Original article

Effectiveness of a multidisciplinary patient care bundle for reducing surgical-site infections

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Background: Surgical-site infection (SSI) is associated with significant healthcare costs. To reduce the high rate of SSI among patients undergoing colorectal surgery at a cancer centre, a comprehensive care bundle was implemented and its efficacy tested.

Methods: A pragmatic study involving three phases (baseline, implementation and sustainability) was conducted on patients treated consecutively between 2013 and 2016. The intervention included 13 components related to: bowel preparation; oral and intravenous antibiotic selection and administration; skin preparation, disinfection and hygiene; maintenance of normothermia during surgery; and use of clean instruments for closure. SSI risk was evaluated by means of a preoperative calculator, and effectiveness was assessed using interrupted time-series regression.

Results: In a population with a mean BMI of 30 kg/m^2, diabetes mellitus in 17·5 per cent, and smoking history in 49·3 per cent, SSI rates declined from 11·0 to 4·1 per cent following implementation of the intervention bundle ($P = 0·001$). The greatest reductions in SSI rates occurred in patients at intermediate or high risk of SSI: from 10·3 to 4·7 per cent ($P = 0·006$) and from 19 to 2 per cent ($P < 0·001$) respectively. Wound care modifications were very different in the implementation phase (43·2 *versus* 24·9 per cent baseline), including use of an overlying surface vacuum dressing (17·2 from 1·4 per cent baseline) or leaving wounds partially open (13·2 from 6·7 per cent baseline). As a result, the biggest difference was in wound-related rather than organ-space SSI. The median length of hospital stay decreased from 7 (i.q.r. 5–10) to 6 (5–9) days ($P = 0·002$). The greatest reduction in hospital stay was seen in patients at high risk of SSI: from 8 to 6 days ($P < 0·001$). SSI rates remained low (4·5 per cent) in the sustainability phase.

Conclusion: Meaningful reductions in SSI can be achieved by implementing a multidisciplinary care bundle at a hospital-wide level.

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Introduction

Surgical-site infection (SSI) accounts for more than one-third of all inpatient infectious events[1]. SSI can manifest as wound erythema and discharge when it is superficial, or as sepsis when it is deep and involves fascia or an intra-abdominal organ space. Along with added morbidity and delayed convalescence, SSI places considerable financial strain on the healthcare system[2,3] owing to prolonged hospital care, readmission and disability[4–6]. Treatments include opening a surgical incision, antibiotics, or an invasive procedure to drain an abscess or debride tissue. A perioperative mortality rate for SSI of 3 per cent has been reported, with 75 per cent of associated deaths directly attributable to the SSI[7].

SSI is a direct consequence of surgery, and some instances may be preventable. Intensive quality improvement initiatives have been developed in the USA, including the Surgical Infection Prevention Project[8] and the Surgical Care Improvement Project (SCIP)[9]. These initiatives were first implemented for high-risk procedures such

as colorectal surgery[6]. The aim of the SCIP was to improve processes of care by having hospitals follow best practices, including appropriate administration of antibiotics, use of optimal hair removal techniques and maintenance of normothermia. However, adoption of SCIP best practice measures did not uniformly lead to SSI reduction[10–13]. Experts have argued that more comprehensive programmes that inspire healthcare providers to develop and implement solutions along with cultural change are necessary to achieve meaningful reduction in preventable healthcare-associated complications[14–21]. Model programmes include those aimed at reducing central-line bloodstream infections[22], ventilator-associated pneumonias[23] and catheter-associated urinary tract infections[24]. This pragmatic study was designed to test the efficacy of a care bundle in reducing SSI at the authors' centre.

Methods

Development of the surgical-site infection reduction programme

In 2013, Memorial Sloan Kettering Cancer Center (MSK), a National Cancer Institute-designated comprehensive cancer centre, developed an SSI reduction programme. Representatives from the Departments of Surgery, Medicine, Anaesthesia, Nursing, Administration, Infection Control, and Quality and Safety were assembled to review care of surgical patients along the spectrum from preoperative evaluation to discharge from the hospital. The literature for optimal preoperative, intraoperative and postoperative care was reviewed as described elsewhere[15,21], and practices were chosen on the basis of high levels of supporting evidence or their being considered (by consensus of multidisciplinary team representatives) reasonable, associated with minimal risk and potentially beneficial. In addition to SCIP measures related to preoperative administration and postoperative discontinuation of antibiotics that were instituted before 2013, a number of standard procedures and approaches were newly implemented (*Table 1*).

A unique intervention that was included comprised providing surgeons with an estimated risk of SSI, via e-mail the day before surgery. It was hypothesized that this information might influence surgeons' decisions regarding wound care and method of wound closure. For example, partial skin closure, subcutaneous drains and negative-pressure surface vacuum dressings on closed incisions might reduce superficial SSI[26]. Any method of closure other than primary closure with a dry dressing was considered 'modified'.

Initially, the National Nosocomial Infections Surveillance (NNIS) risk index, developed by the Centers for Disease Control and Prevention (CDC), was evaluated as described by the CDC[27] on a historical population of 1471 patients who underwent colorectal resection during calendar years 2011 and 2012 at MSK (*Table S1*, supporting information). Preliminary analysis revealed that the model had modest predictive performance, with a concordance index of 0·64. Using this data set, with an overall SSI rate of 13·0 per cent, a custom, colorectal surgery-specific SSI prediction tool was developed. The goal was to develop an automated tool using variables from the electronic medical record. Five clinically relevant factors associated with SSI were chosen for the MSK colorectal SSI prediction tool: concurrent liver surgery, history of smoking, duration of surgery, Charlson Co-morbidity Index and BMI (*Appendix S1*, supporting information). In logistic regression modelling, the tool's area under the curve/concordance index for predicting SSI was 0·74.

The intervention began on 1 November 2013, with adoption of all 13 components of the SSI reduction programme. Compliance with the SSI reduction measures was audited regularly by automatic medical record review and with a patient questionnaire completed on the day of surgery (*Table 1*). Non-compliance triggered a chart review, and compliance data were reviewed at monthly multidisciplinary SSI meetings.

Design of the pragmatic study

Implementation of the bundle precluded randomization. To minimize biases in the absence of random treatment assignment, the study consisted of three phases: baseline, implementation and sustainability[24]. The existing MSK SSI tracking programme was used, which had been implemented to comply with the New York State law mandating that all patients undergoing colorectal surgery be monitored for 30 days and SSI reported to the state every month.

SSI was defined according to CDC guidelines[28]. Superficial SSI involves skin and subcutaneous tissue, deep SSI involves fascia and muscle, and organ-space SSI involves the intra-abdominal space. Because precise distinction of superficial from deep SSI can be a challenge, SSI is categorized in the institutional database as superficial/deep or organ space. Disease and procedure codes used as inclusion criteria are listed in *Appendix S1* (supporting information). As all eligible patients were included in the pragmatic design, informed consent was not obtained. The study was conducted as a performance improvement project in concordance with institutional review board policy.

To be meaningful and important, a relative reduction in the rate of SSI following implementation of the SSI

Table 1 Components of the surgical-site infection reduction bundle

	Source	Enactment team*	Measurement method	Compliance (%)	
				Baseline phase	Implementation phase
Preoperative					
Appropriate antibiotic selection	SCIP	PAT nursing	EMR	99·6	99·4
Consultation for raised haemoglobin A1C level	MDT	PAT nursing	EMR		90·3
Chlorhexidine shower	MDT	OC nursing	PPQ		
Night before surgery					91·6
Morning of surgery					96·1
Mechanical bowel preparation	MDT	OC nursing	PPQ		91·2
Oral antibiotics	MDT	OC nursing	PPQ		
Early evening					93·0
Late evening					88·0
SSI risk assessment provided to surgeon	MDT	QA	n.a.		100
Intraoperative					
Antibiotic administration before incision	SCIP	Anaesthesia	EMR	99·4	98·9
Appropriate method of hair removal	SCIP	Surgery	EMR	100	100
Maintenance of normothermia†	SCIP	Anaesthesia	EMR	100	100
Intraoperative antibiotic redosing	MDT	Anaesthesia	EMR		85·3
Closing tray for open procedures	MDT	Surgery	n.a.		100
Postoperative					
Discontinuation of antibiotics at 24 h	SCIP	Surgery	EMR	100	100
Shower on postoperative day 2	MDT	IP nursing	n.a.		

Data are reported in accordance with the CONSORT guidelines for pragmatic trials[25]. *Nursing includes registered nurses and nurse practitioners; surgery includes attending surgeons, residents and physician assistants. †Temperature measured on arrival at the postanaesthesia care unit. SCIP, Surgical Care Improvement Project; PAT, preadmission testing unit; EMR, electronic medical record; MDT, Memorial Sloan Kettering multidisciplinary team; OC, outpatient clinic; PPQ, preoperative patient questionnaire; SSI, surgical-site infection; QA, quality assurance; n.a., not applicable; IP, inpatient.

reduction programme would have to be at least 50 per cent. With an anticipated SSI rate of 10 per cent in the baseline phase, 450 to 500 patients in each study arm would allow more than 80 per cent power to detect an SSI rate reduction to 5 per cent, controlling the type I error rate at 5 per cent, using the χ^2 test. Interrupted time-series analysis was employed to rule out the possibility that any changes in SSI rate from baseline to intervention were the consequence of time trends[29].

Using surgical volume projections, the baseline phase of the study included patients who underwent surgery between 1 January and 31 October 2013. The SSI reduction programme went into effect on 1 November 2013, and the implementation phase of the study included patients who underwent surgery between 1 November 2013 and 31 December 2014. The sustainability phase included patients who had surgery between 1 January 2015 and 31 March 2016.

In addition to providing an estimated risk of SSI to surgeons before surgery, the SSI prediction tool was used to group patients by SSI risk level. Low-, intermediate- and high-risk groups were defined as groups of patients for whom the risk of SSI was below 0·07, between 0·07 and 0·21, and over 0·21 respectively, according to the MSK prediction tool.

Results

The baseline phase of the trial included 454 patients, the implementation phase 616 patients and the sustainability phase 758 patients. Clinical characteristics and types of surgery for the baseline and implementation phase are listed in *Table 2*. Compliance with SCIP guidelines (monitored at MSK since 2007) was over 98 per cent in both the baseline and implementation phases; compliance in the implementation phase with SSI reduction practices instituted in 2013 was at least 85 per cent (*Table 1*).

Surgical-site infection rates

The SSI rate in the implementation phase was significantly lower than that in the baseline phase (4·1 *versus* 11·0 per cent; $P = 0·001$) (*Table 3*). Interrupted time-series analysis (*Fig. 1*) did not reveal any significant time trends in the baseline phase ($P = 0·358$) or implementation phase ($P = 0·441$), suggesting the reduction in SSI was the result of the intervention.

SSI rates for the three risk groups are shown in *Table 4*. The intermediate-risk group in the implementation phase had a significantly lower SSI rate than in the baseline phase (4·7 *versus* 10·3 per cent; $P = 0·006$). Likewise, the high-risk

Table 2 Characteristics of patients and treatments in baseline and implementation phases

	Baseline phase ($n = 454$)	Implementation phase ($n = 616$)	P‡
Age (years)*	61(14)	61(14)	0·817§
Sex ratio (F : M)	236 : 218	316 : 300	0·853
BMI (kg/m^2)*	30(6)	30(6)	1·000§
History of diabetes	79 (17·4)	108 (17·5)	1·000
History of smoking	222 (48·9)	306 (49·7)	0·805
CCI score*	9·0(3·2)	8·8(3·3)	0·219§
ASA fitness grade III	339 (74·7)	471 (76·5)	0·517
Wound class clean-contaminated	364 (80·2)	495 (80·4)	1·000
Duration of operation (min)†	240 (57–945)	259 (66–825)	0·427§
Surgical procedure			
Resection type			0·377
Right colectomy	227 (50·0)	306 (49·7)	
Left colectomy	51 (11·2)	66 (10·7)	
Sigmoid colectomy	55 (12·1)	71 (11·5)	
Total colectomy	27 (5·9)	40 (6·5)	
Rectal resection	51 (11·2)	52 (8·4)	
Other colorectal	43 (9·5)	81 (13·1)	
Combined colorectal and liver	26 (5·7)	27 (4·4)	0·322
Open	212 (46·7)	348 (56·5)	0·002

Values in parentheses are percentages unless indicated otherwise; *values are mean(s.d.) and †median (range). CCI, Charlson Co-morbidity Index. ‡Fisher's exact test, except §Wilcoxon test.

Table 3 Surgical-site infection rates

	Surgical-site infection		
	Baseline phase ($n = 454$)	Implementation phase ($n = 616$)	P*
Superficial/deep	36 (7·9)	11 (1·8)	< 0·001
Organ space	14 (3·1)	14 (2·3)	0·219
Total	50 (11·0)	25 (4·1)	0·001

Values in parentheses are percentages. *Fisher's exact test.

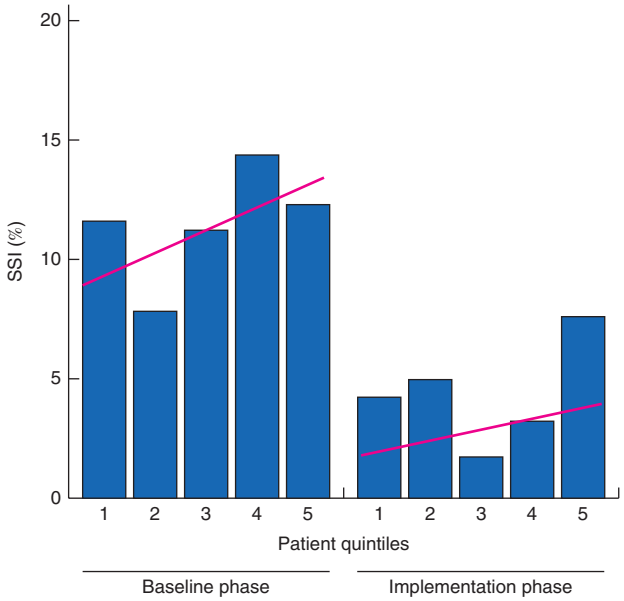

Fig. 1 Surgical-site infection (SSI) rates over time. Each bar represents 20 per cent of consecutive surgical patients in the corresponding study phase. Estimated time trends are indicated

group in the implementation phase had a significantly lower SSI rate than in the baseline phase (2 *versus* 19 per cent; $P < 0·001$).

When analysed by type of infection, differences in the rates of superficial/deep SSIs between the baseline and implementation phases were statistically significant for all three risk groups ($P = 0·001$, $P = 0·034$ and $P = 0·004$ for low-, intermediate- and high-risk groups respectively), but the differences in organ-space SSI were not statistically significant.

Wound closure

In the implementation phase, wound closure modifications were used in a larger proportion of patients than in the baseline phase (43·2 *versus* 24·9 per cent respectively). In the baseline phase, incisions were closed primarily with a dry dressing in 75·1 per cent, closed over a drain in 16·8 per cent, closed with an overlying surface vacuum dressing in 1·4 per cent and left partially open in 6·7 per cent. In the implementation phase, incisions were closed primarily with a dry dressing in 57·0 per cent, closed over a drain in 12·6 per cent, closed with an overlying surface vacuum dressing in 17·2 per cent and left partially open in 13·2 per cent. For the low-, intermediate- and high-risk groups, wound

Table 4 Surgical-site infection rates by infection risk group

	Surgical-site infection		
	Baseline phase	Implementation phase	*P**
Low-risk group	*n* = 93	*n* = 122	
Superficial/deep	4 (4)	0 (0)	0·001
Organ space	2 (2)	4 (3·3)	0·700
Total	6 (6)	4 (3·3)	0·334
Intermediate-risk group	*n* = 282	*n* = 408	
Superficial/deep	22 (7·8)	10 (2·5)	0·034
Organ space	7 (2·5)	9 (2·2)	0·803
Total	29 (10·3)	19 (4·7)	0·006
High-risk group	*n* = 79	*n* = 86	
Superficial/deep	10 (13)	1 (1)	0·004
Organ space	5 (6)	1 (1)	0·087
Total	15 (19)	2 (2)	< 0·001

Values in parentheses are percentages. *Fisher's exact test.

closure modifications were used in 14, 22·2 and 39 per cent of patients respectively in the baseline phase, compared with 27·7, 42·3 and 57 per cent in the implementation phase.

Length of hospital stay

The median length of hospital stay (LOS) was significantly shorter in the implementation phase than in the baseline phase: 6 (i.q.r. 5–9) *versus* 7 (5–10) days respectively ($P = 0·002$). For the intermediate-risk group, median LOS was significantly lower in the implementation phase than in the baseline phase: 6 (5–8) *versus* 7 (5–10) days ($P = 0·006$). Likewise, for the high-risk group, median LOS was significantly lower in the implementation phase than in the baseline phase: 6 (5–9) *versus* 8 (6–12) days ($P < 0·001$).

Median LOS was significantly lower in patients without SSI than among those with SSI in both the baseline and implementation phases. In the baseline phase, the median LOS was 7 (5–10) days for patients without SSI and 8·5 (6–14) days for patients with SSI ($P = 0·016$). Respective values in the implementation phase were 6 (5–8) and 8 (6–27) days ($P = 0·001$).

Readmission rates

The 30-day readmission rate was 14·1 per cent in the baseline phase and 11·7 per cent in the implementation phase ($P = 0·265$). It was significantly lower for patients without SSI than for patients with SSI in both the baseline phase (10·7 *versus* 42 per cent; $P < 0·001$) and the implementation phase (10·2 *versus* 46 per cent; $P < 0·001$).

Analysis of surgical-site infection in the implementation phase

In the implementation phase, the 25 patients with SSI had a significantly higher rate of concurrent liver surgery (5 *versus* 0 per cent; $P < 0·001$) and a somewhat higher rate of diabetes (19 *versus* 7·7 per cent; $P = 0·058$) than the 591 patients without SSI. There was no difference between patients with SSI and those without in terms of BMI, smoking history, Charlson Co-morbidity Index, rate of laparoscopic procedures, or compliance with the SSI reduction bundle.

Sustainability phase

In the sustainability phase, 34 of the 758 patients had an SSI, giving a rate of 4·5 (95 per cent c.i. 3·1 to 6·2) per cent, indicating that the SSI reduction programme had a sustained impact.

Discussion

The multidisciplinary care bundle reported here significantly reduced the SSI rate at MSK. The greatest declines occurred in the rates of superficial/deep SSIs (as defined by the CDC), which involve the skin and/or fascia, in agreement with other reports[15,30]. Organ-space SSIs were not affected, which is not surprising as such infections usually result from anastomotic dehiscence or leak and are minimally influenced by interventions included in the patient care bundle. Implementation of the care bundle reduced LOS but not the 30-day readmission rate, probably because superficial and deep wound infections can be treated adequately on an outpatient basis, whereas more significant SSI requires readmission.

The observed reduction in SSI rate likely resulted from implementation of the bundle, as patient characteristics and risk levels did not change over time, other than a slight increase in open procedures in the implementation phase. The median risk level in the implementation phase did not differ from that in the baseline phase, indicating that the decline in SSI was not a result of a higher proportion of low-risk patients in the implementation phase. In addition, interrupted time-series analysis (*Fig. 1*) demonstrated that there were no time trends to explain the reduction in SSI. This supports the conclusion that the reduction in SSI is attributed to implementation of the intervention.

Previously reported multidisciplinary interventions aimed at reducing SSI rates achieved various degrees of success[15,18,21] and failure[13,31]. A recent meta-analysis[32] of 13 trials with 8515 patients found that implementation of a surgical bundle in patients undergoing colorectal surgery

significantly reduced the SSI rate, although there was variation in bundle components and success.

The present intervention differs from others in that it involves using the MSK colorectal SSI prediction tool to inform surgeons of the SSI risk before surgery, which may influence how a surgeon manages a patient's treatment. The prediction tool also facilitates grouping of patients by SSI risk and comparison of groups with a similar risk. The MSK colorectal SSI prediction tool was created because the NNIS model did not perform well in MSK's cancer-based practice. The difficulty in applying risk calculators developed in one population to another population was described recently by Bergquist and colleagues[33], who evaluated a variety of SSI risk scoring systems in a series of 2376 patients at a single institution. The authors reported concordance indices ranging from 0·57 to 0·62, and hypothesized that institution- and case mix-specific factors accounted for the poor results. Similarly, the NNIS model was not sufficient for the colorectal cancer population at MSK, which has a relatively high rate of concurrent liver resections, with a concordance index of 0·64. The concordance index of the MSK colorectal SSI risk model was 0·74, well within the expected range for a prognostic biological model.

The MSK colorectal SSI prediction tool provided surgeons with an assessment of the risk of SSI before surgery, which may have influenced the method of wound closure in higher-risk patients. In the baseline phase, wound closure modifications[26] were employed in one-quarter of all patients, with a 73 per cent relative increase seen in the implementation phase. The greatest increase was noted for low- and intermediate-risk patients. Wound closure modifications were used in over 40 per cent of high-risk patients in the baseline phase, suggesting that surgeons were able to identify many high-risk patients without the aid of a prediction tool.

The pragmatic trial design[34] employed here had the advantages of flexible delivery, straightforward compliance assessment, an easily measured and clinically important endpoint, and inclusion of all patients, making the study findings applicable to complex and diverse real-world settings[35] (*Table S2*, supporting information). Uniquely, this study included a sustainability phase to assess the long-term effects of the SSI reduction bundle. An important strength was the SSI surveillance system designed to track patients after discharge from hospital. The limitations include an inability to attribute causality to any individual component of the intervention or to distinguish superficial from deep SSI. Although patient compliance was high, some compliance data were self-reported and could not be verified, such as recent and remote history of smoking.

Implementation of the patient care bundle resulted in a sustained cultural change within MSK, as the SSI rate remained low almost 2·5 years after implementation. These findings indicate that SSI rates can be reduced in the long term by hospital-wide implementation of a multidisciplinary care bundle.

Collaborators

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Supporting information

Additional supporting information can be found online in the Supporting Information section at the end of the article.

Snapshot quiz

Snapshot quiz 18/17

Answer: This man had a rectal lipoma (4×4 cm) and underwent uncomplicated transanal excision as a day-case procedure. Colorectal lipomas are rare, and often only found incidentally during endoscopic examination.