Surgical Site Infection in Colorectal Surgery: A Review of the Nonpharmacologic Tools of Prevention

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Surgical site infections (SSI) are among the most common source of nosocomial morbidity for patients undergoing surgical procedures. SSIs are associated with increased hospital length of stay, increased risk of mortality, and decreased health-related quality of life.[1-3] SSIs also increase hospital costs by $1,300 to $5,000 per case.[2,4] So SSIs cause a substantial burden to the patient, the hospital, and the third party payers, and represent an important target for surgical quality improvement.

In the United States, an individual subjected to a major operation is expected to carry a 2% risk of SSI.[5] This rate is substantially higher if the individual undergoes colorectal surgery, with a current rate of 5% to 30% for SSIs in colorectal operations.[6,7] The wide variation in reported rates is largely a function of the varying definitions that have been applied to define SSI.

The most widely used definition for SSIs was provided by the Centers for Disease Control in 1992 and updated in 2003. It broadly categorized SSIs into incisional and organ/space infections.[8,9] Incisional SSIs were further split into 2 categories: superficial (involving the skin and subcutaneous tissue) and deep (involving fascia and muscle layers). This categorization is important because the etiology, risk factors, and clinical consequences vary depending on the location.[10]

An infection in the surgical site is the result of inoculation with a bacterial load that is greater than the ability of the immune system to control it. Therefore, increased contamination (contaminated or dirty-infected wound classes) and decreased host immunity lead to increased incidence of SSI. Since Lister's time, we have applied the scientific method to surgical practice to identify options for decreasing bacterial contamination and augmenting host immunity, and although the incidence of SSI has been reduced by applying the results of our investigations, the current rates of SSI, particularly in colorectal surgery, suggest that there is still room for improvement.

Contributing to the development and/or prevention of SSI are patient factors, surgical technique, and an armamentarium of tools, both pharmacologic and nonpharmacologic. Patient factors have been borne out of large retrospective reviews and multivariate analysis of randomized controlled trials. These include, but are not limited to, American Society of Anesthesiologists score, obesity, tobacco use, COPD, surgical wound class, and age.[6,7,11] Surgical technique (blood loss requiring transfusion, increased operative time, spillage of luminal contents) has also been shown to increase the incidence of wound infection.[7,12] In this report, we examine the available level 1 evidence regarding some of the common nonpharmacologic modalities for decreasing the incidence of SSI, with the inclusion of lesser evidence when appropriate.

We conducted a search of all published English literature using PubMed, from 1960 to 2009, with the limitations of human studies, randomized controlled trials (RCTs), and meta-analyses. We evaluated additional studies cross-referenced in bibliographies. Search criteria included the keywords in each subheading, *colorectal surgery, wound infection,* and *surgical site infection*.

Preoperative shower with skin antiseptics

SSI is a result of a complex interaction between bacterial contamination from the skin and end organs as well as local and systemic host immunity. Bacterial numbers can be reduced by preoperative (within 24 hours of entering the operating room) cleansing with chlorhexidine.[13,14] A meta-analysis of the RCTs investigating the use of preoperative chlorhexidene cleansing in preventing SSI has been reported.[15] Seven studies were evaluated. Application of the preoperative cleansing differed from study to study, with provision of supplies and instructions for 1 versus 2 applications. None provided any objective measure of adherence to instruction. Within the analysis, there were studies comparing whole body cleansing with localized cleansing that found a significant difference in SSI between the groups, favoring whole body cleansing.[15] However, there was no statistically significant difference in SSI between patients who underwent preoperative chlorhexidine cleansing versus placebo, bar soap, and no wash at all. Although commonly practiced, there is no supportive evidence for preoperative cleansing with skin antiseptics.

Skin preparation at the time of surgery

The simplest theoretical approach to decrease SSIs is to eradicate pathogens present on the skin before proceeding with skin incision. Several topical antiseptic agents are available to accomplish this goal. Few RCTs have been performed to evaluate the ability of different preoperative skin preparations to prevent SSIs in clean contaminated cases.

A multicenter RCT evaluating chlorhexidine-alcohol versus povidone-iodine for surgical site antisepsis in clean-contaminated procedures found a significantly lower SSI rate in the chlorhexidine-alcohol group than in the povidone-iodine group (9.5% [39 of 409] vs 16.1% [71 of 440], p = 0.004).[16] For the subgroup of patients undergoing colorectal surgery, patients whose skin was prepared with chlorhexidine had an SSI rate of 15.1% (28 of 186) compared with a rate of 22.0% (42 of 191) in the povidone-iodine group (p = 0.155).

An institutional study evaluated 3 skin preparations in general surgery cases by means of a sequential implementation design at a single center in which sequential 6-month periods were assigned a different skin preparation. There was a significant difference in SSI rates between the povidone-iodine group (4.8%) and the iodine povacrylex in isopropyl alcohol group (4.8%) when compared with the 2% chlorhexidine and 70% isopropyl alcohol group (8.2%, p = 0.001).[17]

Although the data regarding skin preparation for clean-contaminated cases are limited, the best evidence suggests that chlorhexidine preparations dominate over povidone-iodine. Pending further confirmatory studies specifically for patients undergoing colorectal surgery, chlorhexadine-alcohol should probably be used whenever possible.

Mechanical bowel preparation

The idea of removing potential fecal contamination from the patient before surgery through mechanical bowel preparation (MBP) has been present for more than a century.[18] Early studies showed convincing reductions in SSIs based on the use of MBP.[19] Subsequently, MBP rapidly became universal in elective colorectal surgery. Based on these reports and common practice, emergency surgery on an unprepared colon was thought to mandate an ostomy rather than a primary anastomosis secondary to fear of infectious complications.

More recently, the results of several studies have begun to question the utility of MBP. The idea that MBP could potentially be omitted without incurring increased risk of SSI stemmed from the trauma experience in which primary repair of the colon was performed in unprepared bowel with equivalent outcomes.[20] Many theories exist to explain the equivalent outcomes observed with MBP. One suggests that incomplete preparation liquefies the colonic stool, resulting in a potential for increased spillage at the time of operation.[21] Regardless of the exact mechanism responsible, a considerable body of literature exists that calls into question the need for routine MBP.

There have been 3 recent meta-analyses of the RCTs evaluating omission of MBP (Table 1). In one study, 9 RCTs were analyzed to evaluate for primary outcome of anastomotic leakage and secondary outcomes of mortality and wound infection. In total, 791 patients received MBP and 803 had no preparation. There were 6.2% of the patients having MBP who had anastomotic leak, compared to 3.2% of the unprepared patients (odds ratio [OR] 2.03, 95% CI 1.28 to 3.26), favoring no preparation. SSI was observed in 7.4% of the prepared patients and 5.4% of the unprepared patients (OR 1.45, 95% CI 0.97 to 2.18).[18]

A second meta-analysis included 14 RCTs with 2,452 patients in the MBP group and 2,407 in the unprepared group. There was no statistically significant difference observed in the analysis of the primary outcome, anastomotic leakage (4.02% in the MBP group vs 3.44% in the unprepared group, OR 1.12, 95% CI 0.82 to 1.53). However, analysis of secondary outcomes demonstrated a difference in "all SSI" favoring no MBP (15.7% after MBP vs14.58% unprepared, OR 1.4, 95% CI 1.05 to 1.87).[22]

A third analysis was an updated version of an earlier Cochrane review,[23] performed by Guenga and colleagues.[24] This study included analysis of 13 RCTs, with 2,390 patients allocated to MBP and 2,387 to no preparation. The primary outcome measured was anastomotic leakage; secondary measures included wound infection and overall SSIs. Overall anastomotic leakage was 4.2% in the MBP group versus 3.4% in the unprepared group (OR 1.26, 95% CI 0.941 to 1.69). There was no difference in the rate of wound infection (9.6% in the MBP group vs 8.3% in the unprepared group, OR 1.19, 95% CI 0.98 to 1.45).[24]

It has been suggested that there is a difference in the incidence of SSI based on the type of mechanical preparation administered, favoring sodium phosphate over polyethylene glycol. This was demonstrated in a post-hoc analysis of a randomized controlled antibiotic prophylaxis trial,[25] which found that the type of MBP (sodium phos-

Table 1. Three Meta-Analyses of Mechanical Bowel Preparation

	Reference, year		
Variable	Wille-Jorgensen,[18] 2005	Guenaga,[24] 2009	Slim,[22] 2009
Anastomotic leakage			
MBP, n (%)	48/772 (6.2)	102/2,398 (4.2)	98/2,433 (4.02)
No preparation, n (%)	25/777 (3.2)	82/2,378 (3.4)	82/2,381 (3.44)
Odds ratio	2.03	1.26	1.12
95% CI	1.28–3.26	0.941–1.69 (NS)	0.82–1.53 (NS)
Surgical site infection			
MBP, n (%)	59/791 (7.4)	232/2,417 (9.6)	385/2,452 (15.7)
No preparation, n (%)	43/803 (5.4)	200/2,404 (8.3)	351/2,407 (14.6)
Odds ratio	1.45	1.19	1.40
95% CI	0.97–2.18 (NS)	0.82 – 1.45 (NS)	1.05–1.87

MBP, mechanical bowel preparation.

phate vs polyethylene glycol) was a risk factor for SSI (87 of 367 [24%] vs 103 of 303 [34%], observed difference 10%, 95% CI 3.4 to 17.2). However, in the meta-analysis by Slim and associates,[22] which analyzed 9 trials evaluating polyethylene glycol and 4 trials evaluating sodium phosphate, no difference was found between the groups for anastomotic leakage, wound infection, or abdominal abscesses.

Despite the volume of data regarding the lack of utility of MBP in preventing SSI, a survey of colon and rectal surgeons in 2003 suggested that the use of MBP was still nearly universal.[26] Given the large number of studies that these 3 meta-analyses summarize, and given the inconvenience and discomfort required of patients undergoing MBP, clinicians should reconsider mandatory MBP.

Wound protectors
Wound protectors are designed to protect the abdominal wall from desiccation, contamination, and mechanical trauma during abdominal procedures. Theoretically, these devices minimize bacterial contamination of the wound by shielding it from potential contaminants. Consequently, there have been several studies of the use of wound edge protectors as a strategy to prevent SSI. In one study, Raahave[27] compared bacteriology of surgical wounds for gastrointestinal surgery, with and without the use of a wound protector, and found a significant reduction in bacterial density of the wounds in patients in whom a wound protector had been used. Unfortunately there has not been a correlation of this finding with fewer SSIs because many studies using wound protectors have failed to show a significant reduction in the rate of infection.[28-32]

For example, in an RCT of patients undergoing colorectal surgery, Nystrom and colleagues[29] reported that the rate of infection with a wound protector was 10% (7 of 70) compared with a rate of 9% (6 of 70) when a wound protector was not used. Three other RCTs also found no difference in the incidence of SSI with or without the use of a plastic wound protector in patients undergoing transabdominal surgery.[30,33,34] A recent study has been reported that evaluated the use of wound protectors during externalization and anastomosis in laparoscopic colon procedures. In this analysis of a retrospective review of 141 cases, the authors found no difference in the rate of infection with a wound protector versus without (12% [9 of 84] vs 14% [8 of 57], respectively).[35]

Alternatively, a randomized study demonstrated a reduction in the overall infection rate from 29% to 14% (OR 0.31; 95% CI 0.16 to 0.60) when an impervious wound edge protector was used during transabdominal surgery for gastrointestinal operations.[31] In this study, the advantage of wound protectors was most pronounced in contaminated wounds. In 1968, a nonrandomized study comparing the use of a wound protector versus none in 224 gastrointestinal surgical procedures showed a decrease in infection rates from 15% to 2.4% with the use of a wound protector.[28]

The few randomized trials all use different types of wound protection, included differing types of surgical procedures, and came to differing conclusions concerning the efficacy of this intervention. Therefore, the overall benefit of wound protectors in abdominal surgery in preventing wound infection remains unclear, and more controlled randomized studies are required to clarify this issue.

Intravenous fluid
Controversy exists concerning the role of intraoperatively delivered intravenous fluids and their role in reducing SSI. Proponents of supranormal fluid administration argue that increased fluid administration leads to increased perfusion pressure and increased oxygen delivery. Increased oxygen availability should lead to increased oxidative destruction of bacteria. In order to begin testing this hypothesis, a study

was undertaken to evaluate subcutaneous oxygen tension in individuals undergoing colorectal surgery randomized to receive conservative or aggressive fluid management. There was a significant difference in the tissue oxygenation pressure between the 2 groups, favoring the more aggressive fluid delivery (81 ± 26 mmHg in the aggressive group vs 67 ± 18 mmHg in the conservative group, p = 0.03).[36] A subsequent multicenter RCT evaluated the use of supplemental perioperative fluid administration to prevent SSI. In this analysis, 256 patients were randomized to receive large volume (16 to 18 mL/kg/h) versus small volume (8 to 10 mL/kg/hr) fluid administration (5.7 ± 2 L vs 3.1 ± 1.5 L average total fluid). Initial analysis after 250 patients showed an insignificant difference in the rate of SSI between the groups (8.5% in the large volume vs 11.3% in the small volume, p = 0.46), and recalculation of sample size suggested an unrealistic accrual goal would be required to identify a statistical advantage for this small difference so the study was terminated.[37]

Alternatively, it has been theorized that aggressive fluid administration leads to edema that may impede tissue healing, leading to an increased risk of SSI. A multicenter RCT supported this theory. In this study, 172 patients were randomized to a restricted fluid regimen that favored early administration of colloid versus a standard regimen. Significantly more fluid was delivered in the standard group versus the restricted group (intraoperatively, 2.7 L vs 5.4 L, p < 0.0005; and on postoperative day number 1, 500 mL vs 1,500 mL, p = 0.003). There was a statistically significant difference in the rate of wound complications (infection, dehiscence, hematoma) between the 2 groups (13% in the restricted group vs 25% in the standard group, p = 0.03).[38] These authors concluded that restricted perioperative intravenous fluid administration reduces complications after colorectal resection.

Although the intraoperative volume of fluid given in both studies was similar, the outcomes were very different. Therefore, it is premature to draw any conclusions from these studies. Additional RCTs are needed to clarify the issue.

Hyperoxia
Because oxygen is required for neutrophil- and macrophage-mediated destruction of bacteria, it has been theorized that supranormal O_2 administration would increase the partial pressure of O_2 in the wound bed, thereby increasing the oxidative destruction of contaminating bacteria by neutrophils. Several prospective randomized trials attempted to define the effect of supranormal levels of oxygen during anesthesia on SSI.[39-43] The majority of these were included in a recent meta-analysis. In the 5 RCTs evaluated, patients were maintained on an 80% concentra-

tion of oxygen during the operation and for variable periods postoperatively. In all but 1 study, patients were maintained on a 30% concentration of oxygen as the control group. In the fifth, the control group received 35% FIO_2.[43] With 3,001 patients included, the rate of SSI was 12% in the control group and 9% in the group treated with 80% oxygen (risk ratio 0.742 with 95% CI 0.599 to 0.919, p = 0.006).[44] Analyzed individually, the data from the 5 studies are conflicting. However when analyzed together, the data from these 5 studies favor intraoperative hyperoxia. Of note, none of these studies reported any adverse events attributable to the delivery of supranormal concentrations of oxygen.
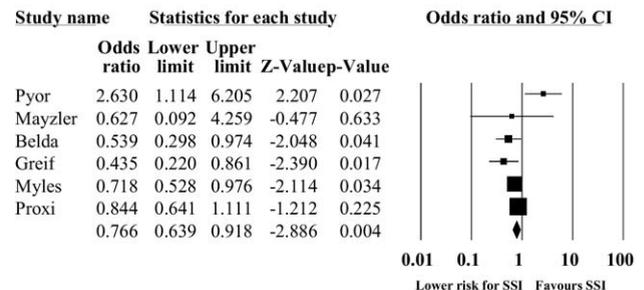
One problem with each of these studies is that the primary outcome was SSI within 14 or 15 days. It has been previously demonstrated that many SSIs occur between 15 and 30 days postoperatively.[10] Therefore, these studies excluded a certain volume of unmeasured adverse outcomes that would potentially affect interpretation of their outcomes.

A recent multicenter study (the Perioperative Oxygen Fraction [PROXI] study) randomized 1,400 patients undergoing laparotomy to receive either 80% FIO_2 intraoperatively and 2 hours postoperatively or 30% FIO_2 in a similar fashion. This study found no significant difference in SSIs between the 2 groups (19.1% in the 80% group vs 20.1% in the 30% group, p = 0.64).[41]

When the results of the PROXI study are combined with those from the previous 5 studies, the analysis still favors hyperoxia for decreasing SSI (Fig. 1). So it is reasonable to conclude that hyperoxia has a beneficial, albeit limited, effect on SSI.

Warming
The main defense mechanism against bacterial contaminants in surgical wounds is oxidative destruction by neutrophils. The risk of surgical wound infections is therefore closely linked with oxygen tension, which is, in turn, related to local tissue perfusion. Hypothermia triggers vaso-

Study name	Odds ratio	Lower limit	Upper limit	Z-Value	p-Value
Pyor	2.630	1.114	6.205	2.207	0.027
Mayzler	0.627	0.092	4.259	-0.477	0.633
Belda	0.539	0.298	0.974	-2.048	0.041
Greif	0.435	0.220	0.861	-2.390	0.017
Myles	0.718	0.528	0.976	-2.114	0.034
Proxi	0.844	0.641	1.111	-1.212	0.225
	0.766	0.639	0.918	-2.886	0.004

Figure 1. Forest plot evaluating hyperoxia and surgical site infection (SSI).

constriction, which decreases tissue blood flow and diminishes tissue oxygenation.

Active preoperative warming as a preventative measure to prevent SSIs was first reported in an RCT by Kurz and colleagues.[11] In their analysis of 200 patients undergoing colorectal surgery, they found a 3-fold increase in infection rate (6% vs 19%, p = 0.009) in the patients receiving routine intraoperative thermal care compared with patients with an active warming strategy using fluid and forced air warming with an average temperature difference of 1.9° C. In a subsequent trial including 421 patients undergoing clean operations, patients were randomized to 1 of 3 groups: standard treatment, local warming, or systemic warming.[45] Nonwarmed patients had a wound infection rate of 14%. Those warmed locally had an infection rate of 4% (p = 0.003); those warmed systemically had an infection rate of 6% (p = 0.026). These authors concluded that preoperative warming before clean surgery aids in the prevention of SSI. So, 2 RCTs demonstrated an advantage to active patient warming as a modality to decrease SSI.

Other retrospective studies, however, failed to demonstrate a positive correlation between patient warming and SSI. A review of 150 patients undergoing colon resection found that despite the fact that one-third of the patients were cooler than 95.5° F at some point during the operation, infection rates were 6% for both warm and cool patients.[46] A second retrospective review of more than 1,400 patients undergoing bowel surgery found that patients who had a lower intraoperative temperature nadir had a lower risk of SSI, although the temperature difference was clinically insignificant (35.8 ± 0.8° C vs 36.0 ± 0.9° C, p < 0.05).[12] Because these studies were retrospective, the results must be interpreted with caution. In the presence of well performed RCTs, the evidence has been considered substantially in favor of normothermia for SSI prevention such that the Veterans Administration Health Care System has incorporated maintenance of patient temperature during and after colorectal surgical procedures as a performance measure. Facilities will be graded on their ability to maintain patient temperature of at least 96.8° F at the first recorded postoperative temperature (within 1 hour of the completion of an operation). This measure has also been incorporated into current Surgical Care Improvement Project guidelines.

Given the present level 1 evidence, every effort should be made to maintain patient normothermia during and after the completion of colorectal surgery. Efforts should include active warming both preoperatively and intraoperatively with fluid, forced air, or conductive blankets.

Laparoscopy

One consistently reported benefit of laparoscopic surgery has been a decrease in postoperative wound complications. A meta-analysis of the short-term benefits for laparoscopic colorectal resection evaluating 25 RCTs from 1981 to 2004 supports this assertion. Data on wound infections were given in 17 trials, totaling 1,771 patients. There was a statistically significant decrease in SSI in the laparoscopic compared with the open patients (4.6% vs 8.7%, p = 0.002), but there was no difference in the rate of intraabdominal abscess.[47] However, most of the studies reviewed were small; only 5 had more than 200 patients. A second meta-analysis published 1 year later included several of the larger RCTs that were incomplete at the time of the first analysis (COLOR [Colon Carcinoma Laparoscopic or Open Resection] and Conventional versus laparoscopic assisted surgery in colorectal cancer [CLASICC] trials). This study found a decreased rate of wound complications (infection and dehiscence) in favor of the laparoscopic group when compared with the open group (4.7% [73 of 1,547]) vs 7.3% [103 of 1,418], p = 0.01).[48]

Individual results of the 5 largest multicenter RCTs comparing laparoscopy with open surgery for colon cancer demonstrated no difference in overall morbidity or wound complications between the groups. These studies are summarized in Table 2. The table shows that in most of these studies, the cases that were converted from laparoscopy to open were included in the laparoscopy arm as intention to treat. If the larger open incisions exhibit a higher rate of SSI, then inclusion in the laparoscopic arm skews the data. Only 2 of the 5 trials performed subset analysis offering any comparison of the morbid outcomes in the conversion group. Another limitation is the exclusion of diverticular disease and inflammatory bowel disease from these large studies.

Although individually, the large randomized studies have demonstrated no difference in SSI, the meta-analyses, including multiple small studies, have shown a decrease in SSI with laparoscopic colectomy for colon cancer. Therefore it is probable that laparoscopic surgery does not increase the risk of SSI and may well reduce the risk. So, when considering measures to reduce SSI, laparoscopic resection should be attempted when possible in order to minimize SSI.

Prophylactic drainage

The intended purpose of prophylactic drainage of colon anastomoses is to remove and/or prevent accumulation of fluid and blood and to allow for early detection of anastomotic problems. Opponents argue that prophylactic drains do not prevent leakage and may even contribute to anastomotic breakdown by causing infection in the region of the

Table 2. Randomized Controlled Trials Evaluating Laparoscopic Versus Open Colectomy

Variable	COST[75]	CLASICC[76]	COLOR[77]	ALCCaS[78]	LAPKON II[79]
			Trial		
Year of publication	2004	2005	2005	2008	2009
n	872	794	1,248	592	472
Study population	Right or left colon cancer	Colon or rectal cancer	Right or left colon cancer	Right or left colon cancer	Colon or rectal cancer
Mean age, y (range)	69 (28–96)	69 (11)	71 (27–92)	34–100	66
Female gender, n (%)	432 (50)	353 (44)	586 (47)	310 (52)	224 (47)
ASA, 1 or 2, n (%)	740 (86)	661 (93)	1,001 (80)	428 (72)	345 (73)
Overall complications, n (%)					
Open	85 (20)	115 (42)	110 (20)	–	53/222 (24)
Laparoscopic	92 (21)	133 (39)	111 (21)	–	63/250 (25)
Converted	included	99 (69)	Included in laparoscopic	–	Included
Wound infection, n (%)					
Open	–	23 (8)	16 (3)	26/298 (9)	19/222 (9)
Laparoscopic	–	24 (7)	20 (4)	10/251 (4)	27/250 (11)
Converted	–	21 (15)	Included in laparoscopic	7/43 (16.3)	Included
Deep space infection or anastomotic failure, n (%)					
Open	–	10 (7)	10 (2)	16/298 (5)	5/222 (2)
Laparoscopic	–	13 (8)	15 (3)	0/43 (0)	12/250 (5)
Converted	–	12 (15)	Included	7/251 (3)	Included

There are not statistically significant differences in the rates.
ASA, American Society of Anesthesiologists; COST, Clinical outcomes of surgical therapy study group; CLASICC, conventional versus laparoscopic assisted surgery in colorectal cancer; COLOR, Colon cancer laparoscopic or open; ALCCaS, Australian laparoscopic colon cancer surgical trial.

anastomosis and in the wound because drains allow for communication of skin flora. Many studies have been performed to evaluate the use of prophylactic intra-abdominal or pelvic drains in colorectal surgery, with conflicting results. A meta-analysis of 6 RCTs was performed with a primary outcomes measure of anastomotic leak and secondary measures including SSI. The analysis demonstrated no benefit to drainage versus no drainage for anastomotic leak or SSI (29 of 573 [5%] vs 28 of 567 [5%], risk difference 0%, 95% CI 0.60 to 1.76).[49]

The evidence suggests that prophylactic drainage does not prevent SSI and its use should be abandoned.

Fascia closure
Various methods for closure of the fascia have been studied throughout the years to determine the best practice for reducing the incidence of incisional hernia and, as an aside, for reducing SSI. Unfortunately, the studies have compared a variety of methods and a variety of suture materials. A meta-analysis analyzing techniques (contin-

uous rapidly absorbable vs nonabsorbable, continuous slowly absorbable versus nonabsorbable, continuous rapidly absorbable vs slowly absorbable, interrupted rapidly absorbable vs nonabsorbable) for closure of midline incisions found no difference in each of these categories in the incidence of SSI.[50] A more recent RCT compared interrupted closure with rapidly absorbable suture, continuous closure with slowly absorbable/longitudinally elastic suture, and continuous closure with slowly absorbable suture. The results demonstrated no difference in the incidence of wound infection between the groups (26 of 210 [12.7%] vs 39 of 205 [19.4%] vs 33 of 210 [16.3%], p = 0.19).[51] Therefore, although it may make a difference in terms of the incidence of hernia recurrence, there appears to be no difference in the method of fascial closure in regard to wound infection.

For continuous closure of the fascia, it has been demonstrated that a suture length-to-wound length ratio of greater than 4 decreases in the incidence of incisional her-

nia.[52] Recently, an RCT compared long suture length and short suture length in continuous fascial closure. The short suture length group took smaller fascial bites at shorter intervals, and was found to have a decreased incidence of SSI (and incisional hernia) when compared with the long suture length group (17 of 326 [5.2%] vs 35 of 343 [10.2%], p = 0.02).[53]

The presence of a foreign body (ie, suture) in the wound can reduce the number of bacteria needed to establish infection.[54] Antibiotic-coated suture has been created to potentially address this problem. A recent single-institution, large prospective trial compared continuous fascial closure using either rapidly absorbable antibiotic coated suture or slowly absorbable suture, and found a decrease in the incidence of wound infection in the antibiotic-coated suture group (113 of 1,045 [10.8%] vs 51 of 1,043 [4.9%], p = < 0.001).[55]

The evidence regarding continuous versus interrupted fascial closure demonstrates no difference in the incidence of SSI. For continuous fascial closure, a suture length-to-wound length ratio of at least 4 should be used with smaller (5 to 8 mm) fascial bites at shorter intervals. Antibiotic-coated suture has been found to decrease the incidence of wound infection in a prospective trial. Although these results are encouraging, they should be subjected to the rigors of an RCT.

Skin closure
The objective of skin closure is to allow for rapid healing with good cosmetic outcome, while avoiding the complications of infection and dehiscence.[56] There are many options for skin closure after laparotomy, including absorbable suture, nonabsorbable suture, external metal staples, and internal absorbable staples. In addition, topical skin glue can be used in conjunction with some of these methods. Surgeon preference guides these choices. Proponents of stapling suggest that they are quicker to apply than sutures; opponents suggest that staplers increase cost.[57] In addition, staple application requires staple removal.

In 2007, a best-evidence report was published evaluating 5 RCTs comparing stapled closure with sutured closure of sternal and leg harvest sites in cardiothoracic surgery.[58] Three of the 5 RCTs found a decreased infection rate with sutured closure compared with stapled closure. The remaining 2 found no difference. The authors concluded that sutured skin closure for chest and leg wounds was superior to stapled closure.

A recent meta-analysis was performed of studies evaluating stapled versus sutured skin closure in orthopaedic surgery.[56] After a thorough literature search, the authors identified and analyzed 6 studies, although admittedly,

only 1 study had acceptable methodologic quality. In addition, the authors excluded any study assessing the effects of 2-octylcyanoacrylate. They found an increase in the rate of wound infection with the use of staples compared with sutures (RR 3.83, 95% CI 1.38 to 10.68).[56]

There is little in the recent medical literature regarding stapled versus sutured skin closure of abdominal wounds, and specifically, of colorectal abdominal wounds. However, a recent study compared stapled skin closure with subcutaneous closure plus 2-octylcyanoacrylate in patients undergoing elective colectomy.[59] The authors found no significant difference in the incidence of wound infection between the 2 groups (6 of 36 [16.7%] vs 8 of 34 [23.5%], p = 0.557).

Reviews of the orthopaedic and cardiothoracic literature support the use of sutures when compared with staples to decrease the incidence of wound infection. The limited data in the colorectal literature suggest no difference. Additional studies are needed to clarify this issue.

Glucose control
In vitro, hyperglycemia causes neutrophil dysfunction, which has been summarized and reviewed elsewhere.[60] This theoretically decreases local immune response at the surgical incision and potentially increases the incidence of postoperative infection. A recent study found decreased neutrophil phagocytic activity in diabetic patients undergoing cardiac surgery, randomly assigned to a standard insulin regimen or an aggressive regimen.[61] A substantial number of studies assessing glucose control and SSIs have emerged from the cardiac surgery literature. Several retrospective reviews evaluating perioperative glucose levels and cardiovascular surgery outcomes demonstrated an increased risk of SSI with perioperative hyperglcemia.[60,62,63] These initial observations prompted the inclusion of perioperative glucose monitoring of the coronary artery bypass grafting patient into the most recent Surgical Care Improvement Project measures.

A prospective study comparing intermittent versus continuous insulin infusion in patients in a sequential fashion undergoing cardiac surgery found a significant decrease in sternal infection between the 2 groups (0.8% [12 of 1,499] in the continuous insulin group versus 2.0% [19 of 968] in the intermittent group, p = 0.01).[64]

Alternatively, more recent data have not been as clear cut in supporting the association of aggressive perioperative glucose control with reduced rates of SSI. In one study, 141 patients were randomized to standard therapy with a glucose goal of <250 mg/dL versus aggressive glycemic control with intravenous insulin infusion to achieve a glucose level of 125 to 250 mg/dL. This study

found a difference in postoperative infections (pneumonia and wound) of 0 of 72 in the standard group versus 9 of 69 (13%) in the aggressive group (p = 0.01).[65] Another study randomized 141 patients to standard therapy with a glucose goal of <250 versus aggressive glycemic control with intravenous insulin infusion to achieve a glucose level of 125 to 250 mg/dL. This study found a difference in post-operative infections (pneumonia and wound) of 0/72 in the aggressive group versus 9/69 (13%) in the standard group (p = 0.01).[65]

Alternatively, more recent data have not been as clear cut in supporting the association of aggressive perioperative glucose control with reduced rates of SSI. Subramaniam and coworkers[66] randomized 236 patients undergoing vascular surgery to IV insulin versus standard intermittent bolus. Although there was a difference in major cardiovascular events, there was no difference in SSI (29 of 122 [24%] in the intermittent insulin group vs 35 of 114 [31%] in the continuous insulin group).[66] More recently, a study in which 109 patients undergoing open heart surgery were randomized to aggressive glucose control (80 to 130 mg/dL) versus standard (160 to 200 mg/dL) found no statistically significant difference in the incidence of SSI, although there was a trend noted in improvement toward SSI (16.7% in the control vs 11.1% in the treatment group, p = 0.09).[67]

There have been no randomized controlled trials in the general surgery or colorectal populations. To date, only 1 study has evaluated the effect in general surgery patients. Ramos and colleagues[68] performed a retrospective study of 995 patients undergoing general and vascular surgery and found that postoperative hyperglycemia increased the risk of postoperative infection (wound infection, pneumonia, urinary tract infection, and sepsis) by 30% with every 40-point increase from normoglycemia (<110 mg/dL). So, whether aggressive attempts at controlling hyperglycemia will result in improved rates of SSI in the colorectal population remains an open question.

Furthermore, it is important to recognize the morbidity and mortality associated with hypoglycemia in an aggressive glucose control model. Although there are data suggesting improvement in infectious morbidity and overall mortality in critically ill patients,[69-71] there are also data from several large RCTs and a recent meta-analysis of the available RCTs[72-74] that suggest that there may be equivalent or worse outcomes associated with aggressive glucose control that may be secondary to the deleterious effects of hypoglycemia.

Tight glucose control appears to decrease the incidence of SSI in selected populations, although further study, specifically in the colorectal population, is warranted. Caution should be used in implementing such practices, weighing the risk of SSIs versus hypoglycemia.

DISCUSSION

The current rate of infection in colorectal surgery remains unacceptably elevated, despite both internal and external pressures encouraging application of current evidence-based practices to decrease infection. This places substantial burden on patients, hospitals, and on the health care system. These unacceptable rates have resulted in mandated measures in both the private sector (Surgical Care Improvement Project) and in the nationalized VA health care system to decrease the rate of infection. However, caution should be used when bundling measures, which, when tested alone, demonstrate a benefit. These bundled measures do not necessarily have an additive benefit, and may actually have a negative impact on the rate of SSI (Anthony T, Murray BW, Sum-Ping J, et al. A randomized controlled trial of standard care versus an evidence-based care bundle designed to reduce surgical site infections for patients undergoing elective colorectal surgery. Unpublished data 2010). Bundled measures should be tested as a bundle before implementation.

The Centers for Medicare and Medicaid Services has designated several suboptimal infectious outcomes as "never" events, and has tailored reimbursement to preclude payment for services involved in these outcomes. It is not difficult to foresee a time in which reimbursement and accreditation are scaled to outcomes including SSI. It is imperative for patient care and for physician autonomy that the problem of SSI be addressed by the thoughtful application of practices that have been evaluated by well-run RCTs and peer reviewed.

In conclusion, review of the current literature revealed data regarding SSI in colorectal surgery to support:

1. Abandonment of preoperative shower with chlorhexidine
2. Use of chlorhexadine-alcohol skin preparation at the time of surgery
3. Reconsideration of the need for mechanical bowel preparation
4. Perioperative maintenance of normothermia
5. Use of laparoscopy when feasible
6. Abandonment of prophylactic anastomotic drains
7. Suture length-to-wound length ratio ≥4, with smaller (5 to 8 mm) fascial bites at shorter intervals when closing the fascia continuously
8. Consideration of the use of perioperative hyperoxia

More study is needed before recommendations can be made in the areas of wound protectors, intraoperative fluid management, skin closure method, antibiotic coated suture, and aggressive glucose control.

Author Contributions

Study conception and design: Murray, Anthony
Acquisition of data: Murray, Anthony, Dineen
Analysis and interpretation of data: Murray, Huerta, Anthony, Dineen
Drafting of manuscript: Murray, Huerta, Anthony
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