that everting anastomoses cause more adhesions but less stenosis.[35-37,130-134] All 3 experimental studies[35-37] published after 1970 included in the present review seem to show improved anastomotic healing for inverted anastomoses. The only clinical study matching the inclusion criteria was an RCT[38] showing a 5-fold increased incidence of AL in patients receiving an everting colorectal anastomosis compared with those receiving an inverting colorectal anastomosis. No cohort studies matching our inclusion criteria were found. Therefore, on the basis of available experimental studies and a level 1b clinical study, there seems to be an advantage of inverting over everting colorectal anastomosis; nonetheless, level 1a evidence is lacking.

SINGLE- VS DOUBLE-LAYER COLORECTAL ANASTOMOSIS

The technique developed by Lembert[125] and later modified by Czerny[135] is based on a double-layer inverting anastomotic technique. In the 19th and the greater part of the 20th centuries, this was the criterion standard for gas-

Table 4. Included Studies on Interrupted vs Continuous Sutures

Source	Level[a]	No. of Cases	Outcome	Results
Clinical				
Deen and Smart,[58] 1995	2b (nonrandomized)	53 Patients, colon	Clinical AL	AL: continuous, 3.8% (n = 26); interrupted, 3.8% (n = 27); not significant
Volk et al,[72] 2011	2b (cohort)	463 Patients, ileocolonic	Clinical AL	AL: continuous, 3.1%
Law et al,[66] 1999	2b (cohort)	500 Patients, colorectal	Clinical AL	AL: continuous, 1.4%
AhChong et al,[59] 1996	2b (cohort)	93 Patients, colorectal	Clinical AL	AL: continuous, 2.2%
Flyger et al,[61] 1995	2b (cohort)	105 Patients, colon	Clinical AL	AL: continuous, 1.0%
Max et al,[68] 1991	2b (cohort)	1000 Patients, colorectal	Clinical AL	AL: continuous, 1.0%
Sarin and Lightwood,[70] 1989	2b (cohort)	65 Patients, colon	Clinical AL	AL: continuous, 6.2%
Harder and Vogelbach,[62] 1988	2b (cohort)	143 Patients, colon	Clinical AL	AL: continuous, 0%
Bailey et al,[60] 1984	2b (cohort)	100 Patients, colorectal	Clinical AL	AL: continuous, 0%
Thomson and Robinson, 1993[71]	2b (cohort)	200 Patients, colorectal	Clinical AL	AL: continuous, 2.0%
Pramateftakis et al,[69] 2010	2b (cohort)	276 Patients, colorectal	Clinical AL	AL: interrupted, 2.5%
Pye and Steele,[31] 1996	2b (cohort)	214 Patients, colorectal	Clinical AL	AL: interrupted, 0.5%
Huguier and Houry,[63] 1982	2b (cohort)	105 Patients, colorectal	Clinical AL	AL: interrupted, 3.8%
Khubchandani and Upson,[65] 1982	2b (cohort)	112 Patients, colorectal	Clinical AL	AL: interrupted, 4.5%
Matheson et al,[67] 1981	2b (cohort)	168 Patients, colorectal	Clinical AL	AL: interrupted, 4.2%
Jonsell and Edelmann,[64] 1978	2b (cohort)	165 Patients, colorectal	Clinical AL	AL: interrupted: 8.5%
Experimental				
Shandall et al,[55] 1985	. . .	40 Rabbits	Blood flow	Continuous vs interrupted: continuous, significantly lower blood flow
Houdart et al,[28] 1983	. . .	210 Rats	Histologic results	Extramucosal continuous vs extramucosal interrupted vs continuous: equal histologic results at days 2 and 180
Jiborn et al,[73] 1978	. . .	64 Rats	Collagen	Continuous vs interrupted vs control: continuous, lower collagen metabolism until day 4
Jiborn et al,[57] 1978	. . .	71 Rats	ABP	Continuous vs interrupted vs control: equal ABP at days 4 and 7
Jiborn et al,[56] 1978	. . .	71 Rats	Breaking strength	Continuous vs interrupted vs control: equal breaking strength at days 4 and 10
Delaitre et al,[54] 1977	. . .	83 Rabbits	Histologic results	Continuous vs interrupted: continuous, more evagination of mucus and better apposition (from 1 d to 3 mo)

Abbreviations: ABP, anastomotic bursting pressure; AL, anastomotic leak.
[a] Highest level of evidence, 2b.

trointestinal anastomosis; in the second half of the 20th century, however, the single-layer anastomosis regained attention through the favorable results obtained by Halstead,[136] Gambee,[137] and Gambee et al.[138] The 13 included experimental studies[36,39-50] came to the same conclusion: double-layer anastomoses are inferior to single-layer anastomoses because of increased inflammation and diminished circulation. One RCT[51] matched the inclusion criteria, showing no significant differences in AL between single- and double-layer colorectal anastomosis in 92 patients. This RCT conducted a subgroup analysis of 25 low colorectal anastomoses, finding a significantly higher incidence of AL in colorectal anastomosis created with the double-layer technique. None of the 3 nonrandomized comparative studies[47,52,53] included in this review found a significant difference in AL between the 2 techniques. In conclusion, these results add to the knowledge that single-layer anastomoses take significantly less time to construct and are less costly[139] and are in favor of single anastomoses on the basis of level 1b evidence.

INTERRUPTED VS CONTINUOUS SUTURES

The question on whether to use interrupted or continuous sutures arose when single-layer anastomoses became common practice. Six experimental studies were included, showing equivocal results: better serosal apposition[54] and blood flow in continuous sutures,[55] with equal results on ABP and histologic examination.[28,56,57,73] Randomized controlled trials investigating interrupted and continuous sutures for colorectal anastomosis are lacking; therefore, only 1 small, nonrandomized, comparative clinical study finding no significant differences was included,[58] and noncomparative cohort studies were selected on continuous and interrupted suturing, finding equally low leak rates.[31,59-72] Clinical and experimental studies have not concluded that one technique is superior to the other, and a high level of evidence is lacking (limited here to level 2b); however, from a technical and time-consuming point of view, a continuous suture is preferable over interrupted sutures for creating colorectal anastomosis.

HAND-SEWN VS STAPLED COLORECTAL ANASTOMOSIS

After the introduction of stapled colorectal anastomosis in the 1980s, both techniques have become prevalent, without defined indications but for the lower rectal anastomoses. Most surgeons apply both techniques, although often with a personal preference.

Thirteen RCTs[74-86] and 3 meta-analyses[87-89] were included in the present review. Lustosa et al[87] published a Cochrane meta-analysis of 9 RCTs conducted between 1981 and 1991. In this group of 1233 patients, there was no significant difference in mortality, AL, strictures, or reoperation between stapled and hand-sewn colorectal anastomosis. An earlier meta-analysis,[88] conducted in

Table 5. Included Studies on Hand-Sewn vs Stapled Colorectal Anastomosis

Source	Level[a]	No. of Cases	Outcome	Results
Clinical				
Choy et al,[89] 2007	1a (meta-analysis)	955 Patients, ileocolic	Clinical AL	AL: stapled, 1.1% (n = 357); hand-sewn, 3.8% (n = 598); not significant
Lustosa et al,[87] 2001	1a (meta-analysis)	1233 Patients, colorectal	Clinical AL	AL: stapled, 6.3% (n = 622); hand-sewn, 7.1% (n = 611); not significant
MacRae and McLeod,[88] 1998	1a (meta-analysis)	2256 Patients, colorectal	Clinical AL	AL stapled vs hand-sewn: odds ratio, 0.89 (95% CI, 0.58-1.29); not significant
Fingerhut et al,[81] 1995[b,c]	1b (RCT)	159 Patients, colorectal supraperitoneal	Clinical AL	AL: stapled, 0 (n = 85); hand-sewn, 0 (n = 74); not significant
Docherty et al,[77] 1995[c,d]	1b (RCT)	625 Patients, colorectal	Clinical AL	AL: stapled, 4.5% (n = 330); hand-sewn, 4.4% (n = 321); not significant
Fingerhut et al,[80] 1994[b,c]	1b (RCT)	113 Patients, left infraperitoneal	Clinical AL	AL: stapled, 3.7% (n = 54); hand-sewn, 8.5% (n = 59); not significant
Sarker et al,[86] 1994[b,c]	1b (RCT)	60 Patients, rectum	Clinical AL	AL: stapled, 0 (n = 30); hand-sewn, 6.7% (n = 30); not significant
Kracht et al,[83] 1993[b,c,d]	1b (RCT)	268 Patients, colorectal	Clinical AL	AL: stapled, 8.8% (n = 137); hand-sewn, 12.2% (n = 131); not significant
Friend et al,[82] 1990[c]	1b (RCT)	239 Patients, left colon	Clinical AL	AL: stapled, 3.5% (n = 114); hand-sewn, 8.8% (n = 125); not significant
Cajozzo et al,[76] 1990[c]	1b (RCT)	48 Patients, colorectal	Clinical AL	AL: stapled, 8.3% (n = 24); hand-sewn, 4.2% (n = 24); not significant
Elhadad,[78] 1990[b]	1b (RCT)	272 Patients colorectal	Clinical fistula	AL: stapled, 8.3% (n = 139); hand-sewn, 11.5% (n = 133); not significant
Moreno Gonzalez et al,[85] 1989[b,c]	1b (RCT)	113 Patients, rectum	Clinical AL	AL: stapled, 10.9% (n = 55); hand-sewn, 10.3% (n = 58); not significant
Everett et al,[79] 1986	1b (RCT)	94 Patients, descending colon	Clinical AL	AL: stapled, 0 (n = 44); hand-sewn, 4% (n = 50); not significant
McGinn et al,[84] 1985[b,c]	1b (RCT)	118 Patients, low colorectal	Clinical AL	AL: stapled, 12.1% (n = 58); hand-sewn, 3.3% (n = 60); significant
Brennan et al,[75] 1982[c]	1b (RCT)	100 Patients, colorectal	Clinical AL	AL: stapled, 10% (n = 50); hand-sewn, 6% (n = 50); not significant
Beart and Kelly,[74] 1981[b,c]	1b (RCT)	70 Patients, colorectal	Clinical AL	AL: stapled, 2.9% (n = 35); hand-sewn, 2.9% (n = 35); not significant
Resegotti et al,[99] 2005	2b (nonrandomized)	122 Patients, ileocolic Crohn disease	Clinical AL	AL: stapled, 2.0% (n = 51); hand-sewn, 14.1% (n = 71); significant
Anwar et al,[100] 2004	2b (nonrandomized)	100 Patients, ileocolic malignancy	Clinical AL	AL: stapled, 0 (n = 41); hand-sewn, 0 (n = 59); not significant
Smedh et al,[101] 2002	2b (nonrandomized)	42 Patients, Crohn disease	Clinical AL	AL: STS stapled, 0 (n = 20); ETE hand-sewn, 0 (n = 22); not significant
Sielezneff et al,[102] 2001	2b (nonrandomized)	116 Patients sigmoid (diverticulitis)	Clinical AL	AL: stapled, 0 (n = 49); hand-sewn, 0 (n = 67); not significant
Montesani et al,[98] 1992	2b (nonrandomized)	533 Patients, colorectal	Clinical AL	AL: stapled, 28.5% (n = 28); hand-sewn, 3.1% (n = 505); significant
Scher et al,[103] 1982	2b (nonrandomized)	242 Patients, colon	Clinical AL	AL: stapled, 2.3% (n = 87); hand-sewn, 2.6% (n = 155); not significant
Adloff et al,[104] 1980	2b (nonrandomized)	51 Patients, rectum	Clinical AL	AL: stapled, 7.7% (n = 26); hand-sewn, 8% (n = 25); not significant
Experimental				
Singer et al,[93] 2004	. . .	20 Pigs	ABP, histologic results, collagen	Corticosteroid model; equal ABP and collagen; inflammation worse for hand-sewn at day 4
Senagore et al,[92] 1992	. . .	42 Pigs	ABP, histologic results, blood flow, collagen	Equal ABP, histologic results, blood flow, hydroxyproline
Kent et al,[105] 1992	. . .	20 Dogs	ABP, histologic results	Hand-sewn: higher ABP; equal histologic results at days 3 and 5
Jansson et al,[90] 1991	. . .	30 Pigs	AL, breaking strength, blood flow, collagen	Hand-sewn vs stapled (vs glued, NIR): no AL; equal breaking strength, blood flow, and collagen
Dziki et al,[106] 1991	. . .	24 Dogs	ABP, histologic results, collagen	Hand-sewn: higher ABP at day 4, better histologic results, equal collagen
Julian and Kolachalam,[97] 1989	. . .	56 Dogs	Blood flow	Equal vascularization at days 3 and 13
Kozol et al,[94] 1988	. . .	8 Dogs	Histologic results, edema	No significant difference in edema at 28 h
Chung,[45] 1987	. . .	30 Dogs	Blood flow	Tight stapling: less blood flow; adjusted stapling: better blood flow vs hand-sewn
Graffner et al,[41] 1984	. . .	18 Pigs	AL, breaking strength, histologic results, blood flow	1-Layer vs 2-layer vs stapled: no AL, more necrosis with stapled, equal blood flow and breaking strength
Moss,[95] 1984	. . .	10 Dogs	ABP	Stapled, higher ABP at day 4
Buchmann et al,[96] 1983	. . .	8 Dogs	Histologic results	Equal histologic results at day 4; stapled had more fibrosis at 2, 3, and 6 mo
Wheeless and Smith,[50] 1983	. . .	81 Dogs	Blood flow	1-Layer (Gambee) vs 2-layer vs stapled: stapled had higher blood flow than 1-layer and 2-layer
Polglase et al,[91] 1981	. . .	24 Dogs	AL, histologic results	Hand-sewn, more narrowing; stapled, more ulcerative gap; equal AL

Abbreviations: see Table 1; ETE, end-to-end; NIR, not included in the present review (in case a supplemental subgroup was also studied, outside the topic of this review); STS, side-to-side.

[a] Highest level of evidence, 1a.

[b] Indicates a randomized controlled trial (RCT) also included in the meta-analysis of Lustosa et al.[87]

[c] Indicates an RCT also included in the meta-analysis of MacRae and McLeod.[88]

[d] Indicates an RCT also included in the meta-analysis of Choy et al.[89]

Table 6. Included Studies on Hand-Sewn vs Compression Colorectal Anastomosis

Source	Level[a]	No. of Cases	Outcome	Results
Clinical				
Påhlman et al,[116] 1997	1b (RCT)	100 Patients, colon	Clinical AL	AL: BAR, 4% (n = 50); hand-sewn, 2% (n = 50); not significant
Gullichsen et al,[114] 1992	1b (RCT)	150 Patients, colon	Clinical AL	AL: BAR, 2.5% (n = 79); hand-sewn 2-layer, 4.2% (n = 71); not significant
Bubrick et al,[113] 1991	1b (RCT)	782 Patients, colorectal	Clinical AL	AL: BAR, 3% (n = 395); hand-sewn, 3% (n = 283); stapled, 4% (n = 104); not significant
Dyess et al,[115] 1990	1b (RCT)	59 Patients, colon	Clinical AL	AL: BAR, 0 (n = 27); hand-sewn, 0 (n = 16); stapled, 0 (n = 16); not significant
Cahill et al,[111] 1989	1b (RCT)	202 Patients, colorectal	Clinical AL	AL: BAR, 2% (n = 101); hand-sewn, 8.2% (n = 85); stapled, 6.3% (n = 16); not significant
Corman et al,[112] 1989	1b (RCT)	438 Patients, colon	Clinical AL	AL: BAR, 2.7% (n = 222); hand-sewn, 2.5% (n = 162); stapled, 1.9% (n = 54); not significant
Experimental				
Bundy et al,[108] 1993	. . .	36 Dogs	ABP	BAR vs hand-sewn vs stapled: hand-sewn higher ABP at day 3; equal ABP at day 7
Gullichsen,[110] 1993	. . .	42 Dogs	Histologic results	BAR vs hand-sewn vs stapled: more edema and inflammation with BAR at days 1 and 7
Smith et al,[107] 1988	. . .	40 Dogs	AL	2 Sizes BAR vs hand-sewn vs stapled: radiotherapy model; 1.5-mm BAR, more AL; other groups, equal
Maney et al,[109] 1988	. . .	178 Dogs	AL, ABP, histologic results	BAR vs EEA vs hand-sewn: no AL; equal ABP and histologic results

Abbreviations: see Table 1; BAR, biofragmentable anastomotic ring; EEA, end-to-end anastomosis stapler.
[a]Highest level of evidence, 1b.

Table 7. Included Studies on Configuration

Source	Level[a]	No. of Cases	Outcome	Results
Clinical				
Brisinda et al,[119] 2009	1b (RCT)	77 Patients, rectum	Clinical AL	AL: ETE, 29.2% (n = 37); ETS, 5.0% (n = 40); significant
Tsunoda et al,[120] 2009	1b (RCT)	40 Patients, rectum	Clinical AL and stump leak	AL: short (3-cm) limb, 5% (n = 20); long (6-cm) limb, 10% (n = 20); not significant
Experimental				
Willis et al,[118] 2006	. . .	18 Dogs	Perfusion	Rectum, stapled ETE vs stapled STE (vs J-pouch, NIR): ETE, better blood flow compared with STE
Sailer et al,[117] 2000	. . .	32 Pigs	Blood flow	Rectum, ETE vs STS (vs small pouch vs large pouch, NIR): equal blood flow

Abbreviations: see Table 1; ETE, end-to-end; ETS, end-to-side; NIR, not included in the present review (in case a supplemental subgroup was also studied, outside the topic of this review); STE, side-to-end; STS, side-to-side.
[a]Highest level of evidence, 1b.

1998, combined 13 RCTs concerning patients with colorectal anastomosis and found similar results: no significant differences in AL or mortality. The Cochrane review conducted by Choy et al[89] included studies on colorectal anastomosis after right hemicolectomy. This review showed significantly less overall AL in the stapled group; however, when clinical AL was used as the only outcome measure, this difference did not reach statistical significance. An interesting subgroup analysis made by Friend et al[82] found more AL in hand-sewn colorectal anastomosis when the anastomoses performed by residents were analyzed separately. Their conclusion was that stapling seems to have an advantage in less-experienced hands. Of 7 included nonrandomized cohort studies included in this review, 5 found no superiority of one technique.[100-104] Two studies found significantly more AL in stapled compared with hand-sewn anastomoses.[98,99] However, one of these had significantly more patients with corticosteroids in the stapled group,[99] while the other included 505 hand-sewn compared with 28 stapled colorectal anastomoses in 20 years.[98] Thirteen experimental studies[41,45,50,90-97,105,106] included herein found results approximately similar to those in the clinical setting: no significant differences in AL, with equal or higher ABP in stapled colorectal anastomosis.

In conclusion, the field of hand-sewn vs stapled colorectal anastomosis has been well studied. On the basis of level 1a evidence, no superiority of stapled over hand-sewn colorectal anastomosis exists.

HAND-SEWN VS COMPRESSION COLORECTAL ANASTOMOSIS

Denans described the first technique to create intestinal anastomoses by compression in 1827,[140] followed by other devices, such as the Murphy button, in 1892.[141] Today the biofragmentable anastomotic ring, made of absorbable polyglycolic acid, is used most often. Four included experimental studies[107-110] showed that compression colorectal anastomosis leads to acceptable healing and strength; 6 included RCTs[111-116] provide equivalent conclusions, finding no significant differences between hand-sewn and compression colorectal anastomosis. Also, noncomparative clinical cohort studies[142-145] including up to 1360 patients have reported incidences of AL between 0.7% and 5%. Although few gastrointestinal sur-

geons routinely use compression colorectal anastomosis, it seems a safe method. On the basis of 6 level 1b studies, no superiority of compression over hand-sewn colorectal anastomosis exists when comparing leak rates.

CONFIGURATION OF COLORECTAL ANASTOMOSIS

Studies regarding the configuration of the afferent and efferent ileal, colonic, or rectal loops are heterogeneous in patient selection and configuration and often concentrate on stapled pouches for very low anastomoses with outcome variables other than AL. Only 2 experimental studies matched the inclusion criteria; one study[117] found no significant difference in blood flow between ETE or side-to-side anastomosis after rectal resection in pigs, and the other[118] found better blood flow in ETE compared with side-to-end anastomosis after rectal resection in dogs. The included RCTs are also scarce: one[119] on ETE vs end-to-side found more AL in ETE, and the other[120] on the optimum side limb for side-to-end colorectal anastomosis found no significant difference between 3- and 6-cm sized limbs. No studies investigating the ideal length of the enterotomy were identified.

It is difficult to draw a conclusion from this small number of studies; there is one level 1b study showing a lower incidence of AL with end-to-side colorectal anastomosis and one level 1b study indicating that a 3-cm or a 6-cm side limb does not affect the incidence of AL.

CONCLUSIONS

In the clinical setting, healing of colorectal anastomosis is obscured from direct postoperative inspection. When AL occurs, diagnosis can be made only after the patient has become ill, making it a feared complication with high morbidity and mortality.[1,4,146-148] This systematic review of all aspects of hand-sewn colorectal anastomosis and the comparison of hand-sewn with mechanical anastomosis provides an overview of the existing colorectal anastomotic techniques combined with the available scientific evidence on anastomotic healing. Evaluation of colorectal anastomosis with clinical AL as the outcome measure and proper statistics produced very little level 1 evidence for all aspects of hand-sewn colorectal anastomosis. Nevertheless, we can formulate a conclusion using experimental results combined with clinical results for many aspects: the single-layer continuous suture technique by an inverting technique with slowly absorbable monofilament material seems preferable on the basis of level 1b evidence. However, for the other aspects of the technique, such as how far to place the suture from the anastomotic edge, the intersuture distance in relationship to the distance to the edge, which layers to include in the bite, how high the tension on the suture should be, and through what configuration the anastomosis should be made, surgeons probably rely on their teachers and instinct rather than on scientific evidence.

Large cohort studies that are available, describing low rates of AL for the used anastomotic technique, might indicate that dedicated, high-volume colorectal surgery has a role in lowering the incidence of AL because of a surgeon's familiarity with a certain technique.

Considering mechanical colorectal anastomosis, level 1a evidence indicates that stapling and hand-sewn anastomoses give equal results with regard to clinical AL, and level 1b evidence determines that compression and hand-sewn colorectal anastomosis have similar AL rates. In contrast to all possible variations that exist when sewing an anastomosis by hand, the technique of a stapled technique is much more uniform in the hands of surgeons. This could lead to standardizing colorectal anastomosis and prevent the nonscientific practice of the preferences of individual surgeons from being handed down from teacher to student without documentation of their exact properties and incidence of AL.

We can conclude from this review that, as of now, hand-sewn colorectal anastomosis is constructed following a largely undefined technique. The circumstances of RCTs do not reflect daily practice; therefore, routine, detailed documentation of anastomotic technique of all colorectal operations will be instrumental in formulating a definitive conclusion on the role of the unstandardized hand-sewn colorectal anastomosis.

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